Foreland Lewisian, the mainland, Northern Highlands of Scotland

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Johnstone, G S and Mykura, W. 1989. British regional geology: Northern Highlands of Scotland. Fourth edition. Keyworth, Nottingham: British Geological Survey.
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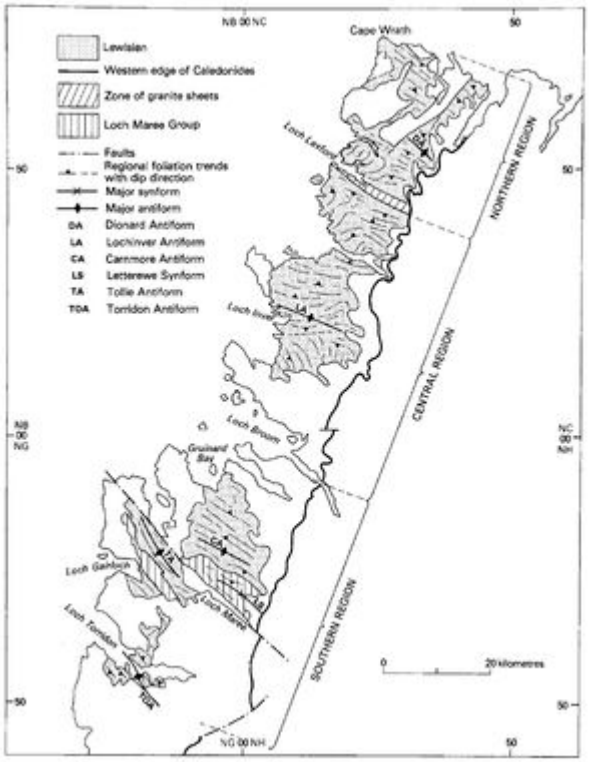

Lewisian rocks of the North-West Highlands.
P915461.

Scourie dykes intrude a late Scourian shear zone in Lewisian gneiss. The gneiss to the left of the dyke still retains a largely Scourian fabric. P008263.

The Lewisian Complex of North-West Scotland was formally divided by Sutton and Watson (1951), following the lines of regional variations outlined by Peach and others (1907). Sutton and Watson defined a central region (P915461) in which the predominant rocks are granular pyroxene gneisses (granulites); these were deformed and altered at considerable depth during an Archaean metamorphic episode, which they termed Scourian. The central region is flanked to the north and south by areas in which gneisses were strongly deformed during a later (early-Proterozoic) metamorphic episode, which they termed Laxfordian. The distinction between gneisses affected only by the Scourian episode of metamorphism and those reworked by the later Laxfordian metamorphism was largely made by reference to a suite of dykes — the Scourie dykes. These dykes cut across the gneissose banding and structures within the Scourian area, but are deformed and metamorphosed within the Laxfordian areas. Sutton and Watson suggested that there was a considerable time gap between the Scourian and Laxfordian, and therefore gave them the status of major divisions of the Lewisian Complex.

Within the Scourian, Sutton and Watson (1969) subsequently defined an early and a late event. The early episode was regarded as the main gneiss-forming event accompanied by granulite-facies metamorphism. The late episode was marked by the production of steep linear deformation belts trending NW– SE, associated with retrograde amphibolite-facies metamorphism. Park (1970) gave this division a more formal status by proposing the term Badcallian for the early Scourian events and Inverian for the later ones. Park also suggested that the Inverian episode was closer in deformational style to the succeeding Laxfordian than to the preceding Badcallian, and suggested that the Badcallian and Inverian divisions should be accorded major status.

Central region

The Central Scourian region stretches from Loch Laxford to Loch Broom (P915461); it consists predominantly of banded gneisses with a variety of basic and ultrabasic inclusions. The gneisses are coarsely banded with alternating acid and mafic layers. Granulite-facies gneisses are common; they have two pyroxenes, brown hornblende and plagioclase assemblages. In areas of retrograde metamorphism the pyroxenes are progressively replaced by hornblende and biotite.

Ultrabasic rocks occur in small bodies ranging from a few centimetres across to several tens of metres. The smaller bodies are generally concentrations of hornblende and biotite. The larger bodies show a considerable variation, including pyroxenites and dunites. The minerals may include olivine, pyroxene, hornblende, garnet and spinel and are commonly arranged to define a rough banding.

Basic rocks are relatively abundant and vary from tiny lenses to large masses which may be tens of metres thick and traceable for several kilometres along the strike. They generally contain pyroxene-hornblende-plagioclase assemblages. In many cases the minerals are arranged in well defined bands with an overall compositional variation within the body from ultramafic to anorthosite. The basic bodies frequently concentrate in zones, of which one of the most notable lies south of Loch Laxford. It is 2 km wide and stretches in a NW–SE direction for over 10 km. According to Davies (1974) the zone occupies a complex syncline within which the basic rocks are associated with a series of brown-weathering schists, believed to be metasediments.

All of these rocks were subjected to the deformation and high-grade metamorphism of the early Scourian (Badcallian). The deformation associated with this metamorphism appears to have been very 'fluid' with major structures seldom persisting for any great distance. The subsequent Inverian deformation, however, occurred in more rigid gneisses with structures confined to near-vertical NW-SE belts. One of the most important of these is the Lochinver Antiform (Sheraton and others, 1973), which stretches from Loch Inver inland for up to 10 km (P915461). This fold has a steep, strongly deformed northeast limb (Canisp shear belt) and gentle south-west limb. Retrogression of the pyroxene gneisses is largely controlled by these structures, being greatest in the highly deformed belts.

Several workers (e.g. Tarney and others, 1972; Holland and Lambert, 1975) have shown that the gneisses are characteristically depleted in many lighter elements (K, Rb, Nb, Th, U). They have also shown that the retrogressive effects of the Inverian were essentially isochemical and did not destroy the characteristic chemistry of the Scourian.

Considerable controversy exists on the origin of the Scourian gneisses. Sutton and Watson (1951) originally considered the complex to be a supracrustal sequence. Sheraton and others (1973) and Bowes and others (1971) suggested that it was largely a dacite-andesite volcanic sequence with intercalated sediments; Tarney and others (1972) suggested that it was part of the crust depleted in lighter elements by mantle degassing, and Holland and Lambert (1975) proposed a model where the crust was built up through a process of 'under-plating' by upper mantle melts, the supracrustal rocks being tectonically incorporated subsequently. On balance it is probable that the bulk of the gneisses were formed from the addition of calc-alkaline igneous rocks into or onto a supracrustal sedimentary sequence. The proportion of intrusive to extrusive material is, however, uncertain (see Watson, 1983). Watson (1975) proposed that the rocks on which the supracrustal sequence was deposited should be defined as the Pre-Scourian Complex. How extensive such rocks are, or even whether they are present at all, is uncertain.

Work on Rb-Sr and Sm-Nd systematics (Hamilton and others, 1979) suggests that the calc-alkaline parents of the gneisses separated from the mantle at c.2900 Ma, approximately 200 Ma before the main high-grade Badcallian metamorphism (Pidgeon and Bowes, 1972). Scourian pegmatites, generally taken as marking the onset of Inverian events, give dates of 2500–2400 Ma. The Central region corresponds to the area dominated by Scourian effects, with only weak or localised Laxfordian reworking. The Northern and Southern regions correspond to the Laxfordian belts.

Scourie dyke suite

Cutting the heterogeneous gneiss complex of the Scourian is a suite of basic and ultrabasic dykes collectively termed the Scourie Dykes. The dykes are discordant to the foliation in the host gneisses; they are steep sided, and can be traced for considerable distances (up to 15 km), the basics trending NW– SE, the ultrabasics near E–W. Many dykes have apophyses and fine-grained margins. Although most of the dolerites retain igneous minerals, they all show evidence of amphibolite-facies metamorphism, the degree of amphibolitisation usually increasing from the centre to the margins of

the dyke. The ultrabasic rocks are dominantly picrites and olivine gabbros. Like the dolerites they frequently show evidence of amphibolitisation, the degree of alteration being greatest at the margins.

O'Hara (1961; 1962) and Tarney (1973) suggested that the textures of the dykes indicate that they were intruded into hot country rocks, the ambient temperatures inducing autometamorphism. Tarney also suggested that the metamorphism of the dykes was probably controlled by aqueous fluids moving upwards along Inverian shear zones during the waning stages of Inverian metamorphism. He also believes that the trend of the dykes was controlled by preexisting Inverian structures (P00826). He cites evidence of minor Laxfordian shearing affecting the dykes of the Scourian block, the geometry of the Laxfordian deformation being largely controlled by pre-existing Inverian structures. The dykes cut amphibolite-facies gneisses and are largely undeformed. They must, therefore, post-date the main Inverian events. It is generally accepted that the dykes were emplaced over a relatively short time span between 2400–2200 Ma; the basic varieties are earlier than the ultrabasic dykes.

Northern region

The Northern region, or Northern Laxfordian area, stretches from Loch Laxford to Cape Wrath (P915461). The area is characterised by relatively uniform acid biotite-hornblende gneisses with a variety of basic and ultrabasic lenses and sheets. Pegmatitic and granitic veins, lenses and sheets are common, giving the gneisses a migmatitic appearance. These veins increase in number southwards culminating in the Loch Laxford granitic zone at the southern boundary of the complex. The ultrabasic bodies are characteristically composed of hornblende and biotite with more subordinate olivine and pyroxene, whereas the basic varieties may contain garnet, plagioclase and minor amounts of clinopyroxene. Chemically the Laxfordian is much richer in the lighter elements than the Scourian.

Many of the basic sheets are regarded as the deformed and metamorphic equivalents of the Scourie dyke suite. Bowes and Khoury (1965) have argued that there is more than one period of post-Scourian basic dyke intrusion, and that basic dykes can be seen cutting structures produced by Laxfordian deformation. This view has, however, been widely challenged and discussed in the geological literature (e.g. Park, 1970; Park and Cresswell, 1972).

The characteristic trend of the Laxfordian foliation is NW–SE. At the southern edge of the zone the foliation dips steeply to the south-west; further north, the dip decreases and the foliation is disposed in a series of rolling folds. In Strath Dionard the regional dip reverses across the major Dionard Antiform (P915461); north of it the dip is to the north-east, with the foliation arranged in a series of rolling folds. The dip steepens at the southern end of the Kyle of Durness, and from there northwards to the coast the foliation has a near vertical attitude (see Park, 1973, fig. 70).

Relationship of the Central region to the Northern region

Considerable controversy exists on the relationship between the Central (Scourian) region and the Northern (Laxfordian) region. Sutton and Watson (1951) regarded the Laxfordian as Scourian gneiss which was strongly metamorphosed and migmatised. The limit of Laxfordian reworking, the Laxford Front, is marked by the Laxford granite zone, the product of metasomatism and migmatisation from depth. One of the main lines of evidence for this contention is the apparently transitional contact between the two areas, with a progressive amphibolitisation of the pyroxene gneisses and the progressive deformation of the Scourie dykes. Sutton and Watson recognised a series of zones within this transitional area. These comprise the Scourie zone of pyroxene gneiss; the Claisfearn zone of partially amphibolitised gneiss; the Foindle zone of completely amphibolitised gneiss; the

Badnabay zone of pegmatite and granite-rich gneiss; and the Laxford zone of biotite-hornblende gneiss. The boundary between the Foindle and Badnabay zones is coincident with the Ben Stack Line, defined by Peach and others (1907) as separating the Central and Northern regions.

This cogenetic concept of the two areas was strongly challenged by Bowes (1978) who suggested that the Laxfordian represented a supracrustal sequence (the Rhiconich Group of Dash, 1967) deposited on the gneissose Scourian basement. Bowes also suggested (1969; Bowes and Khoury, 1965) that certain discordant basic dykes were intra-Laxfordian, thus weakening the use of the Scourie dykes as a time marker. Isotopic data presented by Moorbath and others (1969) indicates that both the Scourian and Laxfordian suffered uranium depletion in the Archean, and therefore both regions were in existence at that time. This argues strongly against Bowes' model. Chemical work, by Holland and Lambert (1973) and Sheraton and others (1973), suggests that the Scourian and Laxfordian areas have quite distinctive chemistries and, even allowing for the possible roles of migmatisation and metasomatism, the two assemblages could not be cogenetic.

Holland and Lambert (1973) suggested that the Laxfordian is a supracrustal sequence laid down on the Scourian basement. This view was strengthened by Bott and others (1972) who suggested, on geophysical grounds, that the dense Archean gneisses of the Scourian block underlay the lighter Laxfordian gneisses. They also stated that the granites at Loch Laxford could not have been generated at depth and introduced to the Laxfordian, but rather that they were the product of local melting of the biotite gneisses. This view has been challenged by Beach and others (1974), who argue that the geometry of deformation across the Laxford Front indicates that the Laxfordian was moved upwards against the Scourian block. Davies (1978) argues that the Laxfordian Front was initiated as a tectonic break in late Badcallian times and acted as a progressive dextral transcurrent displacement during the Inverian and Laxfordian deformations.

Recently, Davies and Watson (1977) have described banded basic gneisses from the Laxfordian area. They regard these rocks as equivalent to the banded basics of the Scourian block. Since the latter can be shown to predate most of the early Badcallian events, it follows that the Laxfordian region must also predate these events. They argue that the chemical differences between the two areas were in existence at the end of the Badcallian.

Opinion is obviously divided. Whatever the origin of the two gneiss groups, both the Laxfordian and Scourian assemblages appear to have been in existence at the end of the Badcallian, although with characteristically different chemistries. The concept of the Laxford Front as a tectonothermal front is valid in the original Sutton and Watson (1951) sense, with the progressive effects of Laxfordian deformation and metamorphism increasing northwards across the transition zone. The *Lewisian* 19 coincidence of this front with the original boundary between the two groups suggests that the pre-existing nature of the complexes controlled the position of the front of Laxford deformation.

Southern region

The Southern region, or Southern Laxfordian belt, stretches from Loch Broom to Loch Torridon (P915461); the area is more varied than the Northern region. Between Loch Broom and Loch Gairloch the rocks are hornblende- biotite gneisses with many basic and ultrabasic knots and lenses. The mineralogy is consistent with the amphibolite facies, although small patches of pyroxene gneiss have been reported from Gruinard Bay and Creag Mhor Thollaidh (Park, 1970). These gneisses, however, lack the pegmatite and granite veining and the general migmatitic character of the rocks of the northern Laxfordian belt. In the area between Gairloch and Loch Torridon migmatitic gneisses are much more common.

This region contains two major belts of supracrustal rocks which together constitute the Loch Maree

Group. The eastern belt lies in a synformal structure on the north-east side of Loch Maree. Hornblende-biotite gneisses lie above and below the supracrustals, but both contacts are highly tectonised, with local development of mylonite. The western belt runs south-eastwards from Gairloch. It is flanked by biotite gneisses and, like the eastern belt, has highly tectonised contacts. The rocks of the Loch Maree Group consist mainly of thick basic sheets, generally of hornblende schist or hornblende-chlorite schist, and a series of interleaved schists including garnet-mica schist, semipelite and siliceous schists. Calc-silicates also occur in association with limestone and dolomite. Small bands of kyanite-mica schist lie in the hornblende-biotite gneiss to the north of the Loch Maree Group. These bands apparently pass laterally into the gneiss.

The basic sheets and dykes are believed to be the equivalent of the Scourie dykes. They are generally in the state of foliated amphibolites. Discordant contacts are seen throughout the area but are particularly common in the region south of Gruinard bay. The general trend of the foliation is NW–SE. It is disposed in a series of major folds, from north-east to south-west (P915461); the most important are the Carnmore Antiform, Letterewe (Loch Maree) Synform, Tollie (Thollaidh) Antiform and Torridon Antiform. Sutton and Watson (1969) considered these folds to be of Laxfordian age, but Park and Cresswell (1973) argue that most of the major structures of the area were largely formed in the Inverian, and that the succeeding Laxfordian deformation, and the structure and trend of the dykes, were generally controlled by these pre-existing Inverian structures. Laxfordian metamorphism was generally of amphibolite-facies grade. A late phase of retrogressive metamorphism, possibly associated with pegmatite intrusion, affected the gneisses, producing chlorite-muscovite-microline assemblages (Park, 1970). The last phase of activity to affect the rocks of this area was the production of brittle zones marked by the presence of pseudotachylite and ultramylonite. These are considered by Park (1970) to be essentially post-

Laxfordian and pre-Torridonian. Moorbath and Park (1972), using K-Ar measurements, give a date of 1700–1500 Ma for the main amphibolite facies metamorphism of the Laxfordian. They place the retrogressive phase at c.1400 Ma and the late-stage cataclasis at c. 1150 Ma. Bickerman and others (1975) give Rb-Sr whole rock dates of 1975 Ma as the main Laxfordian metamorphism, 1745 Ma for the late pegmatites and suggest that the 1500 Ma K-Ar mineral date of Moorbath and Park (1972) reflects cooling of the rocks associated with uplift. Lyon and others (1973) dating rocks from South Rona found no evidence of dates younger than c.1700 Ma, and suggested that this represented the end of the Laxfordian. This conclusion has, however, been challenged by Park *(in* Lyon and others, 1973) who considered the 1700 Ma dates as early Laxfordian.

Relationship of the Southern region to the Central region

Sutton and Watson (1951) regarded the area between Gruinard Bay and Loch Maree as a transitional zone from the Scourian to the Laxfordian. The lack of migmatisation, the presence of deformed but cross-cutting dykes and the few relict patches of pyroxene gneiss all provided supporting evidence. The gneisses in the south around Loch Torridon were regarded by them as examples of thoroughly reworked Laxfordian gneisses.

Holland and Lambert (1973, fig.2) recognised several distinct geochemical assemblages in the southern region. These include the Gruinard assemblage stretching roughly from Loch Broom to Loch Gairloch, the Gairloch assemblage covering the rocks of the Loch Maree Series, and the Laxford assemblage in the area between Loch Gairloch and Loch Torridon. The Gruinard assemblage has the same chemical characteristics as the Scourian rocks of the Central region and is therefore classed as metamorphosed equivalent of the Scourian Complex. Holland and Lambert's data thus support Sutton and Watson's model for a transition. However, Holland and Lambert regard the Laxford assemblage as chemically quite distinct from the Scourian, and equivalent to the rocks of the Northern region. This supports the conclusion of Bowes (1972) that the Northern and Southern

Laxfordian assemblages are chemically similar and distinct from the Scourian.

Isotopic age data from the area of Torridon, Gairloch and Gruinard Bay (Moorbath and others, 1969; Moorbath and Park, 1972) show that both the Gruinard and Laxford assemblages *(sensu* Holland and Lambert, 1973) were subjected to a high-grade metamorphism at c.2900 Ma, and were thus both in existence at that time. The origin of the rocks of the Southern region between Loch Gairloch and Loch Torridon is therefore uncertain, but it is almost certainly the same as that of the Northern region.

Gneisses in the Gruinard Bay-Loch Maree area are cogenetic with those of the central (Scourian) region, although they have been fairly thoroughly reworked in the Proterozoic. They could therefore be equally regarded as a part of the Scourian Complex or the South Laxfordian Complex.

The age of the Loch Maree Group is problematical. The rocks are probably deformed by Inverian structures but appear to post-date the main gneissification events of the Badcallian. Most workers would therefore place them as post- Badcallian and pre-Inverian. Bickerman and others (1975), however, suggested from isotopic evidence that the Group was deposited 2200–2000 Ma ago, which would place it as post-Inverian and pre-Laxfordian. The strips of kyanite gneiss just north of the Loch Maree Group grade into the surrounding gneiss and are therefore considered to have a pre-Badcallian age. This would make them equivalent to the supracrustals seen in the Scourian region (p.19). This conclusion is supported by Bickerman and his colleagues whose isotopic data indicate that the kyanite gneisses were subjected to the main Badcallian events.

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