Aird Torrisdale

[NC 668 636]–[NC 683 623]

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Introduction

The Aird Torrisdale GCR site provides coastal cliff-sections through the northernmost part of the Naver Thrust Zone, which separates the A' Mhoine and Naver nappes (Moorhouse, 1977; British Geological Survey, 1997b; Holdsworth *et al.,* 2001). The thrust zone is a significant structural boundary that telescopes different stratigraphical, tectonic and metamorphic levels within the exposed Moine succession in Sutherland. Below and west of the Naver Thrust Zone lies the A Mhoine Nappe comprising relatively low-grade, non-migmatitic Moine psammites (Altnaharra Psammite Formation). Within the Naver Thrust Zone are weakly to moderately migmatitic Moine psammites and semipelites (Druim Chuibhe Psammite Formation) and the Lewisianoid gneisses of the Torrisdale Inlier. Above and east of the Naver Thrust Zone lies the Naver Nappe in which interlayered migmatitic semipelites and psammites of the Bettyhill Banded Formation and Caledonian granitic rocks dominate. The major shear-zones, lithological contacts and penetrative cleavage/schistosity in the site all lie within the Torrisdale Steep Belt and dip steeply to the north-east (Holdsworth *et al.,* 2001). Pegmatitic granite veins are prominently developed within the thrust zone and in the overlying Naver Nappe.

Aird Torrisdale is the most westerly and structurally lowest of four GCR sites (Aird Torrisdale; Ard Mor; Farr Bay; and Glaisgeo–Farr Point) that together effectively constitute a cross-section through the Naver Nappe of north Sutherland. Archaean high-grade felsic and mafic gneisses of the Lewisianoid Borgie Inlier are infolded with the psammites of the underlying

Mhoine Nappe, and Lewisianoid gneisses also form smaller highly tectonized inliers in the overlying Naver Nappe (Figure 6.22). Early mafic sheets and dykes of the Bettyhill Suite, now foliated amphibolites, are notably abundant in the Naver Nappe. Pegmatitic granite and quartz-feldspar pegmatite veins and pods, in places up to tens of metres thick, are abundant both in the Naver Thrust Zone and in the overlying Naver Nappe. Appinitic mafic bodies also occur in the Naver Nappe, for example the Clerkhill Intrusion is a major feature of the Glaisgeo–Farr Point GCR site.

B.N. Peach first mapped the area around Aird Torrisdale for the Geological Survey in 1886. Moorhouse (1979) revisited the area in the 1970s, and the results of more-recent mapping of the Torrisdale area by I.E. Alsop, I.M. Burns and R.A. Strachan are incorporated in the revised geological map of the Tongue district (British Geological Survey, 1997b) and accompanying Sheet 114E memoir (Holdsworth *et al.,* 2001).

Previous geological accounts of Aird Torrisdale have described a discrete Naver Thrust rather than a zone of thrusting. Moorhouse (1979) placed the thrust along the sheared upper contact of a large Lewisianoid body, the Torrisdale Inlier, whereas Holdsworth *et al.* (2001) positioned it farther west along the sheared lower contact of the inlier (see Figure 6.22), (Figure 6.23). This latter contact is faulted out on the coast section. In fact there are a number of individual ductile thrust planes and narrow shear-zones exposed in the coastal section. Holdsworth *et al.* (2001) recognize the Druim Chuibhe Psammite Formation as being confined to a thrust zone bounded to the west by the Naver Thrust and to the east by the Torrisdale Thrust (Figure 6.23). Hence, the Aird Torrisdale site provides a cross-section through the Naver Thrust Zone rather than through a single discrete Naver Thrust plane. This is also more in accord with its occurrence to the south in the Ben Klibreck GCR site, where the Naver Thrust Zone is up to about 0.5 km wide, and includes a number of thrust dislocations together with tight Caledonian folding (Moorhouse, 1977; Strachan and Holdsworth, 1988). The thrust-bounded Torrisdale Lewisianoid Inlier strikes north-west and is faulted to the west against the larger Borgie Inlier.

Description

There is continuous rock exposure all along the steep, but largely accessible E- to SE-trending coastline of Aird Torrisdale, and moderate rock exposure on the inland peat-clad hills that rise up to 100 m OD. The regional strike of lithologies is generally north-west, so the coastline provides an oblique cross-strike section. A traverse from Skerray Church [NC 6730 6243] north-east across Aird Torrisdale to the coast also provides an admirable cross-section through the main geological units. Moine psammites (Altnaharra Psammite Formation) and Archaean gneisses of the Torrisdale and Borgie Lewisianoid inliers in the A'. Mhoine Nappe are exposed at the start of this traverse. The sheared contacts of the Torrisdale Inlier lie within the Naver Thrust Zone. The overlying migmatitic and gneissose Moine psammites and semipelites (Druim Chuibhe Psammite and Bettyhill Banded formations) of the Naver Nappe are beautifully exposed on the coastal cliffs and on the sandblasted, glacially scoured outcrops at the north end of Druim Chuibhe (Figure 6.23), (Figure 6.24).

The rocks of Aird Torrisdale lie in the Torrisdale Steep Belt, where the regional bedding, gneissic foliation and main cleavage all dip between 50° and 75° to the north-east and east.

The compositional layering and foliation in Naver Nappe to the east mostly have a similarly steep orientation but the Torrisdale Steep Belt flattens out gradually southwards after about 10 km. Within the belt the dominant mineral lineations and fold axes plunge gently to the north-west and south-east, unlike the rocks farther west or east where the lineations and fold axes plunge predominantly down-dip.

Psammites of the N. Mhoine Nappe are exposed on both sides of the Skerray–Torrisdale road where, although deformed, they show prominent bedding; locally remnants of cross-bedding are seen. They are characterized by a steep NE-dipping, composite foliation and steep SE-plunging lineation, both attributed to the main regional Caledonian deformation events (D2 and D3). On the north-east side of the road at [NC 6745 6257], non-migmatitic Moine psammites are structurally overlain by variably schistose biotitic and hornblendic mafic gneisses. Moorhouse *et al.* (1988) recognized these highly deformed mafic rocks as part of the Torrisdale Lewisianoid Inlier. This NW-trending lenticular inlier is approximately 0.5 km wide, sandwiched between ductile thrusts in the Naver Thrust Zone. It is separated from the main Borgie Inlier towards its northwest end at Skerray village by a steep NNW-trending fault. It is possible that the Torrisdale Lewisianoid Inlier and the surrounding Moine psammites are disposed in a large NW-closing F2 fold that is truncated by this fault (Figure 6.23). The Torrisdale Inlier comprises highly deformed and folded felsic and mafic Lewisianoid gneisses.

The Lewisianoid gneisses are typically interlayered felsic, mafic and intermediate orthogneisses with subsidiary amphibolite, ultramafic rock, metagranite and granitic pegmatite (Holdsworth *et al.,* 2001). The mafic gneisses consist of medium- to coarse-grained hornblende, biotite, quartz and plagioclase with secondary epidote and accessory titanite, zircon and opaques. Three generations of hornblende were recognized by Burns (1994). A planar fabric, defined in part by aligned hornblende grains, wraps early asymmetrical hornblende poikiloblasts. Late sub-idioblastic hornblende grains randomly overgrow this planar fabric. The biotite-bearing felsic lithologies superficially resemble Moine gneisses, particularly where they are strongly deformed, but they are dominated by plagioclase feldspar, quartz and epidote and their geochemistry is distinctive (Moorhouse, 1976). There are several large amphibolite mafic bodies in the Torrisdale Inlier, typically between 150 m and 800 m long and 10 m to 100 m wide, the largest of which lies north-east of Achtoty at around [NC 672 630]. In rare instances cross-cutting contacts between the mafic bodies and the host gneisses can be seen.

There are two critical exposures of individual thrusts within the Naver Thrust Zone in the GCR site area. Near Lon [NC 6875 6040] a 10 m-thick sliver of sheared Lewisianoid hornblende schists and layered hornblende-biotite felsic gneisses, define the Naver Thrust that here separates non-migmatitic psammites with infolded Lewisianoid lithologies to the west from variably migmatized and gneissose psammites of the Druim Chuibhe Psammite Formation to the east. Examples of fold interference patterns are seen in the gneissose psammites. On the Aird Torrisdale coast at [NC 6710 6358] a *c.* 1 m-thick zone of flaggy, striped, biotite-rich, schistose psammites with subconcordant quartzofeldspathic lenses marks a thrust that separates Lewisianoid gneisses of the Torrisdale Inlier from overlying, flaggy migmatitic psammites. Farther south-east on the coast of Aird Torrisdale at [NC 6840 6234] a 3–5m-thick unit of finely layered Lewisianoid hornblende-biotite gneiss separates gneissose psammites of the Druim Chuibhe Psammite Formation from overlying darker-grey, partly migmatitic micaceous psammites of the Bettyhill Banded Formation. Holdsworth *et al.* (2001) term this contact the 'Torrisdale Thrust' and hence it marks the upper boundary of the Naver Thrust Zone. It can be traced

south-east across Torrisdale Bay onto Druim Chuibhe where complex thrust relationships are exposed. At the northern end of Druim Chuibhe [NC 687 614], platy psammites of the Druim Chuibhe Psammite Formation are in direct contact with interlayered gneissose psammites and amphibolites of the Bettyhill Banded Formation. These localities illustrate the geological relationships across the Naver Thrust Zone. Coherent pink pegmatitic granite sheets and veins occur within the Naver Thrust Zone and are spectacularly exposed on Aird Torrisdale. Note that an extensional (detachment) fault that is exposed on the coast at [NC 6837 6235] masks the location of the Torrisdale Thrust here (Holdsworth *et ed.,* 2001).

Interpretation

The Naver Thrust Zone separates the non-migmatitic predominantly psammitic Moine lithologies of the A'. Mhoine Nappe in the foot-wall from the predominantly migmatitic Moine semipelites, psammites and pelites of eastern Sutherland in the hangingwall. The approximate western limit of abundant granite and pegmatite veins within H.H. Read's 'zone of veins' also coincides with the Naver Thrust Zone. The abundance of pegmatites in the Naver Thrust Zone may have resulted from enhanced fluid flow through the thrust system. The veins, part of the Torrisdale Vein-Complex, are described in the Ard Mor GCR site report (this chapter).

Relict garnet-pyroxene granulites locally occur as kernels in the amphibolites within the Torrisdale and Borgie Lewisianoid inliers. Moorhouse (1971, 1976, 1977) showed that these lenses are petrologically and geochemically similar to ones in Scourian gneisses of the foreland Lewisian. Similarly, the less-foliated and deformed amphibolites in these inliers may be equivalent to mafic dykes of the Scourie Dyke Suite seen in most of the foreland Lewisian outcrops. Moorhouse *et al.* (1988) inferred that the Lewisianoid gneisses originally formed a crystalline basement unconformably overlain by arenaceous Moine sediments and hence that the present inverted sequence is a result of Caledonian deformation.

The Naver Thrust Zone appears to have a complex and extended history, possibly commencing as early as the Neoproterozoic during Moine sedimentation. It has been the site of Caledonian ductile thrusting probably with major westward movement in both the Grampian (*c.* 470 Ma) and Scandian (*c.* 425 Ma) events (Kinny *et al.,* 1999; Friend *et* al., 2000; Dallmeyer *et al.,* 2001). Kinny *et al.* (1999) carried out U-Pb SHRIMP analysis of zircons from partially blastomylonitic migmatitic psammites west of Druim Chuibhe at [NC 688 614]. The low and Th clear rims of the zircons yielded an age of 467 ± 10 Ma, interpreted as dating metamorphism and deformation during the Grampian Event.

The characteristic steep dips in this area form part of the Torrisdale Steep Belt, which Holdsworth *et al.* (2001) interpreted as a result of rotation during late-stage (late D3) dextral transpression. Dallmeyer *et al.* (2001) obtained hornblende and muscovite $^{4\circ}$Ar-^{39}Ar plateau ages ranging from 417 Ma to 421 Ma from rocks of the Naver Thrust Zone 1–2km south-east of Aird Torrisdale. They interpreted these Scandian ages as dating the formation of the Torrisdale Steep Belt. It is unclear as to whether these cooling ages also date the end of Scandian thrusting across the Naver Thrust Zone. What is clear is that late-stage orogenic movement and related strain have been focused along an earlier thrust zone, in turn possibly reflecting an even older Neoproterozoic lineament.

Conclusions

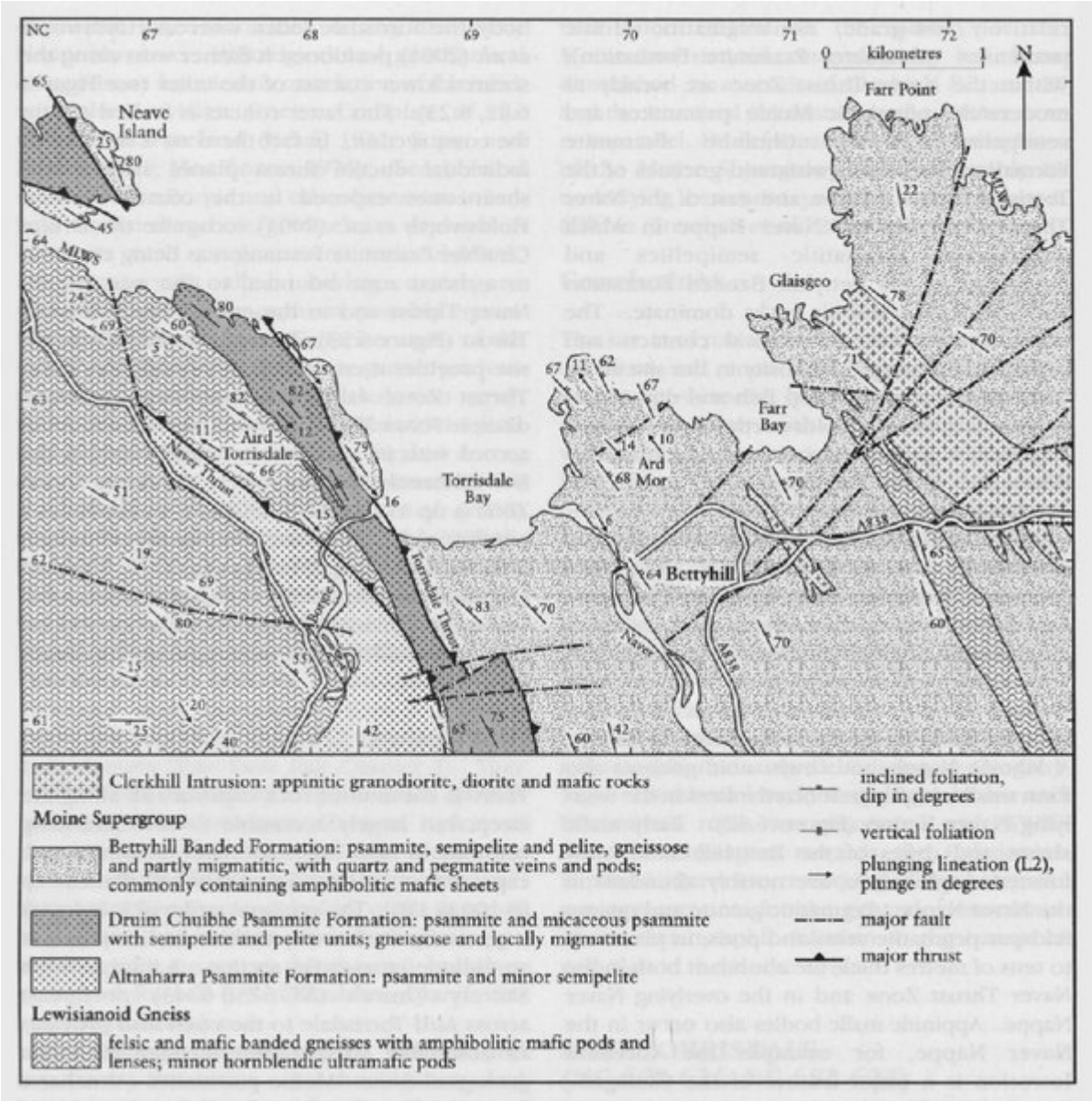
The Aird Torrisdale site exposes the northern extremity of the Naver Thrust Zone, a major tectonic boundary within the Moine succession of Sutherland. The thrust zone separates the A'. Mhoine Nappe in its footwall from the Naver Nappe in its hangingwall. Moine and Lewisianoid lithologies above and below the thrust zone, as well as individual thrust planes and folds within the zone are well exposed in accessible, cross-strike coastal sections and scattered inland exposures. Bedding, cleavage and all planar structural features dip steeply north-east and lie within the Torrisdale Steep Belt. The main Lewisianoid body, the Borgie Inlier, occurs below the thrust zone in the A'. Mhoine Nappe whereas a smaller body, the Torrisdale Inlier, lies within the thrust zone. The Lewisianoid rocks consist of banded felsic and mafic gneisses of Archaean age with larger amphibolitic mafic bodies and small ultramafic pods.

The lithological differences in the Moine rocks above and below the Naver Thrust Zone are also manifest in the coast section. The thrust zone is responsible for stacking migmatitic Moine psammites, semipelites and pelites of the Bettyhill

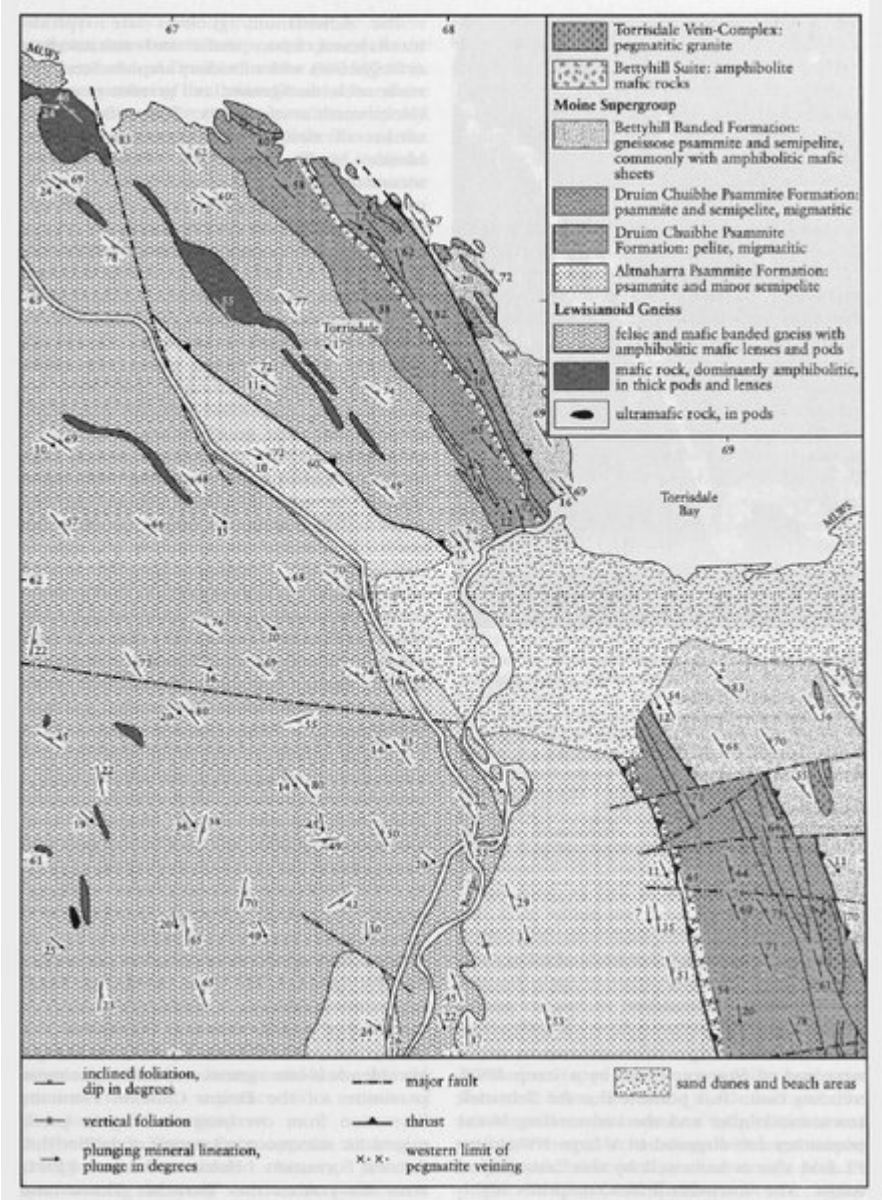
Banded Formation to the east on top of non-migmatitic Moine psammites, the Altnaharra Psammite Formation, and their Lewisianoid basement to the west. Most of the translation has occurred across ductile thrust zones and some of these have been dated as Early Ordovician (467 Ma) (Kinny *et al.,* 1999), but others are probably of Late Silurian age (*c.* 425 Ma). In the pelitic rocks of the Bettyhill Banded Formation migmatitic lits are pervasively deformed and feldspar porphyroblasts are present, resulting in augen gneisses. This implies that at least part of the major ductile movements post-dated the main migmatization event. The Moine psammites and semipelites within the thrust zone, the Druim Chuibhe Psammite Formation, are strongly cleaved, tightly folded and partly migmatitic (Holdsworth *et al.,* 2001). They contain abundant discordant pegmatitic granite veins as well as smaller quartzofeldspathic segregation veins and pods.

The site is of national importance because it provides superb, readily accessible exposures across a major structural boundary within the Caledonian orogenic belt of northern Scotland. The ductile thrust contacts between the Lewisianoid inliers and younger Moine gneisses and within the Moine gneisses are readily seen and ideal for further work.

References



(Figure 6.22) Map of the Aird Torrisdale–Bettyhill-Farr area, showing the general geology encompassing the Aird Torrisdale, Ard Mor, Farr Bay and Glaisgeo–Farr Point GCR sites. Adapted from British Geological Survey 1:50 000 sheets 114E, Tongue (1997b), 115W, Strathy Point (1996), and Cheng (1942, 1943).



(Figure 6.23) Map of the Aird Torrisdale–Torrisdale Bay area. Compiled from data collected by G.I. Alsop, J.R. Mendum, C.G. Dyke and V.E. Moorhouse.

(Figure 6.24) Sheared amphibolitic mafic rocks inter-banded with micaceous psammite and semipelite, showing tight F2 folds, cut by a quartz-feldspar pegmatite vein that is in turn deformed and folded by F3 folds. The hammer (37 cm long) is aligned with its handle parallel to the trace of the dominant planar fabric (S2). The exposure lies in the Naver Thrust Zone and Torrisdale Steep Belt. Druim Chuibhe, Torrisdale Bay [NC 6901 6167]. (Photo: J.R. Mendum, BGS No. P581267, reproduced with the permission of the Director, British Geological Survey, © NERC.)