Allt an Dherue

[NC 540 464]–[NC 535 443]

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Introduction

The Allt an Dherue GCR site in central north Sutherland provides a wide cross-section across structurally interleaved and folded Moine psammites, garnet-staurolite-kyanite-bearing semipelites and pelites, and thick sheets of Lewisianoid gneisses (Figure 6.15). The area shows various aspects of the Moine–Lewisianoid relationships, the effects of major shear-zones on the succession, and is the type area for the Meadie Pelite Member and the so-called 'Meadie Schists'.

The geology is a southerly continuation of the complex zone of thrust and folded Lewisianoid inliers and Moine rocks found in the Tongue and Talmine areas to the north. The rocks have been strongly deformed and metamorphosed under amphibolite-facies conditions during Caledonian and earlier Neoproterozoic orogenic episodes. The deformation, metamorphism, widespread occurrence of shear zones, and local folding all serve to obscure the original Moine–Lewisianoid relationships in this area. The rocks are intruded by Neoproterozoic-age, partly garnetiferous amphibolites, mostly sills of the Ben Hope Suite. Ultramafic and mafic pods of the late Caledonian Loch a' Mhoid Metadolerite Suite are also common, and immediately north-east of the site area is the Loch Loyal Syenite (Holdsworth *et al.,* 2001). These latter intrusions cross-cut the penetrative Caledonian fabrics but are partly foliated, particularly adjacent to their margins. The nature and geological history of the rocks provide significant constraints on the regional geological synthesis of Sutherland (e.g. Moorhouse *et al.,* 1988).

D. Haldane first mapped the area for the Geological Survey in 1926 (Geological Survey of Scotland, 1931). He did not differentiate between the Moine and Lewisianoid rocks, but recognized the intrusive metadolerite and ultramafic bodies. The ultramafic rocks were correlated by Read (1931) with those found in the Lewisianoid gneisses north of Loch Naver, but Moorhouse and Moorhouse (1979) showed that there were two mineralogically and geochemically separate ultramafic suites, an earlier Archaean Lewisianoid suite, and a later Caledonian Loch a' Mhoid Metadolerite Suite, which comprises both mafic and ultramafic bodies. Mendum (1979) carried out reconnaissance mapping and briefly discussed the structure of the area in the context of regional Caledonian thrusting.

Description

The Allt an Dherue GCR site area consists of the wide valley floor (Srath an Dherue), and the tiered, craggy, hill-slope and ridge top that lies to the south-east of the valley (Figure 6.16). The NE-trending lines of crags and the wide, undulating rocky ridges expose clean sections through the Moine and Lewisianoid rocks. The Loch a' Mhoid Metadolerite Suite intrusion forms a prominent upstanding crag at [NC 5351 4516], and further bodies form crags to the north by Haluim Burn at [NC 543 466]. Prominent yellow-grey-weathering, massive ultramafic erratics form a northward train in the lower part of the strath.

The main inlier of Lewisianoid gneisses forms a gently SE-dipping sheet, about 1 km wide (*c.* 175 m thick). The gneiss is typically massive to blocky, and comprises laminated felsic gneiss with rare hornblende-rich layers, and a finely striped felsic and hornblendic mafic gneiss. Locally, hornblendite lenses, up to 15 cm across, are present. The lower and upper parts of the inlier contain pervasive D2 deformation fabrics and the gneissic banding is highly attenuated (Figure 6.17). In the more-central parts quartz-feldspar veins and pods and irregular amphibolite masses occur, and tight minor pre-D2 folds of the gneissic banding, formed prior to D2, are overprinted by only a weak S2 schistosity. However, where felsic Lewisianoid gneisses are highly deformed and pervasively recrystallized they can be difficult to distinguish from the adjacent Moine psammites. However, epidote, plagioclase feldspar, biotite and hornblende typify the Lewisianoid gneisses, whereas potash feldspar is common in the Moine psammites, particularly if gritty. Garnet and muscovite occur in the more-pelitic Moine lithologies. Smaller lenses of Lewisianoid gneisses, from a few centimetres to tens of metres

thick, occur within the Moine psammites outwith the main inlier.

The Moine psammites belong to the Altnaharra Psammite Formation. They are typically poorly bedded and locally gritty, and generally carry a penetrative S2 schistosity. The psammites lying above the main Lewisianoid inlier grade upwards to the south-east into a mottled, massive, schistose, micaceous semipelite and pelite with garnet, staurolite and locally kyanite — this is the Meadie Petite Member. Garnets range from 2 mm to 12 mm in diameter, and the staurolite forms elongate orange-brown porphyroblasts up to 2.5 mm long. In thin section, small kyanite laths can be seen in a coarse matrix of interleaved muscovite and biotite, chlorite sheaves, quartz and plagioclase. Tourmaline is a very abundant accessory. Epidote-rich layers are locally common both in the semipelitic and psammitic Moine rocks. The pelitic unit contains abundant quartz veins and pods. Read (1931) cited a chemical analysis of a staurolite-garnet schist from some 500 m southeast of Cnoc an Daimh Beag (4 km south of the Allt an Dherue GCR site), from which he inferred that the rock was originally a shale with an above average MgO and K_2O content.

Sheets of pervasively foliated garnetiferous amphibolite, related to the mafic sills on Ben Hope (see Allt na Caillich GCR site report, this chapter), are intrusive into the Lewisianoid and Moine rocks. Locally discordant relationships are still discernable, for example at [NC 5344 4486] where thin amphibolite sheets cross-cut Lewisianoid amphibolitic mafic gneisses and quartz-feldspar pegmatitic veins. Mafic sheets also occur sporadically in the Moine psammites farther east around Loch Haluim.

Within the interleaved Moine and Lewisianoid rocks are several discordant mafic (meta-dolerite) and ultramafic pods, assigned to the Loch a' Mhoid Metadolerite Suite of Moorhouse and Moorhouse (1979). Individual pods are up to 60 m wide and 200 m long. These generally retain their igneous textures and in parts even their igneous mineralogy, but also show tectonic fabrics and metamorphic assemblages, especially at their margins.

One such metadolerite pod, elongated NNW-SSE, forms a prominent knoll at [NC 5351 4514] (Figure 6.16). Typically it is a mottled, very dark and pale grey-green, massive to blocky, medium-grained rock composed of hornblende, plagioclase feldspar (oligoclase-andesine), quartz, sphene, ilmenite and epidote. However, in its central part it is fresher, undeformed, coarser grained, and consists of plagioclase (andesine-labradorite), hypersthene (part altered to blue-green amphibole), biotite and minor opaques, identifying it as a norite. The western contact of this pod against the Lewisianoid gneisses trends NNE and is well exposed. The metadolerite is fine grained adjacent to the margin and markedly cross-cuts the gently SE-dipping foliation in the sheared Lewisianoid gneisses. To the north-east, the intrusion terminates at a SE-trending gully, possibly marking a fault or shear zone. Here, the metadolerite is distinctly foliated for some 10 m. NNE of this main intrusion further small meta-dolerite bodies occur in the lower part of the Haluim Burn.

Two ultramafic pods intrude the Lewisianoid gneisses at [NC 5393 4524] and [NC 5389 4509]. They consist of yellow-grey-weathering, massive, dark-green, serpentinized and chloritized dunite and peridotite. They are composed of chlorite, tremolite, serpentine, relict olivine and altered enstatite. Magnetite and possibly chromite are present in patches, and some late-stage carbonate also occurs. 500 m NNE of the in-situ pods are a series of massive clean exposures of 'elephant-grey'-weathering, ultramafic rock that stretch north towards Dherue itself. The original survey joined up these exposures to form a large lenticular body (Geological Survey of Scotland, 1931) but Moorhouse *et al.* (1988) pointed out that they represent an ice-transported boulder train. However, the most southerly bodies are particularly massive and may constitute a third in-situ pod.

The structure of the area is dominated by the normally pervasive main schistosity, S2, which dips gently eastwards and locally intensifies into several shear-zones. Some of these shear zones apparently interleave Lewisianoid and Moine rocks. This broad zone, termed the Neadie Shear Zone' by Moorhouse *et al.* (1988), is a southerly extension of the Kyle of Tongue–Talmine Imbricate Zone (see Melness and Port Vasgo–Strathan Bay GCR site reports, this chapter; Holdsworth *et al.,* 2001). The degree of Caledonian strain varies from low in the internal parts of the Lewisianoid lenses to very high adjacent to some of the Moine–Lewisianoid boundaries. A distinct NE-trending shear-zone occurs around [NC 5344 4434], but more-complex relationships are seen around [NC 540 453]. At this latter locality, close to tightly folded, thinly layered, felsic and mafic Lewisianoid gneisses exhibit a strong N-plunging rodding (L2) and lie adjacent to strongly foliated Moine psammites and schistose semipelites. Quartz and quartz-feldspar veins are abundant, particularly in the Moine rocks. The folded contact and striped Lewisianoid gneisses pass downwards with increasing strain into a

planar shear-zone in the underlying psammitic and semipelitic Moine rocks. Although shear zones are generally located on attenuated major fold limbs and along Moine–Lewisianoid contacts, in some areas they diverge and lie wholly within Moine psammites or, less commonly, within Lewisianoid gneisses. Tight to isoclinal minor F2 folding occurs locally within these high-strain zones with the penetrative S2 schistosity axial planar to the folds.

A rodding lineation, L2, is developed over much of the area. It shows a gentle to moderate plunge (Figure 6.15) both to the north and south, but in the shear zones it commonly plunges to the SSE or south-east. However, in the north-western part of the Allt an Dherue GCR site area the lineation plunges gently to moderately east or ENE. In parts it represents the Caledonian extension direction, but more commonly it is formed by the intersection of S2 with an earlier planar fabric. It is difficult to separate or even recognize earlier and later fold phases, as folds of possible different generations are generally coaxial and parallel to the L2 lineation. In places the S2 fabric is locally folded, with the generation of a weak S3 schistosity.

Interpretation

The nature of the relationship between Lewisianoid basement gneisses and the overlying Moine rocks in the Allt an Dherue area remains unclear, despite the moderately good rock exposure, and the work done by several authors (Read, 1931; Moorhouse, 1977; Mendum, 1979; Moorhouse *et al.,* 1988). Where the layering in the Lewisianoid felsic and mafic gneisses is well developed, their identity is readily ascertained. In contrast, where the Lewisianoid gneisses are dominantly felsic and/or strongly sheared and metamorphosed, they are less easy to identify. Similarly, the Moine psammites show diagnostic features in some areas, namely where bedding can be readily distinguished or where semipelitic units are present. However, where the psammites are not well bedded, or are strongly deformed, their identity is less clear.

Even the affinity of the garnet-staurolite-bearing semipelitic Meadie Pelite Member has been questioned. The Meadie Pelite is regarded here as representing originally Fe-Al-rich silty and shaly units of definite Moine parentage, but Moorhouse *et al.* (1988) noted that the geochemistry of the 'Meadie Schists' did not accord with either of the distinctive signatures of Moine and Lewisianoid lithologies elsewhere in Sutherland. Hence, they tentatively interpreted them as of Lewisianoid origin. Although Moine–Lewisianoid relationships are now strongly disrupted, it is probable that the Moine psammites and semipelites originally formed the basal units that lay unconformably on the Lewisianoid gneiss basement prior to Caledonian and earlier Neoproterozoic deformation and metamorphism. Some of the Moine–Lewisianoid contacts may well represent a modified unconformity (see also Melness and Port Vasgo–Strathan Bay GCR site reports, this chapter), but most now represent structural breaks.

The early garnetiferous amphibolite sheets represent sills and discordant sheets, originally of dolerite and basalt, that were intruded into the Moine and Lewisianoid rocks prior to the earliest deformation and metamorphism (Moorhouse and Moorhouse, 1979). They are linked to the Ben Hope Suite and their age of intrusion is bracketed at between 980 Ma and 830 Ma by the depositional age of the Moine rocks and the earliest metamorphic event (Strachan *et al.,* 2002b). Winchester and Floyd (1984) used their trace- and major-element geochemistry to infer that they were products of a differentiated sub-alkaline tholeiitic basaltic magma formed in a continental within-plate environment, possibly transitional to plate margin.

In contrast, the metadolerite body and the two ultramafic pods belong to the considerably younger Loch a' Mhoid Metadolerite Suite (Moorhouse and Moorhouse, 1979). Their geochemistry shows that they are mildly alkaline and on a Zr/Y vs Ti/Y diagram they plot in the within-plate basalt field (Moorhouse and Moorhouse, 1979). Their geochemistry suggests that early olivine and clinopyroxene fractionation of the magma was followed by late-stage ilmenite fractionation. Moorhouse and Moorhouse (1979) argue that the ultramafic pods represent olivine cumulates formed during fractionation of the basic magma. The central parts of the meta-dolerites retain their igneous textures and mineralogy, and the ultramafic pods contain relict olivine. The intrusions of the Loch a' Mhoid Metadolerite Suite are only partially deformed and post-date D2. Moorhouse *et al.* (1988) suggested that they were intruded towards the close of D2 deformation, but they may be later (or possibly even earlier) if the internal foliation cannot be correlated with the external structures, as seems probable. The intrusions represent a phase of probable Ordovician- or Silurian-age mafic and

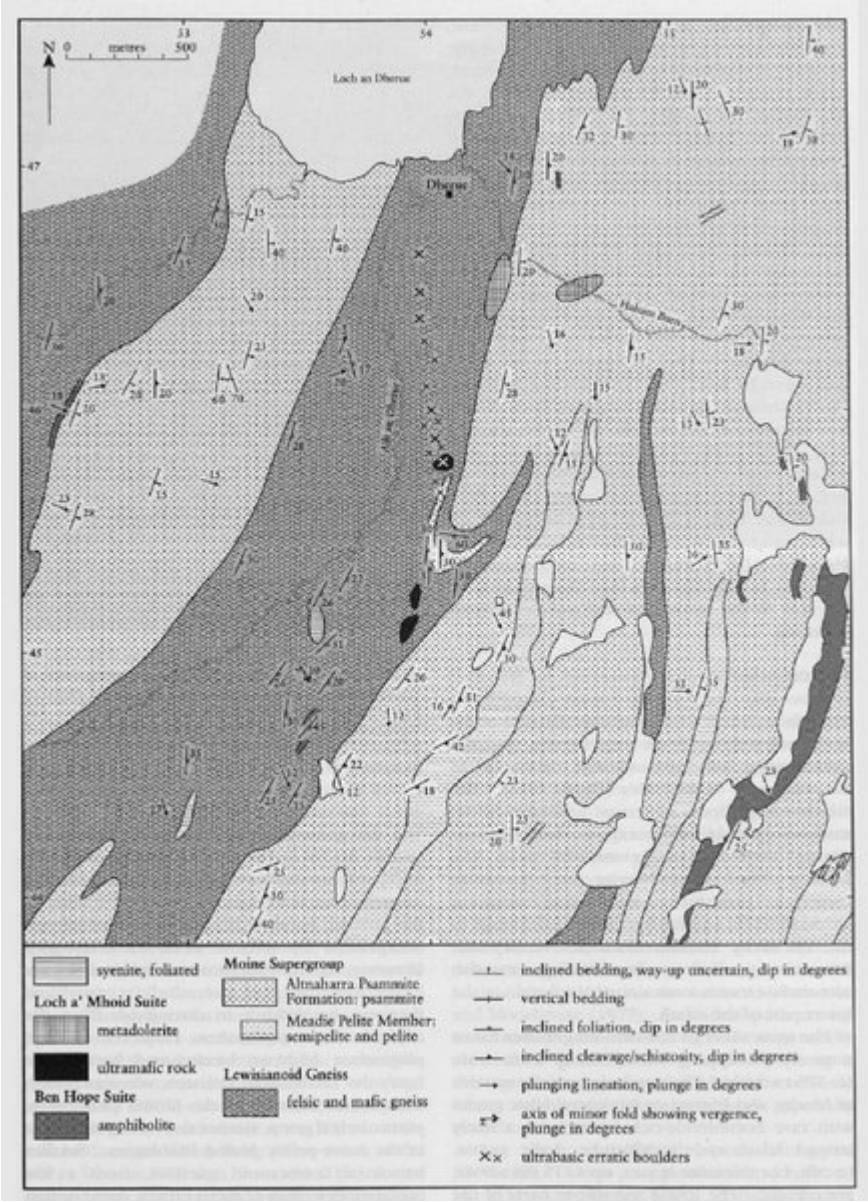
ultramafic intrusion during the waning stages of the Grampian Event or the Scandian Event.

The D2 structures in this area are dominated by the S2 schistosity and by shear zones. The Lewisianoid rocks form large lenticular masses, in part in thrust contact with the Moine psammites, but locally also tightly infolded with the psammites. The folds verge towards the west but there is no evidence of significant areas of inverted sequence. Some of the D2 folds are reclined, as they are farther north around Talmine (see Melness and Port Vasgo–Strathan Bay GCR site reports, this chapter) and farther south in Strath Oykel (see Oykel Bridge GCR site report, this chapter), but elsewhere they plunge north-east and northwards. There is a complex strain pattern in this area, with possible differential rotation in some lenticular zones during D2 and possible again during D3. D3 folding and fabrics are present, but are generally difficult to distinguish from the earlier pervasive D2 structures.

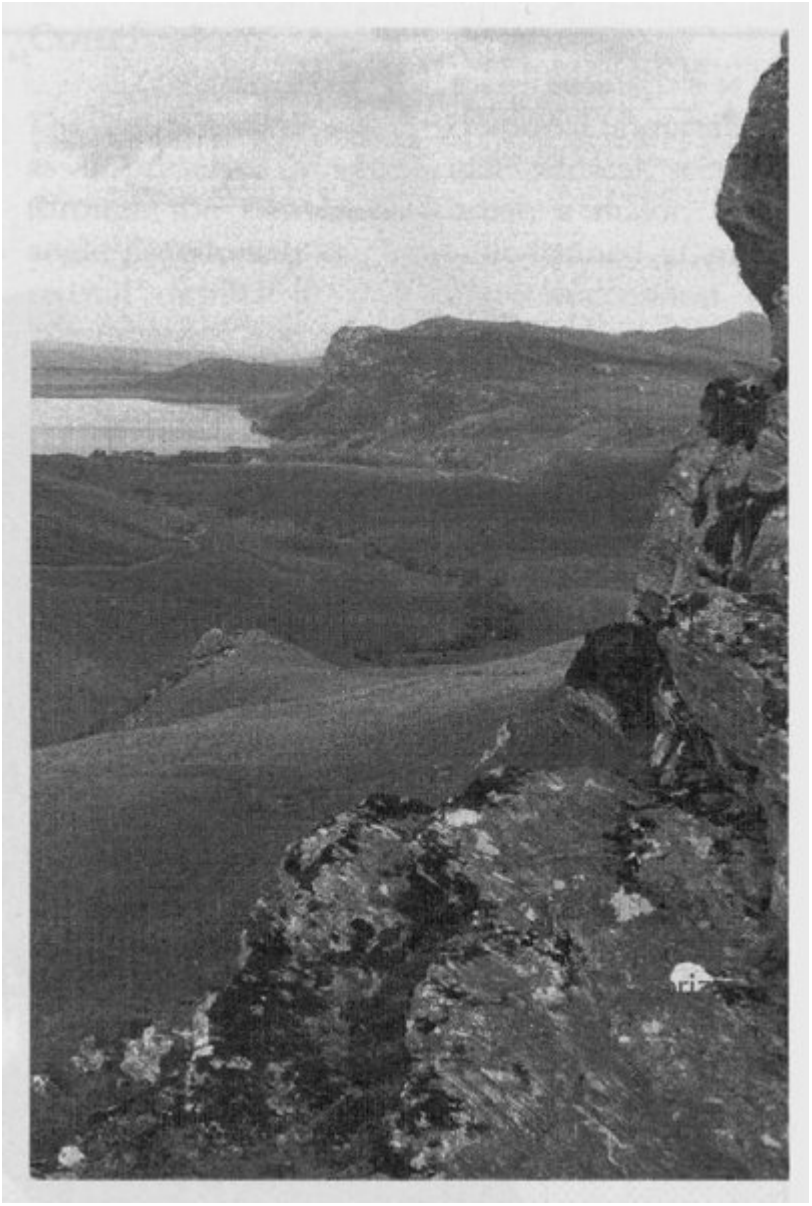
Conclusions

The Allt an Dherue GCR site is of national significance as it represents an important area for the study of Moine–Lewisianoid relationships, Caledonian thrust-related ductile deformation features, and the nature and significance of the Loch a' Mhoid Metadolerite Suite of intrusive mafic and ultramafic pods. Within the Moine Altnaharra Psammite Formation is the Meadie Pelite Member, which contains the metamorphic index minerals staurolite, garnet and kyanite. This originally aluminous iron-rich siltstone has been metamorphosed during the Caledonian Orogeny and possibly earlier in Neoproterozoic times. Garnetiferous amphibolites, which represent early-formed intrusive basalt and dolerite sills, cross-cut the Lewisianoid and Moine rocks. They are Neoproterozoic in age and are linked to those on Ben Hope. Polyphase deformation is ubiquitous and several high-strain zones occur, commonly coincident with Moine-Lewisianoid contacts. Lewisianoid and Moine rocks are intruded by mafic and ultramafic pods, which form part of the late Loch a' Mhoid Metadolerite Suite. These intrusions apparently post-date the main Caledonian D2 penetrative deformation and metamorphism, and were probably intruded during the waning stages of the Grampian Event or the Scandian Event.

References



(Figure 6.15) Map of the Alit an Dherue GCR site.



(Figure 6.16) Srath an Dherue, looking NNE to Loch an Dherue. The foreground crags are composed of Lewisianoid gneisses and the small knoll is formed of the Loch a' Mhoid Metadolerite Suite. (Photo: J.R. Mendum, BGS No. P552312, reproduced with permission of the Director, British Geological Survey, © NERC.)

(Figure 6.17) Attenuated Lewisianoid felsic and mafic gneisses with small ultramafic (hornblendite) pods and lenses, 300 m west of Loch an Dherue. The compass is 18 cm long. (Photo: J.R. Mendum, BGS No. P552305, reproduced with the permission of the Director, British Geological Survey, © NERC.)