Summary of the geology, Northern Highlands of Scotland

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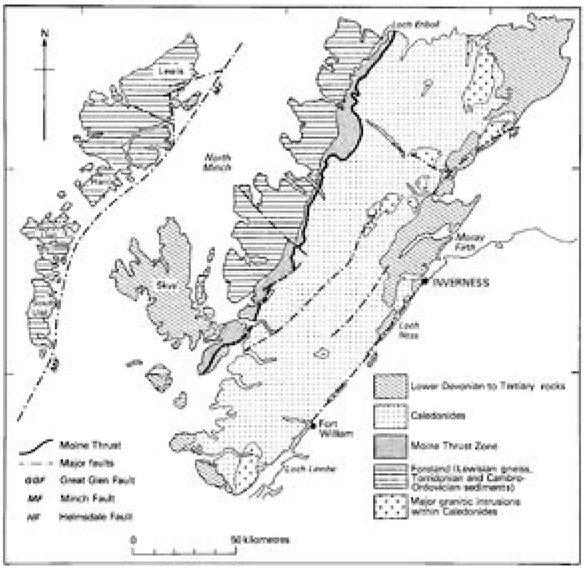
Summary of the geology



Sketch map showing the main elements of the geology of the Northern Highlands. P915459.

The basement rocks of the Northern Highlands consist of gneisses of the Lewisian Complex ([P915459](#)). They are the products of repeated deformation, metamorphism and migmatisation of early Precambrian crust of uncertain origin, cut by acid and basic igneous intrusions, with some subordinate sedimentary and volcanic rocks. The time interval between the formation of the oldest and youngest rocks of the complex may have been as much as 1200 million years. Two major metamorphic, tectonic and intrusive events can be recognised, separated by a period of crustal tension during which a swarm of tholeiitic dolerite dykes (the Scourie Dykes) was emplaced. The earlier event produced the Scourian Complex, which comprises high-grade (granulitefacies) gneisses of diverse origin, while the later event gave rise to the Laxfordian Complex, in which Scourian rocks have been reconstructed by tectonism and metamorphism to lower-grade (amphibolite-facies) gneisses to a greater or lesser degree. Associated with these ‘reworked’ gneisses is a suite of granitic intrusions and migmatites.

While Lewisian terrain can be mapped on the basis of these divisions it should be appreciated that the two Complexes do not define chronostratigraphic groups.

It is inferred from radiometric age dating, however, that the gneiss-forming process which gave rise to the Scourian Complex took place 2900–2300 Ma (million years) ago (Archaean to Early Proterozoic). There were two major episodes within the Scourian: the Badcallian (c.2800 Ma) and the more localised Inverian (2500 Ma). The Scourie dykes have been dated at about 2400– 2200 Ma, the intrusion of the suite being spread over a considerable period of time. The Laxfordian Complex was formed between 2300 Ma and 1700 Ma ago, the main episode being at around 1700 Ma (younger dates of down to 1100 Ma in the Laxfordian Complex probably represent local cooling ages).

After the formation of these basement gneisses the area that is now the Northern Highlands apparently lay on the south-eastern[1] margin of a large continental mass which included most of present-day Greenland and the Laurentian Shield of north-east Canada. About 1000 Ma ago, after a prolonged period of uplift and erosion the deepseated Lewisian gneiss was exposed on a land surface. It formed moderately hilly country of up to 400 m relief with gentle slopes and fairly extensive areas of flat, knolly terrain between groups of hills. To the northwest lay higher ground traversed by large rivers. To the south-east may have lain NNE-trending lacustrine rift-basins, the precursors of a major ocean — the Iapetus — which later developed as Laurentia and Baltica (the south-eastern continent); gradually drew apart.

On this hilly surface, and in the basins between the uplifted areas, a great thickness of fluviatile and lacustrine red beds accumulated, comprising mainly arkosic sandstones and conglomerates with subordinate shales and some scree preserved as breccia banked up against former hillslopes. With some grey sandstones and grey, probably lacustrine, shales these beds make up the ‘Torridonian’ rocks, a late Precambrian succession of Riphaean age. This essentially unmetamorphosed sequence contains a notable angular unconformity, which separates the Stoer Group, (deposited at about 1000 Ma) from the overlying, more extensively developed Torridon Group, (750–800 Ma). There is a considerable disparity between the palaeomagnetic orientations of the rocks above and below the unconformity, although the environment of deposition did not change greatly. This disparity suggests that the unconformity itself represents a considerable time gap.

Some distance to the east of these terrestrial accumulations a thick sequence of sandstones and shales was laid down in shallow seas. Unlike the Torridonian rocks, however, they have undergone deformation and metamorphism and are now represented mainly by psammitic, semipelitic and pelitic gneisses and schists. They make up the Moine Succession which may in part be the shallowwater marine, or estuarine, equivalent of the continental Torridonian rocks. An interpretation of isotopic ages from pegmatites and metamorphic minerals in the Moines of the Northern Highlands suggests that most of the rocks were metamorphosed at c.750 Ma (during the Morarian episode, whose status as an orogenic event is uncertain) and some have been involved in the earlier Grenvillian Orogeny (c.1100 Ma). It was at one time considered that a depositional age of more than 1000 Ma implies that the Moine rocks are too old to be equivalent to the Torridonian, but the most recent age proposed for the Stoer Group has again revived this possibility.

In the Grampians south of the Great Glen, rocks long held to be Moines show only Caledonian or ‘Grampian’ (c.500 Ma) deformation (see below) and these ‘young’ Moines may also be present in the Northern Highlands, although no unconformity has been detected. Some workers, however, hold that a group of younger Moines overlies a Grenvillian basement in parts of the area.

In the North-West Highlands the Torridonian rocks underwent a period of gentle tilting and considerable erosion prior to a marine incursion which laid down basal Cambrian strata on a peneplaned surface. Baltica and Laurentia were separated by the developing Iapetus Ocean by this time, and the Cambrian quartzites, shales and limestones (which extend upwards into the Ordovician) are shallow-water marginal shelf deposits of the Iapetus Ocean. As these Cambrian beds were separated by the Iapetus from their equivalents in England and Wales they contain a fauna allied to that of North America, not that of Europe. To the south of the Northern Highlands, elongate basins on the continental margin of the Iapetus Ocean received vast quantities of sediment. As the continents approached each other again in Ordovician times, the basement and overlying sedimentary rocks along the continental margins were folded and metamorphosed to rise in a mountain belt which stretched from what is now East Greenland and Scandinavia through the British Isles to the east coast of America.

To this mountain belt the name Caledonides has been applied, and the process of mountain building which gave rise to it is termed the Caledonian Orogeny[2]. This orogeny is generally taken to have commenced in post-Cambrian pre-Silurian times (c.500 Ma).

In the Northern Highlands the Caledonian belt is sharply limited, and the rocks of the region are divided into two associations of fundamentally different geological structure. To the east of a line extending from Loch Eriboll to the Sound of Iona the Caledonides comprise mainly metamorphic Moine strata within which appear small, but significant, inliers of the Lewisian basement entirely reconstructed by the effects of the Caledonian Orogeny (and earlier Grenvillian and Morarian events). To the west of this line the Lewisian basement, with its cover of Torridonian and Cambro-Ordovician strata, has remained virtually unmoved from Laxfordian times onwards. This stable block constitutes a foreland. The Caledonides have been pushed westwards over the foreland along a network of low angle thrusts which forms the Moine Thrust Zone, so named after the most important single thrust plane in the group. The mechanism which gave rise to this overthrusting was the eventual collision of the Laurentian and Baltic plates, much further to the south-east. This collision resulted in compressive forces being directed upwards and outwards away from their line of junction, through some of the thrust sheets along the Moine Thrust Zone may have been emplaced by gravity sliding as part of the general process.

An orogenic belt such as the Caledonides, which results from the mechanism of continental collision, is commonly accompanied by intense igneous activity. The Northern Highlands contain many intrusions of acid and basic dykes, sheets and plutons collectively referred to as the Caledonian Igneous Suite. These intrusions can be assigned to groups which are pre-tectonic, syn-tectonic and post-tectonic with respect to the main Caledonian deformation. Certain of the pre-tectonic intrusions in the Northern Highlands in fact may not be associated with the Caledonian Orogeny; they could belong to an earlier magmatic episode.

Laurentia and Baltica welded together to form a new continental mass, within which the Caledonides were subjected to erosion. The resulting debris was deposited in intermontane, possibly fault-bounded, basins as thick accumulations of conglomerate, sandstone and siltstone laid down in alluvial fans, on the flood plains of rivers, and in lakes. These deposits are now known as the Old Red Sandstone and they are mainly found on the east side of the Northern Highlands.

In several respects these rocks resemble the earlier Torridonian strata, and are analogous to the Alpine Molasse, i.e. they are typical of the degradation products of an uplifted mountain belt. It is probable that they never completely covered the degraded Caledonian mountains. They did, however, fill in the through-valley of the ancient Great Glen and adjacent hollows.

The Caledonian Orogeny is generally taken to have terminated prior to the deposition of the Middle Old Red Sandstone, but in the Northern Highlands late movements continued into Middle Devonian times.

The Northern Highlands (and the adjacent Grampians) are traversed by several faults trending NE–SW and a lesser (although also important) number of fractures with the complementary NW–SE orientation. The faults show considerable sinistral (NE–SW suite) and dextral (NW–SE suite) displacement up to and including the Middle Old Red Sandstone, although it is becoming clear that some faults have a long history of pre- and post-ORS movement, of which the present apparent strike-slip displacement is the end result. Of the faults, that along the Great Glen is the most important, although the direction and amount of movement along it are in dispute.

A small outlier of Carboniferous strata is found on the north-east shore of the Sound of Mull in Morvern, apparently lying directly on Moine rocks. These fluvial and deltaic deposits were probably laid down in one of the ephemeral basins on the continental margin of a Highland massif which at that time bounded the Midland Valley trough.

There followed, in late Carboniferous to early Permian times, the intrusion of an important suite of dykes, mainly of camptonite and monchiquite; the dykes form several almost discrete swarms whose members trend mainly E–W. A few volcanic vents have also been identified and the igneous activity seems to be related to a period of crustal tension; this was possibly a precursor of that later event responsible for the opening of the Atlantic Ocean.

Mesozoic rocks, comprising mainly Triassic and Jurassic strata, are found on the eastern and western seaboards of the Northern Highlands. In the west they were deposited directly on the Precambrian rocks of both Foreland and Caledonides. Thick sequences are found in asymmetrical west-tilted, fault- bounded basins (‘half-grabens’) in what is now the Minch and the Sea of the Hebrides. The Minch Fault, which lies close offshore along the eastern edge of the Outer Isles, is a boundary of one basin; the Camasunary Fault, seen onshore in Skye, is another. On the western mainland, however, only small outcrops of these rocks are found. (For descriptions of the extensive outcrops in the Inner Hebrides the reader should refer to the companion handbook, *The Tertiary Volcanic Districts.)* The Helmsdale Fault on the east coast of Sutherland and, further south along the coast of Cromarty, the Great Glen Fault limit the landward extension of the Mesozoic strata which occupy the Moray Firth Basin.

During Triassic times a relatively arid climate prevailed, and red sandstones and conglomerates were deposited in alluvial cones and on the plains of ephemeral rivers. Later, during the Jurassic, the basins were inundated by the sea and the deposition of shallow-water marine and estuarine sandstones, siltstones and limestones was eventually followed by the deposition of deep water shales, which are the source rocks of most of the North Sea oil. A seam of coal at Brora was formed during a period of emergence, and later the spectacular Helmsdale Boulder Bed was laid down as a series of submarine fans along the foot of the active Helmsdale Fault scarp.

It is likely that the subsiding fault-bounded basins in which the thick Hebridean Mesozoic sequences accumulated resulted from tensional stresses which heralded the break-up of the supercontinent formed by the fusion of the Laurentian and Baltic shields during the Caledonian Orogeny. The tension within this continental crust produced a number of fractures and half grabens, such as the Mid-North Sea Viking graben and the troughs in the Hebridean Sea. They were all sites of early ‘failed’ Atlantic spreading centres. The final successful rift took place in late Cretaceous times somewhat further west along the Mid- Atlantic Ridge. Ocean spreading from this fissure at an average rate of 2 cm per annum has created the Atlantic Ocean, separating the present outcrop of Lewisian gneiss in the Northern Highlands from its parent Laurentia.

During the Mesozoic the Highland massif was an area of low relief, and in Cretaceous times it may even have been completely covered by a shallow sea. The Hebridean region was the main locus of the Tertiary igneous activity which took place mainly in Palaeocene times (50–60 Ma ago). During this period basaltic plateau lavas accumulated over the Inner Hebrides and the adjacent mainland to a thickness of many thousands of feet. This outpouring of lava was followed by the eruption of central volcanoes; their eroded roots form the Cuillins of Skye and Rhum, and the hills of Ardnamurchan, Mull and St Kilda. Other volcanic centres have been discovered under the sea at the Blackstones Bank, SW of Mull, and in the Malin Basin, NW of Malin Head. Swarms of NW-trending basalt and dolerite dykes are aligned on (though they do not necessarily emanate from) the Skye, Rhum and Mull centres and cut the older rocks of the North-West Highlands and the Outer Hebrides.

After the cessation of the Tertiary igneous activity there was a renewed period of uplift and erosion (as described on p.163). The ice sheets, and more especially the later valley glaciers, of the Pleistocene glacial period (c.1 million to 10 000 years ago) modified the river valley profiles; they are largely responsible for the detail of the present-day topography. Isostatic adjustments of land and sea levels due to the melting of the ice sheets gave rise to a fringe of raised beach deposits around the coast, as the land (in general) emerged from the sea. Areas of submerged topography are found marginally, in the Outer Hebrides.

Selected bibliography

Footnotes

1. ↑ When referring to ancient rocks which have existed through periods of plate move- ment and relative polar shift, compass directions given in the text refer to their present situation unless otherwise stated.
2. ↑ The term Caledonian Orogeny is also commonly used to refer to the *period* over which the *process* took place.

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