Excursion 6 West Glenelg and Loch Hourn

John Ramsay

Purpose:	To examine relationships between Moine metasediments and Lewisianoid basement rocks above the Moine Thrust, and the nature of the polyphase deformation that affects both units.
Aspects covered:	Lewisian orthogneisses and associated mafic intrusions (locally eclogitic), Moine psammites and sedimentary structures, polyphase folds and fabrics.
Useful information:	Hotel and B&B accommodation are available in and near Glenelg village.
Maps:	OS: 1:25,000 sheet 413 Knoydart, Loch Hourn and Loch Duich; BGS: 1:50,000 sheet 71E Kyle of Lochalsh.
Type of terrain:	Rocky coastline.
Distance and time:	The excursion is best followed over 2 days; Localities 6.1-6.3 can be visited on the first day and 6.4-6.7 on the second.
Short itinerary:	For visitors only interested in Moine-Lewisian relations, Localities 6.1, 6.3 and 6.6 can be completed in a single day.

This is a classic region for establishing the differences between Lewisian basement and Moine metasediments above the Moine Thrust. These are especially apparent in the west of the region but are progressively overprinted towards the east by the effects of superimposed (Caledonian?) deformation and metamorphism. Detailed descriptions, maps and structural analysis relevant to this excursion are provided by Peach *et al*. (1910), Ramsay (1958), Sutton & Watson (1959) and Ramsay & Spring (1962).

The Lewisian gneisses comprise 'Western' and 'Eastern' facies (Figure 6.1). Both are dominated by acid and mafic orthogneisses, but the Eastern facies is particularly distinctive because of the presence of metasediments and eclogites (see also Excursion 7). The Lewisian rocks are found in three strips (Figure 6.1) which are interpreted as the cores of D_1 anticlines. The two western fold cores are of Western facies aspect (Figure 6.1) and the third is of Eastern facies aspect (Figure 6.1). The Moine rocks comprise a well-defined stratigraphic sequence of psammites, semi-pelites and pelites that has been assigned to the Morar Group (Figure 6.1). Towards the east, the Moine rocks become progressively migmatitic.

Three major deformation phases have been recognized in the Lewisian and Moine rocks (Figure 6.2). The Lewisian and Moine were interfolded by D_1 tight to isoclinal folds (Figure 6.2). Fold-axis parallel lineations are mainly quartz rods that probably formed at no higher than the low amphibolite facies. D_2 folding resulted in the Beinn a' Chapuill-Beinn nan Caorach Antiform and the Glen Beag Synform ((Figure 6.2), BC and GB respectively) as well as numerous associated minor folds. D_2 folding was accompanied by strong recrystallization and migmatization of both Lewisian and Moine. A strong axial-planar schistosity is present and a prominent D_2 lineation is parallel to local D_2 fold axes. D_3folds trend NE–SW and have axial planes that dip SE. The most important regional folds are the Loch Hourn-Loch Duich anti-form and the Ben Sgriol Synform ((Figure 6.2), LH-LD and BS). D_3folds crenulate earlier fabrics and were probably accompanied by low amphibolite facies metamorphism.

Locality 6.1 North Glenelg Bay [NG 809 205]

North Glenelg Bay (Fig 6.1), (Figure 6.3). Tectonically modified unconformity between Western facies Lewisian gneisses and Moine psammites.

From the Y-road junction of the road northeast of Glenelg village, take the road towards the Kylerhea Ferry. After about 1.5km [NG 8094 2049], a small track on the west of the asphalt road and beneath an imposing old sea cliff with raised beach and sea caves leads down to the present beach where there is space to park. These outcrops will take around 0.5-1 hour of study.

Just to the north of a newly-built (2005) house 'Beach-Haven', a prominent red-brown lamprophyre dyke cuts grey Moine psammites (Figure 6.3). South of this dyke, a contact between Moine psammites and Lewisian gneisses is exposed [NG 8080 2036]. The outcrops are best visited at lowtide. The best exposures are to be found just below high water mark. The mineralogical and textural contrasts between the grey Moine psammites and the orange-brown Lewisian gneisses are very marked, and at several localities the actual contact between the two groups of rocks may be investigated. Most of the Western facies Lewisian gneiss consists of coarse-grained biotite-hornblende gneiss with a banding produced by variations in the biotite and hornblende content. The gneisses often show an agmatitic structure with clots and lenses of biotite and hornblende-rich material. There is no evidence of a sedimentary origin. The gneisses locally have boudinaged sheets of amphibolitic rock and, although these are here parallel to the banding in the enclosing biotite gneisses, their contacts are generally sharp. They probably represent amphibolitized basic dykes which at some other localities in the Glenelg region can be seen to be discordant to the gneissic banding. Lenticular masses of ultrabasic material are also common, consisting of green actinolite and diopside, dark brown biotite and black hornblende. At some localities, S-shaped minor folds (D_2) are present with their hinge lines parallel to an intense rodding lineation.

The Moine psammites are well-bedded, muscovite-biotite-quartz-feldspar rocks. Gneissic material is completely absent, although some quartz veins are present. Certain beds show their original clastic grain structure and are marked with small pock-marked weathering holes. At several localities, cross-bedding is preserved and truncated foreset bedding is often well preserved especially in the hinge zones of minor folds. These sedimentary structures consistently indicate that the Moine rocks young in a direction away from the Lewisian-Moine contact. There are abundant tight D_2 folds with regionally consistent S-forms. These folds generally show well-developed axial-plane schistosity, together with an E-plunging and intense schistosity-bedding intersection parallel to a rodding-lineation and to the fold hinge lines. At one locality (Figure 6.3) small isoclinal folds are refolded by the dominant D_2 structures, but it is uncertain if these structures are tectonic (D_1) or sedimentary in origin.

The contrast of rock type between the Lewisian and Moine units is very marked and the contact is sharp with stratigraphic relationships that suggest that the Moine sediments were deposited on a basement that had already undergone upper amphibolite facies metamorphism and had been intruded by basic and ultrabasic sheets. At the actual contact here is no clear evidence of an angular unconformity and some of the finer grained bands of Lewisian gneiss superficially resemble the adjacent Moine psammite. This similarity in appearance is a good example of metamorphic and textural convergence, whereby two groups of quartz-feldspar-mica rocks with initially distinct textures and fabrics converge in grain size and overall appearance as a result of undergoing identical deformational and metamorphic processes. Both Lewisian and Moine have experienced intense common ductile folding and such deformation is well known to generally reduce angles of discordances (Ramsay, 1967; Ramsay & Lisle, 2000). However, certain structural features do suggest that the two groups were originally structurally discordant. Although the orientations of the main folds which affect the Lewisian and Moine are similar, there are slight but consistent differences between the common geometric features. For example, the orientations of the fold hinges and rodding structures in the Lewisian and Moine are not quite the same: those in the Lewisian plunge to the ESE with a generally more varied and steeper plunge than the more constant and easterly plunging structures of the Moines. These differences are probably best interpreted as being the result of differences in the orientations of the Lewisian banding (steeper and more variable) from those of the Moinian bedding surfaces (less steep and more constant).

If the visitor has extra time (10 minutes walk) some nearby coastal outcrops a little further to the south and to the SE of the headland of Creag Mhor at [NG 8086 2013] of Lewisian agmatitic gneisses can be highly recommended, and are especially photogenic (see Clough in Peach *et al*., 1910, plate VI).

Locality 6.2 Glenelg village [NG 8092 1921]

Glenelg village (Figure 6.1). Western facies Lewisian gneisses and amphibolite sheets.

At Rudha Mhic Cuinn, on the foreshore just west of the Glenelg War Memorial, banded hornblende-biotite gneisses show hornblende agmatites injected by acid veins [NG 8092 1921]. The gneisses are cut by massive sheets of amphibolite with sharp contacts and with little or no gneissic material. These sheets are interpreted as basic intrusions injected into the gneissic host and subsequently recrystallised in amphibolite facies metamorphic conditions during D_2. All the rocks show an intense D_2 rodding lineation plunging 15°-25° to the ESE. Just south of the monument are exceptionally clean outcrops of banded gneiss cross-cut by a massive amphibolite with a knife-sharp contact. The gneiss shows an easterly dipping schistosity oblique to the banding and with schistosity/banding intersection parallel to the prominent rodding which is exactly parallel to the hinge line of nearby D_2 folds.

Locality 6.3 Sandaig [NG 7680 1463] to [NG 7706 1520]

Sandaig (Figure 6.1). Western facies Lewisian gneisses and amphibolites, some of which show eclogitic cores; tectonically modified unconformity with cross-bedded Moine psammites.

Drive along the asphalt surfaced road south from Glenelg village, and after 1.5km turn right to cross the Gleann Beag river at Eilanreach. Continue along this road for about 4km where a gravel track branches left into a forestry plantation just north of the reed-filled Loch Drabhaig [NG 7836 1517]. Park by the roadside and proceed through a locked forestry gate into the forestry plantation following the main track (there are various branching tracks) to cross the Allt Mor Shantaig by a bridge. About 600m from the bridge a complex of tracks meets at a cross road: take the track on the right which descends towards the sea. After several bends the track finishes and is replaced by a narrow footpath descending towards the Bay of Sandaig. This descent from the park place will take about 30 minutes. Sandaig [NG 7724 1472] is now a ruined croft, once inhabited by Gavin Maxwell who wrote a well known book describing his stay there (*The Ring of Bright Water*, Penguin Books, 2001). Pass through a gate and follow a footpath to two small monuments, one with a small bronze plaque in memory of Maxwell, the other to his otter Edal (site marked on the 1:25,000 map 'meml.'). If the season has been dry it is possible to cross the river (Allt Mor Shantaig) where it enters the sea. More normal Scottish conditions will require wading or by using the shaky double-rope bridge, one rope for the feet the other for the hands.

From the rope bridge a footpath leads westwards to the Sandaig Islands where there are excellent wave-washed outcrops [NG 7680 1463] of quartz-feldspar-hornblende gneiss with a strongly developed, easterly plunging rodding lineation (D_2) (Locality 6.3A). The gneissic banding is often crosscut by dark-green hornblende-garbenschiefer spears. Some of these hornblendes are up to 4cm long, while others occur as stellate aggregates following hornblende-rich layers. Because they cross-cut the rodding structures it is clear that the metamorphism which led to their development must be post D_2. If tide and time allow it is well worth visiting the more westerly of the islands (although that in the far west where the lighthouse is located is generally inaccessible except by boat). Here the quartz-feldspar rich gneisses contain amphibolite sheets free of gneissic material and are sometimes boudinaged. Their contacts are invariably sharp and locally discordant to the gneissic banding, and they are best interpreted as representing basic intrusions into the gneisses.

From the Sandaig Islands, proceed northward past the headland of An Gurraban. In a small bay (Locality 6.3B, [NG 7696 1506]) a contact between Lewisian gneisses and Moine metasediments is exposed. At the actual contact, the SE-dipping Moinian sediments contain elongated blocks of Lewisian gneiss material which has been interpreted as representing a true basal conglomerate of the Moine Series (Clough in Peach et al., 1910, p. 50). Unfortunately the best and most convincing exposures of this conglomerate are now practically inaccessible, overgrown by moss and situated in a steep forest-covered hillside further to the northeast [NG 7868 1649]. The basal Moine sediments form alternating bands of garnetiferous pelitic mica-schist and semipelitic material (the so-called 'basal Moine pelite', Ramsay & Spring, 1962). In contrast to the immediately adjacent Lewisian rocks, the Moine metasediments contain no gneissic material, only a few crosscutting quartz veins. The pelitic Moine sediments contain perfectly idiomorphic dark red-brown garnets up to 8mm in diameter and which, under the microscope, are seen to contain spiral inclusion trails suggesting that they grew during and after the D_2 deformation. The pelitic bands nearest to the Lewisian gneisses contain some small hornblende-garbenschiefer spears, and these are believed to have formed at the same period of metamorphism as those

seen in the Lewisian gneisses described earlier (post D_2). Generally the Moine sediments of the Glenelg region lack amphibole. The origin of the hornblendic material is uncertain: it could be have been derived from the erosion of Lewisian material, or it could be the result of migration of the mineral constituents from the adjacent gneisses during metamorphism.

A broken wire fence comes down to the coast just north of the Moine-Lewisian contact. Just north of this fence the more psammitic parts of the Moine are well exposed at Locality 6.3C [NG 7706 1520] and show good cross-bedding structures indicating that the SE-dipping metasediments are inverted and young away from the Lewisian. The psammitic Moines show beds with well preserved (although tectonically stretched and recrystallised) clastic feldspars. The cross-bedding features are especially well developed as the distance from the Lewisian–Moine contact increases and are especially well preserved in the sea cliffs on the headland of Rubha na h-Airde Beithe ([NG 7785 1640]; and see Peach *et al*., 1910, p. 53), but a visit to this headland will take at least 20 minutes (low tide conditions necessary).

If the tide is low and the visitor has time (½-1 hour) it is worth visiting the coastal outcrops of the Lewisian south of Sandaig. The Lewisian along this stretch of coast, in contrast to that seen in the Sandaig Islands, has been very highly deformed, and much of the coarse-grained fabrics have been replaced by laminated, very fine grained quartz-feldspar-hornblende-biotite rocks. Because of their fine- and rather even-grain size, these rocks were once described as 'granulites', this description applied because of their granular nature and not because of their metamorphic state. The rocks are intensely and finely banded, and the sheets of hornblende schist have been boudinaged into pod-like pieces. At Locality 6.3D [NG 7675 1404] the centres of the largest pods sometimes have an altered eclogitic mineralogy (the eclogite transforming to garnet amphibolite and amphibolite), a feature which is more characteristic of the Eastern Lewisian facies and generally absent in the Western facies. In fact, these outcrops are the only ones seen in the Western facies and the eclogitic remnants here have been dated at ~1700 Ma (Storey *et al.*, 2010), markedly different from the ~1100 Ma eclogites in the Eastern Lewisian facies (Excursion 7; Sanders *et al*., 1984; Sanders, 1988). The strongly banded Lewisian gneisses show lenticulate blebs of feldspar, while the quartz crystals are found as sinuous streaks around the feldspar porphyroclasts. The timing of this granulation of the rocks is uncertain at this locality. Elsewhere in the Glenelg region, such highly deformed fabrics are also found in Moinian rocks, appear to predate the strong recrystallization that is attributed to D_2 and post D_2, and are attributed to the first of the deformation in common to both Lewisian and Moine (D_1) (Ramsay & Spring, 1962). From south Sandaig return to the road.

Locality 6.4 Road section west of Arnisdale [NG 8320 1118]

Road section west of Arnisdale (Figure 6.1). Relationships between D_2 and D_3 structures within Moine psammites.

From Upper Sandaig drive along the road in the direction of Arnisdale. The road climbs to a hilltop [NG 7802 1302] where it is worth stopping to view to the SW of the Tertiary Volcanic islands of Rhum and Eigg. Continue downhill, passing into a forestry plantation (cattle grid) and through roadside outcrops situated in the complex core zone of the Loch Hourn-Loch Duich D_3 antiform. On emerging from this forest (cattle grid), the road passes close to the shore line passing the cottage at Rarsaidh. After about 0.5km, park by roadside exposures of gently inclined Moine psammites which are Locality 6.4 [NG 8320 1118] (Figure 6.1). Proceed by foot along the road towards Arnisdale.

The Moine psammites progressively change dip from SE to west as the trough line of a D_3 syncline is crossed. Excellent roadside exposures on the north of the road show sections of typical Moine psammites with thin bands of pelitic material with well developed D_3 crenulation cleavage. As one proceeds along the road to the SSE, the bedding surfaces of the Moines are exposed and one can see the development of two distinct crossing lineations: a D_2 quartz feldspar rodding is cut and refolded by strongly developed D_3 crenulation folds. The dip of the bedding gradually increases as one passes through the hinge of the D_3 synformal fold (the Arnisdale Synform, (Figure 6.4)). The dip gradually increases to vertical: the D_3 linear features remain constantly oriented, with sub-horizontal axes, whereas the D_2 lineations become progressively steeper, passing through the vertical to plunge towards the south and SE at the top of the hill [NG 8370 1054]. The angular relations between the constant D_3 direction and the variable D_2 lineation seen here indicates that the D_3 fold geometry cannot be that of a simple flexural slip fold. In fact, this geometry is directly comparable with the small

scale lineation refoldings seen at Loch Monar (Excursion 8), only here the deformed lineations are on a regional scale. The geometrical distribution of the D_2 lineations is best explained by the flow kinematics described at Loch Monar, with the principal fold-forming flow ('a'-direction) calculated from the intersection of the mean D_2 great circle and the axial planes of the D_3 folds (Ramsay, 1960). The significance of this locality in understanding the kinematics of superimposed folding is of fundamental importance here and elsewhere in the Scottish Highlands (Ramsay, 1960).

Return to the vehicle, and drive along this same road descending into the village of Arnisdale. Continue through the village and where the coast road bends abruptly to the left [NG 8468 1006] find a park place by a gate. Walk 400 m south along the beach to the rocks at Crudh 'Ard [NG 8464 0963].

Locality 6.5 Crudh 'Ard [NG 8464 0963]

Crudh 'Ard (Figure 6.4). Relationships between D_2 and D_3 structures within Moine psammites.

This locality is situated close to the hinge of the D_3 Ben Sgriol Synform. On the east side of the outcrop, Moine psammites dip steeply to the east on the overturned limb of the synform and these psammites (ii) become folded in the hinge (M-shaped D_3 folds) of the main fold which is occupied by semi-pelitic rocks (Figure 6.4). This is an excellent outcrop to study the deformation of the D_2 linear structures around the hinges of small scale D_3 folds. The D_2 quartz-feldspar rods undulate over the D_3 hinges. In the more pelitic parts the D_3 folds show excellent coarse crenulation structures. Before leaving this locality it is good idea to view the hillside on the south face of Ben Sgriol above Arnisdale village. The Ben Sgriol Synform is extremely well displayed in this face. To the left (on Creag an Fhithich), ribs of Moine psammite dip eastwards (to the right) at ~20°. The actual curve of the fold hinge is seen just to the right of a prominent stream (Allt an Fhuarain) and further to the right the psammites turn through the vertical into an overturned position.

Return to the vehicle and drive along the road to a large parking place just before the village of Corran.

Locality 6.6 Corran to Rudha Camas na Caillin [NG 85 08]

Corran to Rudha Camas na Caillin (Figure 6.4). D_1 interfolding of Lewisian gneisses and Moine psammites.

Cross the bridge over the River Arnisdale and proceed southward along the foreshore of a raised beach for about 300m to the first prominent coastal outcrops at Locality 6.6A [NG 8500 0886]. These outcrops show the contact relations between strongly banded Lewisian gneisses forming the western part of the anticlinal strip of Western facies Lewisian (Figure 6.4). The Moine rocks are a mixture of psammitic and muscovite-biotite pelitic bands with bedding planes parallel to the Lewisian banding. A strong D_2 lineation is developed plunging down the dip of the layering to the ESE. In the Lewisian rocks, the distinctions between the original deformed gneissic bands and fresh augen and veins of new D_2 quartz-feldspar are clear. Continue southwards. If the tide is low it is possible to skirt the outcrops along the shore; if not, it is best to follow a small footpath in the woods above to coastal exposures into a sandy bay. There are very clean outcrops of Moine psammites with strongly developed D_1 isoclines plunging towards the south and SSE, with D_2 migmatite veining. Leave the footpath and aim for the low rocky headland of Rudha Camas na Caillin which is Locality 6.6B [NG 8500 0800] (Figure 6.4), (Figure 6.5). The western Lewisian D_1 anticlinal core, which has been narrowing to the south on account of its southern plunge, splits into three narrow southward plunging isoclinal fold cores at this locality and perfect exposures of all the Moine-Lewisian contact relations and three sets of superposed folds are to be seen (Figure 6.5). The lithological differences between Lewisian and Moine occur at knife sharp contacts, yet there are no anomalous high strain zones at these contacts. Clear D_1 southward-opening synformal folds are seen in the Moine psammites, and D_1 southward closing antiformal folds in the Lewisian and the Moine-Lewisian relationships appear to be those characteristic of sets of isoclinal D_1 folds. All these D_1 folds have been overprinted by Z-shaped D_2 folds which plunge to the ESE accompanied by a strong rodding, especially well developed in the hinge zones of the D_2 folds. The refolding of small D_1 isoclines in the cores of the D_2 folds is exceptionally clear. Locally within the banded Lewisian gneisses, small, angular, almost kink-like D_3 folds deform the D_2 linear fabric. These are not present in the Moine psammites presumably because the massive recrystallised nature of the psammites proved too competent for such folds to form. These outcrops are exceptionally clear in the view that they present of the differences between Moine and

Lewisian and the successively overprinted folds of the three deformation events: they should on no account be missed. All the geological relationships seen in this region and shown in (Figure 6.4) and (Figure 6.5) confirm Clough's interpretation that the primary relationship between Lewisian and Moine is that of early isoclinal folding.

If the visitor has time it would be instructive to spend a further half hour proceeding eastwards along the Loch Hourn coast where there are many examples of SSE-plunging isoclinal D_1 folds (this represents the synclinal zone between the two western facies anticlines (Figure 6.4) superposed by D_2 folds and intense SE-plunging linear fabrics associated with the development of migmatite veins).

Return to Corran where a welcome cup of tea can be obtained in 'Sheena's Tea Hut'. Return along the road through the village of Arnisdale and just after entering a forestry plantation west of Rarsaidh one crosses a cattle grid. Park in a large site on the left of the road at [NG 8094 1193].

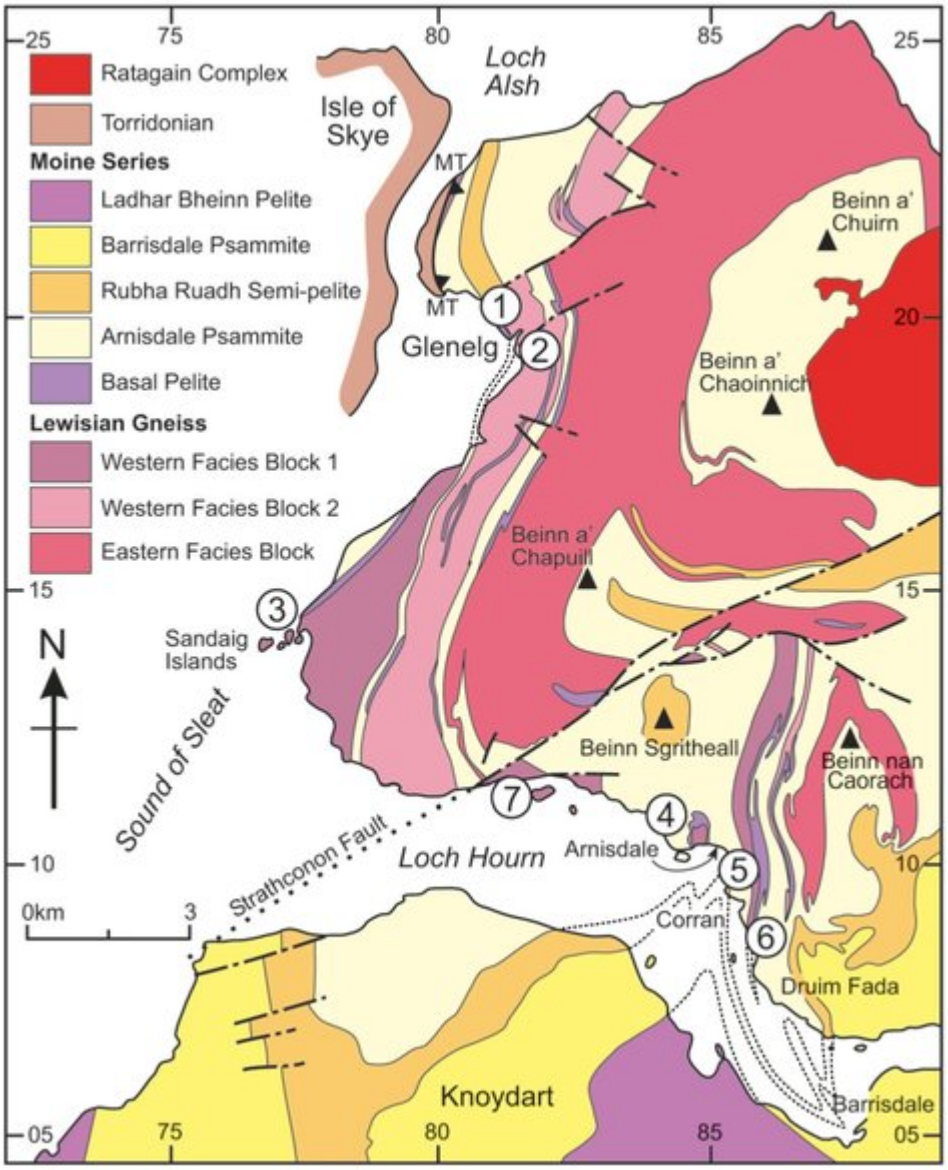
Locality 6.7 Loch Hourn [NG 8193 1181]

Loch Hourn (Figure 6.1). Western facies Lewisian gneisses; Strathconon Fault Zone.

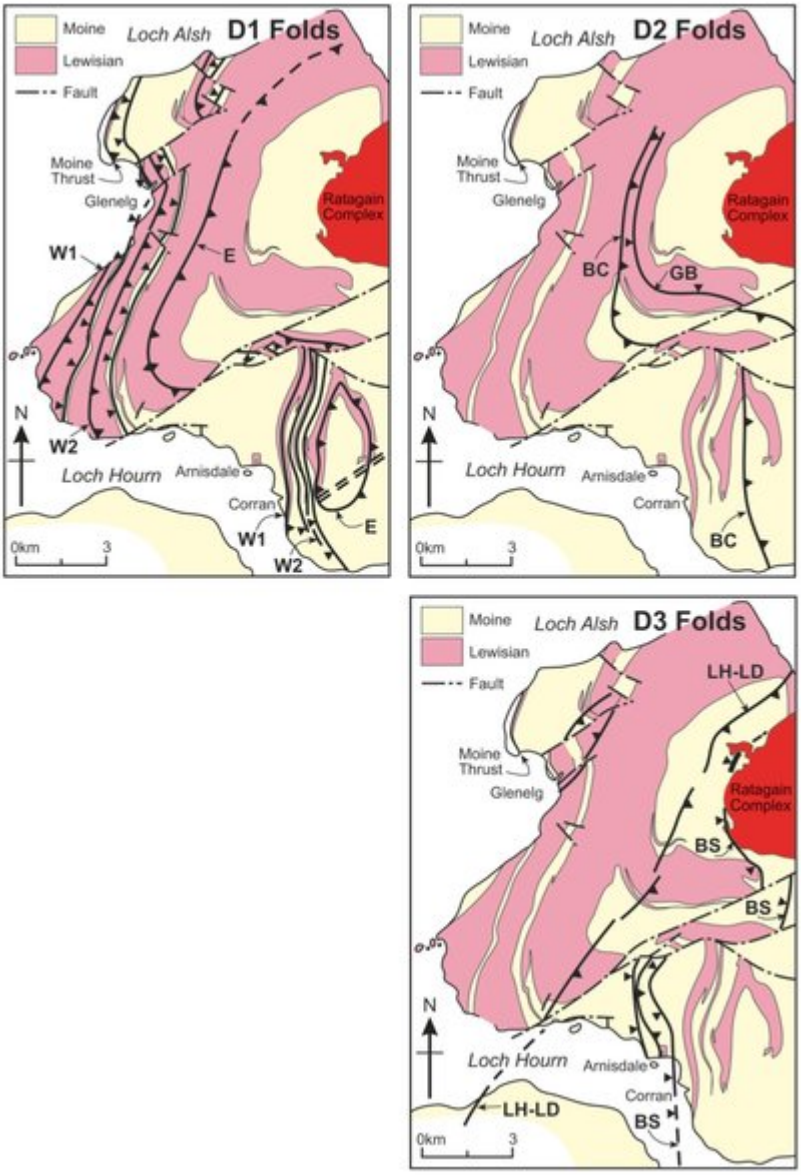
The outcrops to be visited are coastal exposures which lie directly below the park site. One can descend directly through the forest, but the recent state of the newly-cut trees with a jungle of small branches knit together with thorny brambles is not encouraging. The best solution is to re-cross the cattle grid and descend to the foreshore at some convenient place at Leac Glas, then walk towards the west along the shore. At Locality 6.7 ((Figure 6.1), [NG 8193 1181]) banded coarse-grained Lewisian hornblende-gneisses of western facies with lenticular masses of ultrabasic rock are cut by discordant amphibolite sheets which are clearly intrusive basic dykes. These dykes completely lack any gneissic material, but are cut by en-echelon quartz veins.

If time allows, it is instructive to proceed westward from these outcrops to visit the zone of faulting associated with the main Strathconon fault. Lewisian gneisses and Moine psammites are traversed by NE–SW-trending zones of shattered rock with subsidiary faults, and both become intensely crushed towards the main fault plane seen at Sgeir a'Chuirn-uisge [NG 8014 1181]. Some mono-clinal and conjugate folds, probably related to the fault movements, are found with their kinked sectors fractured and brecciated. Occasional dykes of brick-red-coloured late Caledonian lamprophyre show partial brecciation.

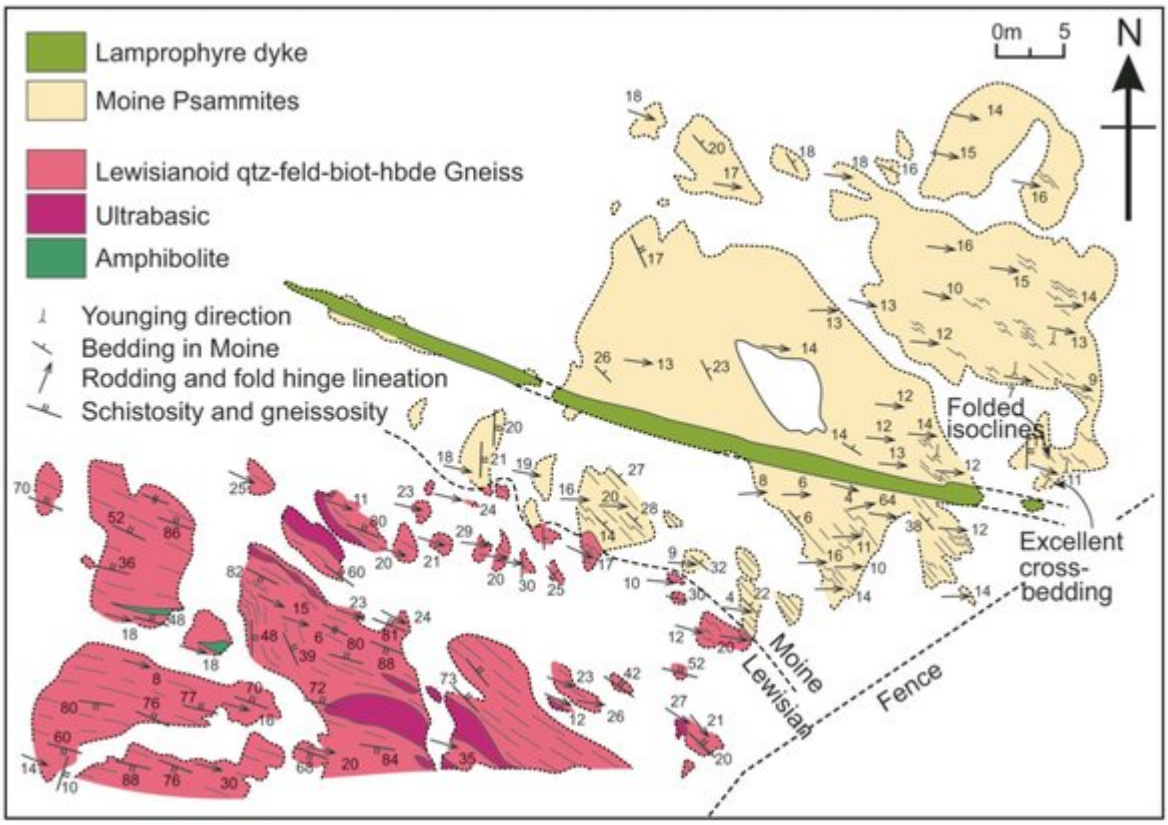
References



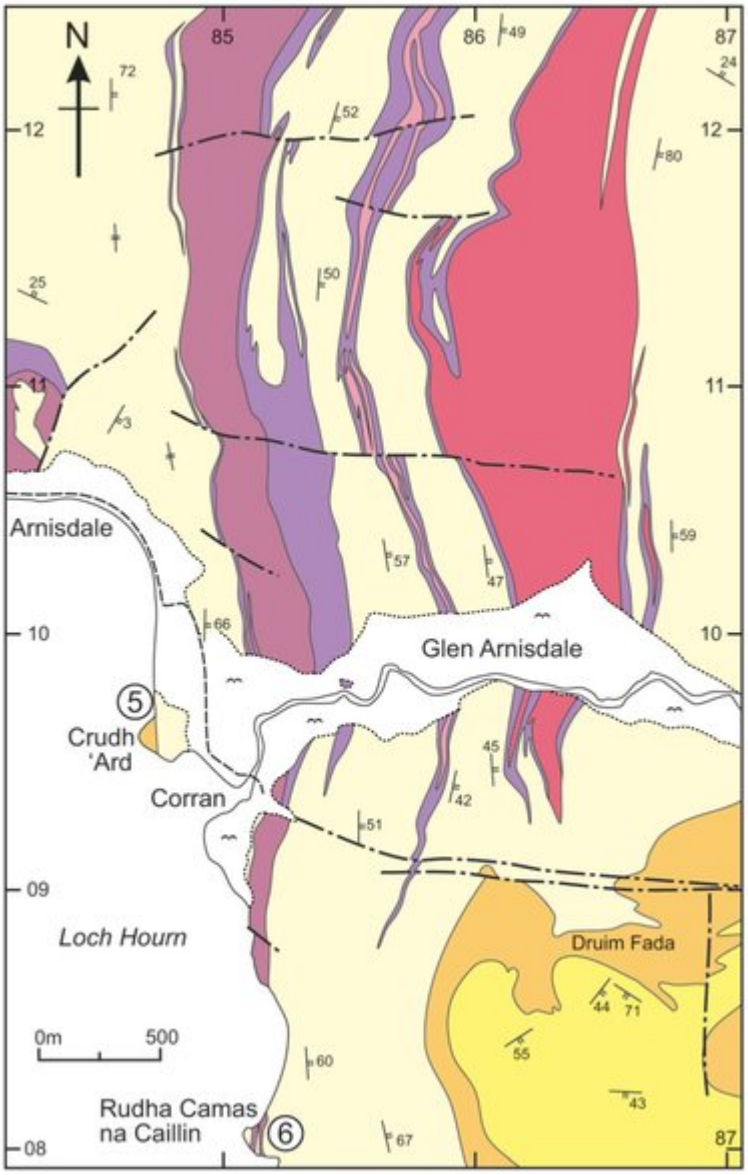
General geological map of the Glenelg and Loch Hourn region.



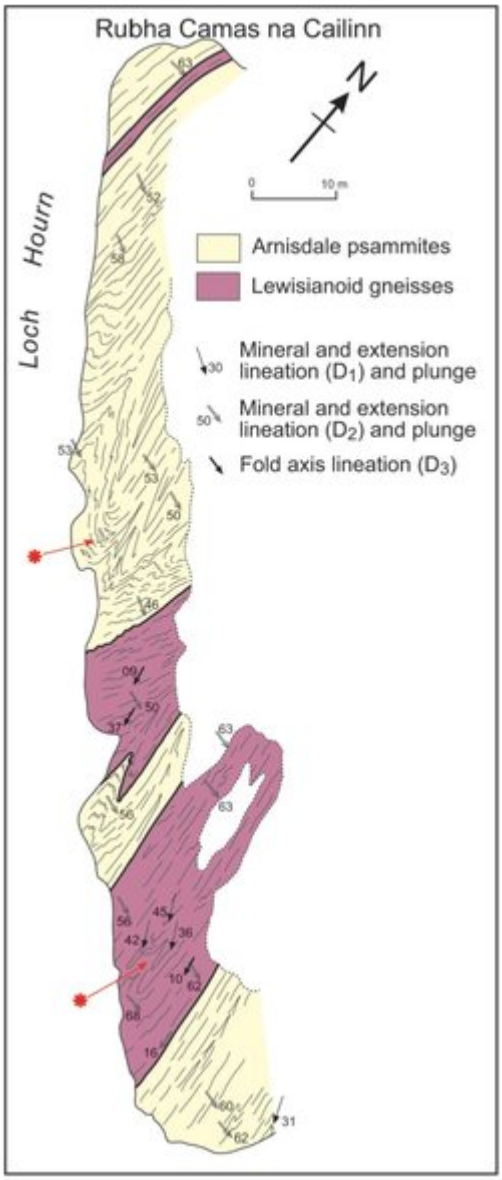
Axial traces of the major D_1, D_2 and D_3 folds.



A detailed outcrop map of the exposures in Glenelg Bay at Locality 6.1.



Map of the Moine and Lewisian rocks in the Arnisdale-Corran region. The Lewisian is found in three fold hinges, two of western facies (A and B) and one of eastern facies (C), an arrangement exactly comparable with that seen on the NW side of the Strathconon Fault. The Moine strip between B and C opens southward into a major D_1 syncline on Druim Fada.



Detailed map of the coastal exposures on Rudha Camas na Caillin (Locality 6.6B). The Lewisian gneisses are found in the cores of SE-plunging D_1 anticlines and the Moine rocks in the cores of D_1 synclines. The red stars refer to outcrops of special interest.