Clèit an t-Seabhaig

[NC 507 682]–[NC 524 685]

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Introduction

The sea cliffs to the east of Whiten Head preserve some of the most northerly exposures in mainland Scotland of Moine and Lewisianoid rocks within the Moine Thrust Sheet, together with mylonites of the uppermost Moine Thrust Belt (Figure 5.10). Several distinct lithotectonic units are exposed, dipping mainly ESE at shallow angles. Moine psammites overlie a 15 m-thick unit of Lewisianoid orthogneiss followed by 200 m of white mica-chlorite phyllonite (the 'Oystershell Rock' of Peach *et al.,* 1907) that includes interleaved units of mylonitic Lewisian gneiss. The phyllonites overlie a thin, discontinuous unit of mylonitic Cambrian quartzites and Lewisian-derived mylonites interleaved with further units of mylonitic quartzite. The intensity of shearing decreases downwards and the lowest parts of the section consist of relatively undeformed Lewisian gneisses. The dominant deformation fabrics in the rocks are associated with mid- to low-greenschist-facies mineral assemblages.

The site is of historical importance, since it was in these steep coastal cliffs in 1884 that B.N. Peach and J. Horne of the Geological Survey first observed directly the structure that they considered to be the Moine Thrust (Peach and Horne, 1884; Peach *et al.,* 1907). The recognition of this major low-angle fault and of the down-faulted klippe, which exposes a similar structural sequence of rocks in the Durness area (see Faraid Head and Sango Bay GCR site reports, this chapter), showed clearly that the Moine Thrust Sheet had been displaced westwards by at least 15 km. This resolved the 'Highlands Controversy' concerning the nature of the contact between the overlying metamorphosed rocks of the Moine and the underlying Cambro–Ordovician sedimentary succession (see Oldroyd, 1990). It was also one of the first demonstrations that large-scale horizontal movements have occurred in an orogenic belt. Following remapping of the area (British Geological Survey, 1997b), Holdsworth *et al.* (2001) suggested that the structure identified by the Geological Survey as the Moine Thrust at Clèit an t-Seabhaig is a late-formed brittle extensional detachment, named the 'Lochan Riabhach Thrust', which lies at the base of the mylonites ('Oystershell Rock'). Holdsworth *et al.* (2006) suggested that this structure truncates earlier thrusts in its footwall, and formed during a hiatus in thrust stacking. The earlier, ductile Moine Thrust, across which the main shortening has occurred, lies some 200 m higher in the section (see (Figure 5.10)).

Description

The site comprises mainly steep, inaccessible cliffs, 160–200 m high, in which the large-scale geological structure is best viewed from a boat. Other than the cliff tops, there are few inland exposures, apart from short stream sections in the Alltan Riabhach and Allt Clais Eirgill. These sites have recently been described by Holdsworth *et al.* (2007).

The Moine rocks at the top of the exposed section comprise a sequence of grey-brown, lithologically monotonous, fine-grained flaggy psammites that here lack any structures indicative of way-up. The underlying Lewisianoid gneisses have a conspicuous striped appearance and comprise fine-grained units of pink and dark grey-green, strongly mylonitized felsic and mafic gneiss, interbanded on a millimetre- to centimetre-scale. Lenticular pods of concordant dark-green amphibolites and hornblendite up to 10 cm thick are also present locally. The concordant contact between Moine and Lewisianoid rocks is exposed in the steep cliff on the west side of Geodha nan Aigheann [NC 531 682], in the cliff between [NC 525 683] and [NC 530 684], and in the Allt Clais Eirgill stream section around [NC 522 683], immediately south-west of the Ben Hutig Fault (Figure 5.10). The rocks are all highly sheared and although the psammites adjacent to the Lewisianoid gneisses contain some pebbles, there is no trace of a basal conglomerate or discordance. The sharp, concordant contact between the Lewisianoid-derived mylonitic rocks and the underlying 'Oystershell Rock' is exposed in the cliffs between Geodha nan Aigheann [NC 531 682] and Allt Clais Eirgill [NC 520 682].

Most of the 'Oystershell Rock', so termed by the early surveyors because of numerous lunate quartz segregations and veins (resembling 'oysters'), is a fine-grained, dark grey-green white mica-chlorite-rich phyllonite. In thin section it consists of muscovite, chlorite, quartz, plagioclase (albite) and calcite with accessory magnetite, pyrite, apatite, biotite and potash feldspar. Relict garnet porphyroclasts up to 2 mm across are preserved in this phyllonite unit 2–3km inland and to the south of the coastal section (Holdsworth, 1987; Holdsworth *et al.,* 2001). Subordinate layers of grey quartzofeldspathic rock up to several metres thick, and grey-brown, fine-grained metacarbonate lenses up to 1 m thick occur locally within the phyllonites, notably near to the contact with the overlying Lewisianoid rocks (e.g. at [NC 532 683]) (Peach *et al.,* 1907). Some units of pink- and green-striped mylonite within the phyllonites (e.g. at [NC 524 683]), appear to be interleaved Lewisian-derived mylonite (Figure 5.10). The base of the phyllonites is defined by a gently E-dipping brittle fault plane that is well exposed near to the base of Clèit an t-Seabhaig [NC 521 685]. A thin (up to 8 m) unit of mylonitic Cambrian quartzite crops out immediately below this fault in the cliff top just east of Alltan Riabhach [NC 512 682] (Figure 5.11). This unit lenses-out rapidly down-dip and to the east, so that in the lower parts of the cliff, phyllonites directly overlie Lewisian-derived mylonites.

The Cambrian quartzite units are exposed in cliff-top outcrops and 20 m lower down in the section at [NC 515 682], where at least one further unit is interleaved with Lewisian mylonites. They are fine- to medium-grained, pale grey-pink recrystallized mylonitic rocks. For 20–30 m below the base of the phyllonites, the Lewisian rocks have been strongly deformed into pink- and green-striped, fine-grained mylonites. However, the intensity of mylonitization decreases rapidly below and to the west of the lower quartzite unit, and the Lewisian rocks at the base of the section are coarse-grained, banded gneisses with numerous discordant 'Laxfordian' pegmatites, similar in appearance to the gneisses of the adjacent foreland.

Most of the rocks in the section carry a strong foliation dipping gently to the ESE with a well-developed down-dip mineral-stretching lineation defined by aligned mineral grains and elongate mineral aggregates. The dominant fabric in the Moine psammites (assigned to S2) is mylonitic but is mostly annealed, as the quartz-microstructure is dominated by secondary recrystallization textures that coarsen eastwards (Holdsworth, 1987; Holdsworth and Grant, 1990). The mylonitic fabric can be traced downwards into finer-grained, sub-parallel, mylonitic L-S fabrics that affect the underlying mylonitic units, including the Cambrian quartzite. Here, abundant shear criteria such as shear bands and asymmetrical porphyroclasts show clearly that movement was top-to-the-WNW Secondary minor folds of the mylonitic foliation occur only in the mylonitic units where they display variable plunges and vergence patterns typical of high-strain zones.

The site is traversed by a number of steeply dipping, brittle dip-slip faults, including the NNW-trending Ben Hutig Fault (Figure 5.10). This fault is exposed at the cliff top at [NC 522 683] where it dips steeply to the southwest and is marked by 10 cm of incohesive red breccia and gouge. A 3 m-wide zone of irregularly orientated brittle folds and closely spaced, steep, SW-dipping fractures is found in the adjacent phyllonites. In the metamorphic rocks adjacent to the fault, bending of the foliation due to fault drag suggests that the south-west side has been dropped down and that the movement sense is normal. Offsets of the major boundaries indicate between 50 m and 100 m of vertical offset.

Interpretation

Lithologically and structurally, the units exposed at this site are typical of those recognized in the uppermost parts of the Moine Thrust Belt to the east of Loch Eriboll (see the Eriboll, Faraid Head and other GCR site reports). The origins of the 'Oystershell Rock' are uncertain, but Holdsworth *et al.* (2001) considered them to represent a highly deformed metamorphic unit of Lewisian affinities. The problem of defining the Moine Thrust in this area is difficult, because gneissose rocks of Lewisian and Lewisianoid parentage are juxtaposed and possibly interleaved in this area. The Geological Survey (e.g. Peach and Horne, 1884; Geological Survey of Scotland, 1889; Peach *et al.,* 1907) placed the Moine Thrust at the base of the 'Oystershell Rock' phyllonites, hence including them within the Moine Thrust Sheet. However, subsequent mapping in the region east of Loch Eriboll has shown that this unit is overlain by quartzite mylonites derived from Cambrian rocks of the foreland (e.g. Soper and Wilkinson, 1975). Unless the quartzite mylonites represent an example of breaching, this suggests that the phyllonites are more correctly assigned to the Moine Thrust Belt and that the Moine Thrust at Clèit an t-Seabhaig should be placed at the basal contact of the Lewisianoid rocks overlying the mylonitic 'Oystershell Rock' (Figure 5.10). The same unit of Lewisianoid gneisses, termed the 'Loch Fada

inlier', can be traced for over 20 km to the south on to the west side of An Lean Charn (Geological Survey of Scotland, 1889; Peach *et al.,* 1907; Soper and Wilkinson, 1975; Holdsworth, 1987; Holdsworth *et al.,* 2001). The contact between the Lewisianoid and overlying Moine rocks is interpreted as a highly sheared unconformity (cf. Holdsworth, 1989a).

The observed continuity between D2 fabrics in the Moine and the mylonitic fabrics in the underlying units is consistent with these structures having a common origin and being of *broadly* the same age. Shear-sense criteria throughout are consistent with top-to-the-WNW thrust displacements and are presumed to be of Caledonian age based on their similarity with other parts of the Moine Thrust Belt. The grade of metamorphism in the lower part of the Moine Thrust Sheet is difficult to assess due to the dominantly psammitic lithologies. Garnet porphyroblasts in coarse-grained pelites on nearby Ben Hutig are strongly wrapped by S2 and carry relict 51 inclusion trails, suggesting that the metamorphic grade in the Moine prior to the D2 deformation was at least garnet grade (Wilson, 1953; Barr *et al.,* 1986; Holdsworth, 1987, 1989a). In the same locality, biotite and garnet are extensively altered to chlorite defining the S2 fabric, and new chlorite and white mica overgrowths are developed in pressure shadows. These features suggest that the syn-D2 metamorphism was a retrograde mid- to low-greenschist-facies event, as first recognized by Read (1931, 1934). This is broadly consistent with the mineral assemblages and deformation textures developed during the main phase of shearing in the underlying mylonites derived from Lewisian gneiss and Cambrian quartzite protoliths. Greenschist-facies retrogression is ubiquitous in the originally gneissose Lewisian rocks, with amphiboles extensively replaced by chlorite, and calcic plagioclase by fine-grained aggregates of albite, sericite and epidote. As the intensity of mylonitization increases, the effects of retrogression are more widespread, suggesting that these processes are inter-related.

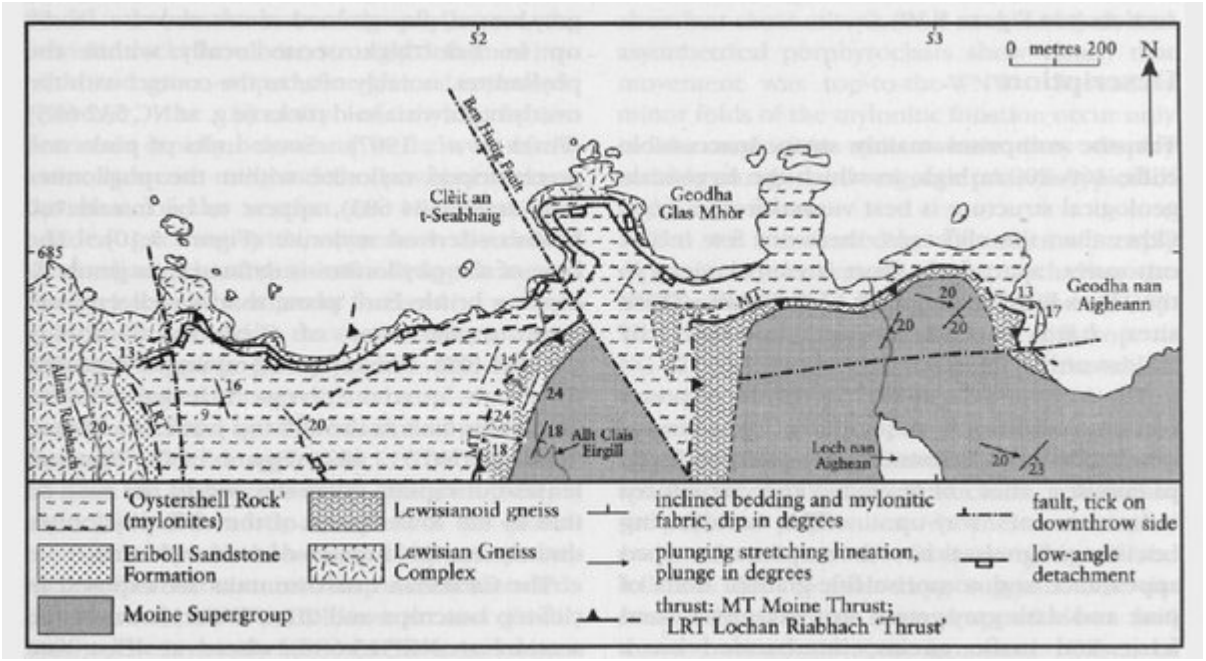
The age and sense of movement on the low-angle detachment at the base of the phyllonites in this area is uncertain, as this structure is nowhere exposed in an accessible location. Holdsworth *et al.* (2006) have identified a similar extensional detachment that cuts across earlier thrust-related structures in its footwall farther south through the Loch Eriboll area. They term this structure the 'Lochan Riabhach Thrust' and contend that it is a regional structure that formed by collapse of an evolving thrust wedge during a hiatus in thrust stacking. They correlate the detachment with a similar low-angle thrust fault at the base of the 'Oystershell Rock' at Sango Bay some 11 km to the west, where it is preserved in a down-faulted klippe (Hippler and Knipe, 1990; see Sango Bay GCR site report, this chapter, for alternative interpretation).

Conclusions

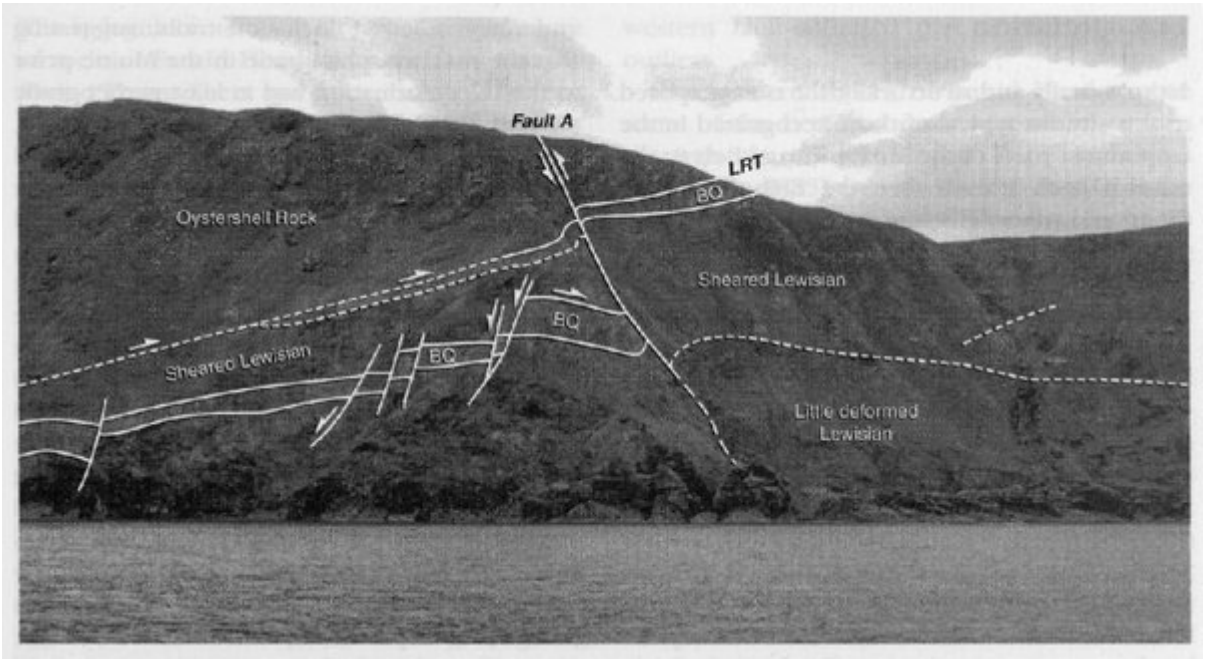
The Clèit an t-Seabhaig site contains some of the most northerly exposures of the Moine Thrust Sheet and upper Moine Thrust Belt in mainland Scotland. Historically, the site is of international importance, as it was here in 1884 that the structure considered to be the Moine Thrust was first observed directly in the steep coastal cliffs.

The recognition of a similar structural sequence of rocks at Faraid Head showed clearly that the Moine Thrust Sheet had been displaced at least 15 km westwards and formed one of the first demonstrations that large-scale horizontal movements occurred in orogenic belts. This resolved the 'Highlands Controversy' concerning the nature of the contact between the overlying metamorphosed rocks of the Moine and the underlying Cambro-Ordovician sedimentary succession. The mainly ESE-dipping structural succession preserves a transition from annealed Moine psammitic mylonites downwards into finer-grained mylonites and phyllonites derived from Lewisian and Lewisianoid orthogneisses, metasedimentary rocks and Cambrian quartzite. Mylonitization occurred under mid- to low-greenschist-facies metamorphic conditions. The textural sequence seen in the succession is typical of fabrics formed by foreland-propagating thrusting synchronous with uplift and erosion (Barr *et al.,* 1986). The low-angle brittle fault that defines the base of the phyllonites is well displayed in the cliffs and is interpreted as a regional structure, formed by extensional collapse during a period of thrust stacking.

References



(Figure 5.10) Map of the area around Cleit an t-Seabhaig. See Figure 5.12 (Faraid Head GCR site report) for location.



(Figure 5.11) Southward view of the cliff section near Alltan Rhiabhach (stream with waterfalls to right) in the western part of the Creit an t-Seabhaig GCR site. Lewisian mylonites ('Oystershell Rock') have been thrust westward over Basal Quartzite (BQ), which overlies Lewisian gneisses, which are less pervasively sheared than the Dystershell Rock'. LRT — Lochan Riabhach Thrust, mapped as the Moine Thrust by the original surveyors. In the eastern part of the cliff, sheared Lewisian below the LRT is thrust over a unit of Basal Quartzite that in turn unconformably overlies almost undeformed Lewisian gneisses at the base of the cliff. The westward continuation of the quartzite and associated thrust is uncertain to the right of the subvertical Fault A, but the thrust may follow the indicated boundary between sheared and less-deformed Lewisian gneisses. Note that the lower quartzite is offset by several steep late normal faults. (Photo: R.E. Holdsworth.)