Glencoul

[NC 236 304]–[NC 295 288]

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Introduction

Loch Glencoul is a spectacular glacier-carved fiord with steep valley-sides that leads eastwards into the remote country north of the Ben More Assynt range. The dramatic scenery also provides one of the most important sections through the Moine Thrust Belt, in which the various rock units form well-marked features distinguishable from a great distance. The view across Loch Glencoul of the slopes of Beinn Aird da Loch and the Stack of Glencoul, from the A894 above Kylesku (Figure 5.20) has inspired generations of geologists since Callaway (1883) first recognized its significance. It is undoubtedly one of the most dramatic geological views in the British Isles and this, together with its historical association, has assured wide international recognition.

On Beinn Aird da Loch, Lewisian gneisses have been emplaced upon a thin tract of imbricated An t-Sron Formation, resting on intact Cambrian quartzites that in turn lie unconformably upon Lewisian of the foreland. Callaway described these field relationships and concluded that they are the result of lateral tectonic forces; the tectonic contact was subsequently termed the 'Glencoul Thrust' (Peach *et al.,* 1907). The displaced Lewisian above the Glencoul Thrust has its own cover of Cambrian quartzites that are overlain by Moine metasedimentary rocks. Here too, Callaway (1883) interpreted a tectonic contact; this is the Moine Thrust. Its dramatic exposure on the Stack of Glencoul includes several hundred metres of mylonites derived both from the Moine and the underlying Cambrian quartzites.

The foreland part of the Glencoul site has additional structural significance in that the famous 'double unconformity' between Lewisian, Torridonian and Cambrian units is exposed (Figure 5.21). The sub-Cambrian unconformity oversteps from Lewisian onto Torridonian in an up-dip direction. This feature is important for correlating thrust sheets in the Assynt district (Elliott and Johnson, 1980).

As with much of the Moine Thrust Belt, following the pioneering studies of the late 19th century (Peach *et al.,* 1907), subsequent research in the Glencoul area concentrated on using minor structures to establish kinematic histories. Christie (1963, 1965) used minor folds to infer movement directions on the Moine Thrust and pioneered quantitative studies of mylonite formation using crystallographic methods. Christie's work on the mylonitized Pipe Rock has been greatly extended by Law and co-workers (Law *et al.,* 1986; Law, 1987). These Pipe Rock outcrops were used for early attempts to quantify the strain associated with mylonite formation (McLeish, 1971; Wilkinson *et al.,* 1975). Larger-scale studies of thrust geometry were given impetus by Elliott and Johnson's (1980) re-interpretation of the original survey by Peach *et al.* (1907). They proposed that the Glencoul Thrust acted as a roof to underlying imbricated Cambrian strata. At the Stack of Glencoul, where Durness Group carbonate rocks are found inter-sliced with Pipe Rock, extensional tectonics have been inferred, acting in tandem with compressional imbrication (Coward, 1983). More recently, Butler (2004a) used the Glencoul site to support the notion of synchronous, rather than sequential thrusting, a model developed further for the Foinaven GCR site. Various researchers have used Precambrian structures within the Lewisian basement of the Glencoul Thrust Sheet and their correlation with foreland Lewisian structures to estimate displacements on the Glencoul Thrust (e.g. Ramsay, 1969; Coward *et al.,* 1980; Elliott and Johnson, 1980). Krabbendam and Leslie (2004) have questioned the validity of such deductions and their re-interpretation of the Ben More Thrust geometry implies a composite structure to the Glencoul Thrust Sheet. Nevertheless, the classic status of this site is reflected by the extensive coverage in field guides (e.g. MacGregor and Phemister, 1948; Barber and Soper, 1973; Johnson and Parsons, 1979; Butler, 1988a); indeed its inclusion is almost *de rigueur.*

Description

The Glencoul GCR site includes a natural section from the foreland up to the mylonitized Moine metasedimentary rocks in the hangingwall to the Moine Thrust (Figure 5.21)b. For the most part, the area consists of basement Lewisian gneisses of the Glencoul Thrust Sheet (Figure 5.21)a, sandwiched between two tracts of Cambrian quartzites. One of these tracts represents the cover to the Lewisian gneisses of the thrust sheet; the other, with a thin veneer of An t-Sron Formation and carbonate rocks of the Durness Group, is the cover of the foreland succession. The carbonate rocks form the immediate foot-wall to the Glencoul Thrust. The Lewisian gneisses in the hangingwall have remained virtually unaffected by Caledonian strain despite having being carried on the Glencoul Thrust (Wibberley, 1997). Fortuitously, they have preserved Proterozoic structures that can be correlated with those of the foreland. Most important of these is the structural and metamorphic transition between the Archaean Central Region (Scourie block) and its reworked margin against the Northern Region, which is characterized by penetrative Laxfordian deformation (Figure 5.21)a. These foreland structures are described in Chapter 3. Although elements of this basement structure were recognized and correlated by Peach *et al.* (1907), a complete analysis was not performed until Coward *et al.* (1980) remapped the Lewisian gneisses of the foreland and the Glencoul Thrust Sheet. They established the offset of the Glencoul Thrust Sheet to be between 25 km and 33 km, using a three-dimensional reconstruction of the thrust surface and its kinematics.

The Glencoul Thrust is well exposed in cliff sections above Loch Glencoul at Tom na Toine [NC 261 302]. Here Lewisian gneisses overlie Durness Group carbonate rocks, with the thrust contact marked by a few metres of Lewisian-derived cataclasites, now strongly retrogressed to a very fine-grained aggregate mainly composed of quartz, chlorite and epidote. The contact itself is marked by a few centimetres of crushed carbonate. The footwall contains anastomosing arrays of carbonate gouge.

The Glencoul Thrust is gently folded as a result of imbrication of the underlying An t-Sron and Durness units (Figure 5.21)b. These imbricate slices are well exposed in cliff- and shore-sections around the mouth of Loch Beag and on small islands near the old Glencoul Lodge (e.g. Eilean an Tuim, [NC 264 303]). The floor thrust to the duplex that underlies the Glencoul Thrust is the regional Sole Thrust, the structurally lowest tectonic contact recognized by the Geological Survey (Peach *et al.,* 1907). There are minor thrusts in the underlying units of the Eriboll Sandstone Formation, but these are difficult to trace and probably have not accommodated much displacement.

The eastern part of the Glencoul GCR site is the most complex and most controversial. At the Stack of Glencoul [NC 290 286], the Moine Thrust marks the boundary between Moine metasedimentary rocks and Pipe Rock (Figure 5.22)a. Both lithologies are strongly mylonitized. Intense ductile strain in the Pipe Rock is indicated by the deformed *Skolithos* pipes that have been extended and now lie at a low angle to the bedding/foliation. The pipes plunge gently to the ESE, parallel to the intense stretching lineation developed in both mylonite lithologies. Wilkinson *et al.* (1975) used the deformed pipes to infer bed-parallel simple-shear strains of 9 or greater, but Coward (1983) proposed that the strains also involved significant (5:1) layer-parallel extension.

Mylonites derived from the Pipe Rock and the Moine metasedimentary rocks have been imbricated together by discrete thrusts. Lithological alternations occur on the centimetre-to metre-scale (Law *et al.,* 1986; Law, 1987); locally thin slivers of gneissose mylonite also occur. Within the mylonites at the Stack there are tight/isoclinal folds that plunge to the ESE.

Remapping of the ground west of the Stack of Glencoul has shown that, below this zone of imbrication, the lower Cambrian quartzites that form the cover to the Lewisian basement of the Glencoul Thrust Sheet contain microsyenite sills. These provide useful qualitative strain markers. Shear bands downthrowing to the WNW cut both the quartzites and the sills. Layer-parallel extension is implied on a larger scale by local excision of the An t-Sron Formation, so that outcrops of highly deformed Durness Group carbonate rocks rest directly upon Pipe Rock [NC 288 287]. Layer-parallel compressional structures are also present. Lewisian gneisses are imbricated with the False-bedded Quartzite Member and the quartzites are tightly folded into recumbent anticline–syncline pairs that face west and whose axes plunge gently to the NNE. These folds and imbricate thrusts are in turn cut by normal faults that downthrow towards the south-west (Figure 5.22)b. As a whole these relationships strongly suggest broadly coeval layer extension and compressional tectonics, with the bulk kinematics dominated by WNW-directed shearing. The intensity of ductile deformation increases upwards towards the Moine Thrust.

Interpretation

Field relationships in the Glencoul GCR site have been controversial in various models of structural evolution in the Moine Thrust Belt. Elliott and Johnson (1980) interpreted the relationships between the Glencoul Thrust and its underlying imbricate zone to imply that the Glencoul Thrust moved across an undeformed footwall of Cambrian strata, which later imbricated to form a duplex. The floor to this duplex was presumed to lie at the top of the Pipe Rock as this lithology is absent from the imbricate slices. However, although the broad structure of the duplex can be established at Glencoul, few of the exposures are easily accessible. Similar structures are well seen however, some 6 km farther south at the Skiag Bridge GCR site.

The simple duplex model proposed by Elliott and Johnson (1980) has been challenged by Butler (2004a) because not all imbricate slices contain Durness carbonate rocks. This could be explained if the Glencoul Thrust has not acted as a true roof thrust, but instead has decapitated the imbricate slices in its footwall (see Butler *et al.,* 2006). This overstep behaviour was favoured by Peach *et al.* (1907). However, the thrust does appear to be folded by the underlying structures, particularly in the ground to the north of the Glencoul GCR site (Elliott and Johnson, 1980). An alternative explanation is that the Glencoul Thrust cuts gently down stratigraphical section in its footwall and that it was this partially incised stratigraphy that formed the duplex (Butler, 2004a).

The Glencoul Thrust Sheet has been translated with almost no significant internal deformation (Wibberley, 1997). However, interpretation of its internal structure has recently become controversial. Krabbendam and Leslie (2004) suggest that the Ben More Thrust (see the eponymous GCR site below) branches onto the Glencoul Thrust at the mouth of Loch Beag. This model implies that the Lewisian gneisses that lie within the thrust belt on either side of Loch Glencoul belong to separate thrust sheets, making the correlation of Precambrian structures between the Glencoul Thrust Sheet (as originally mapped) and the Caledonian Foreland unwarranted (cf. Coward *et al.,* 1980; Elliott and Johnson, 1980). Undoubtedly, there are problems associated with correlation of structural and metamorphic features between the thrust belt and the foreland, but this revised model has yet to attain general acceptance, and existing syntheses still retain the original correlations and thrust linkages (e.g. Butler *et al.,* 2006).

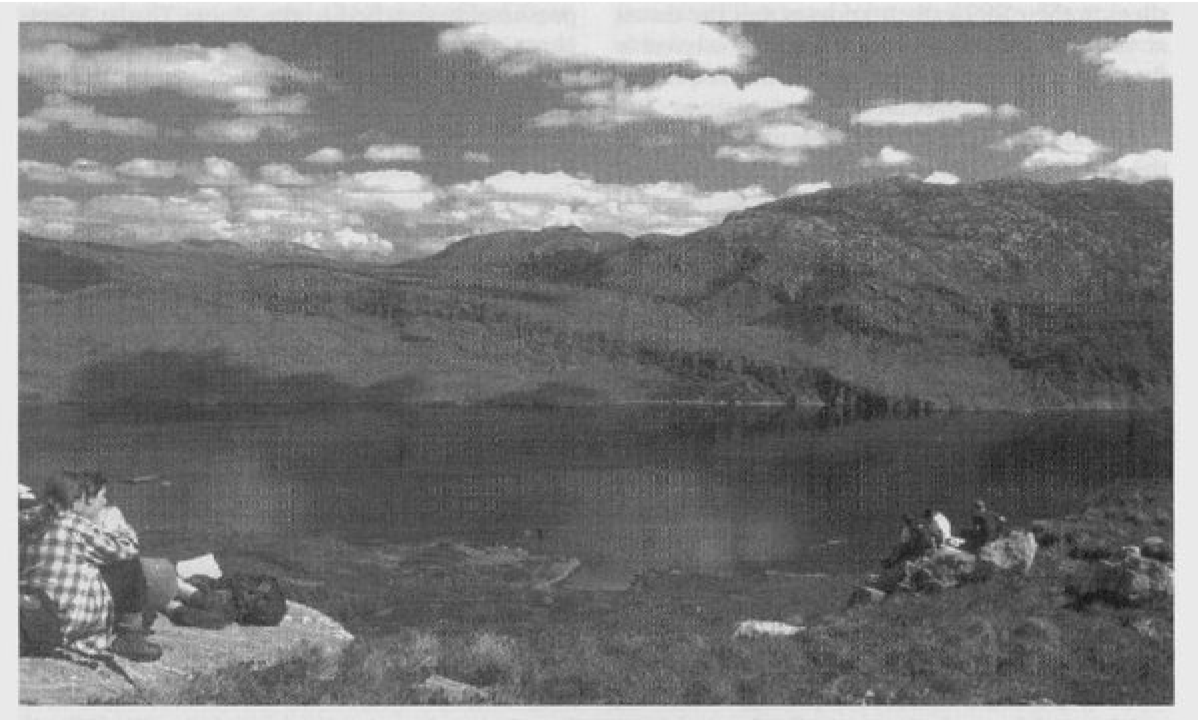
Stratigraphical excision and the interplay between compressional and possibly extensional tectonics have been especially controversial in tectonic interpretations for the Stack of Glencoul. Extensional tectonics at high levels within the Moine Thrust Belt were proposed by Coward (1983) who envisaged a significant component of gravity spreading in driving thrust displacements. Detailed field and micro-structural investigations by Law *et al.* (1986) and Law (1987) confirmed formerly held opinions that the Moine Thrust mylonites developed by predominantly WNW-directed simple-shear. However, they also showed that the Moine and Pipe Rock-derived mylonites are interleaved, implying a component of layer-parallel compression and imbrication. Yet crystallographic fabrics derived from the mylonitized quartzites imply layer-parallel extension too. The original cross-sections of Peach *et al.* (1907) also imply combined imbrication and extension. Thus an alternative model to Coward's (1983) notion of extensional flow within the upper part of the thrust belt is that the deformation represents a bulk simple-shear modification of thrust structures. In this model, the distribution of deformation alternates between being localized onto discrete structures such as imbricate thrusts and more broadly distributed shearing (Butler *et al.,* 2006). A similar model is a plausible explanation of the relationships between folds, mylonites and the Moine Thrust in the Bealach Mhari area of the Eriboll GCR site.

Conclusions

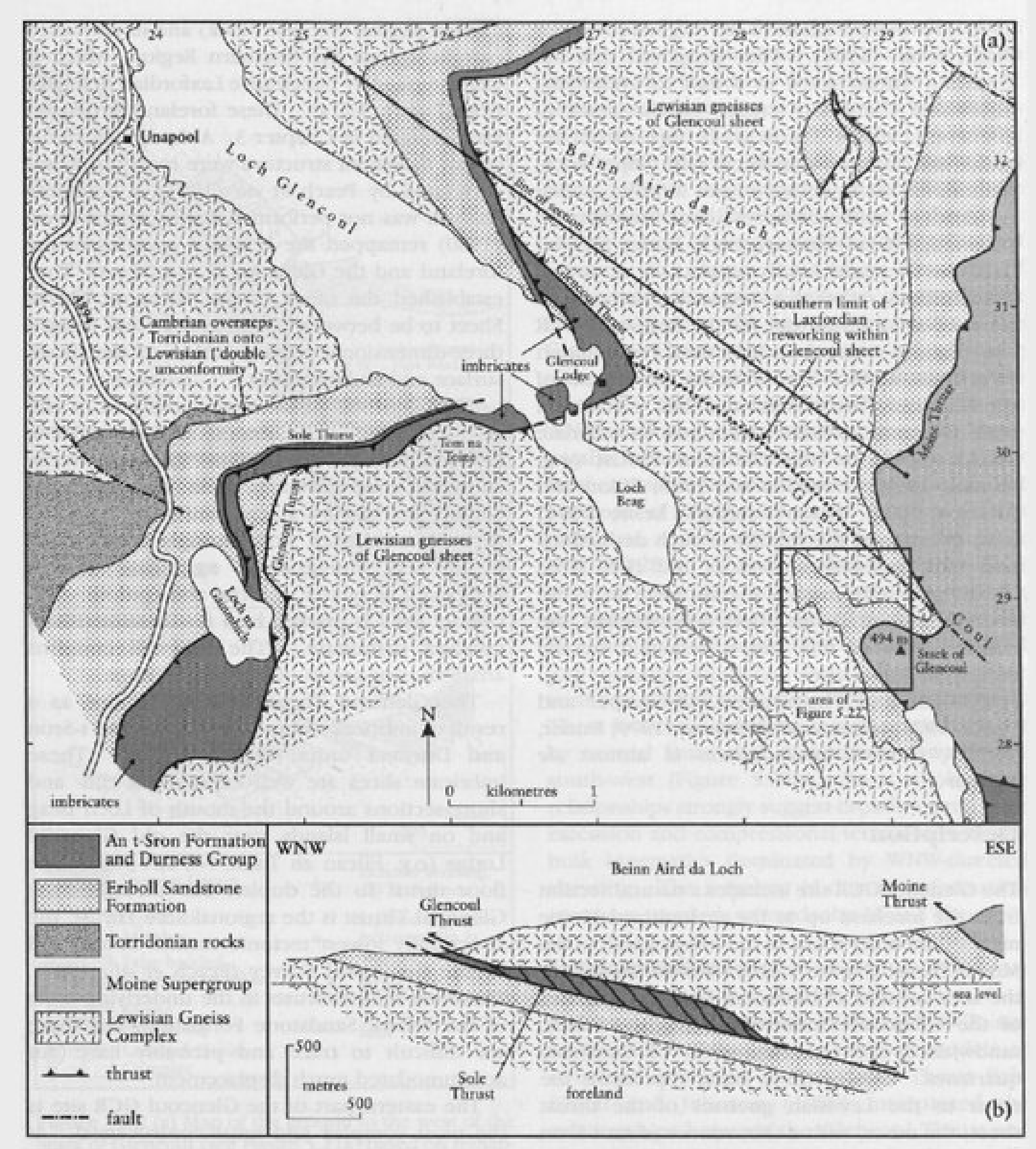
The Glencoul GCR site provides unrivalled opportunities for viewing and understanding the large-scale structure of thrust belts, particularly the incorporation of slices of crystalline basement. The Lewisian gneisses that form the bulk of the Glencoul Thrust Sheet have experienced between 25 km and 33 km of displacement but show virtually no evidence of internal strain. The thrust surface and underlying imbricate zone are well exposed around the head of Loch Glencoul. Foreland stratigraphical relationships below the imbricate zone are also well exposed, particularly overstep of the basal Torridonian unconformity by the planar sub-Cambrian unconformity.

At a higher structural level, the Moine Thrust at the Stack of Glencoul is a ductile shear-zone that is well marked by mylonites. Cambrian quartzites which dominate the lower part of the shear zone show spectacular deformed pipe-like burrows (*Skolithos*), which record combinations of WNW-directed overshear and layer-parallel extension. These quartzites have been important for qualitative and quantitative studies of mylonite formation through crystallographic analysis. The upper parts of the shear zone here contain imbricate thrusts and recumbent folds, together with ductile extensional structures and normal faults. WNW-directed overshear appears to have dominated all these structures, whether compressional or extensional. These relationships, formed during the emplacement of the overlying Moine Thrust Sheet during the mid-Silurian Scandian Event, may be explained by gravitational spreading or by cyclic localization of shear displacements. Thus the area is internationally important both for the understanding of the early history of the Moine Thrust Belt and for the development of dynamic models of thrust tectonics.

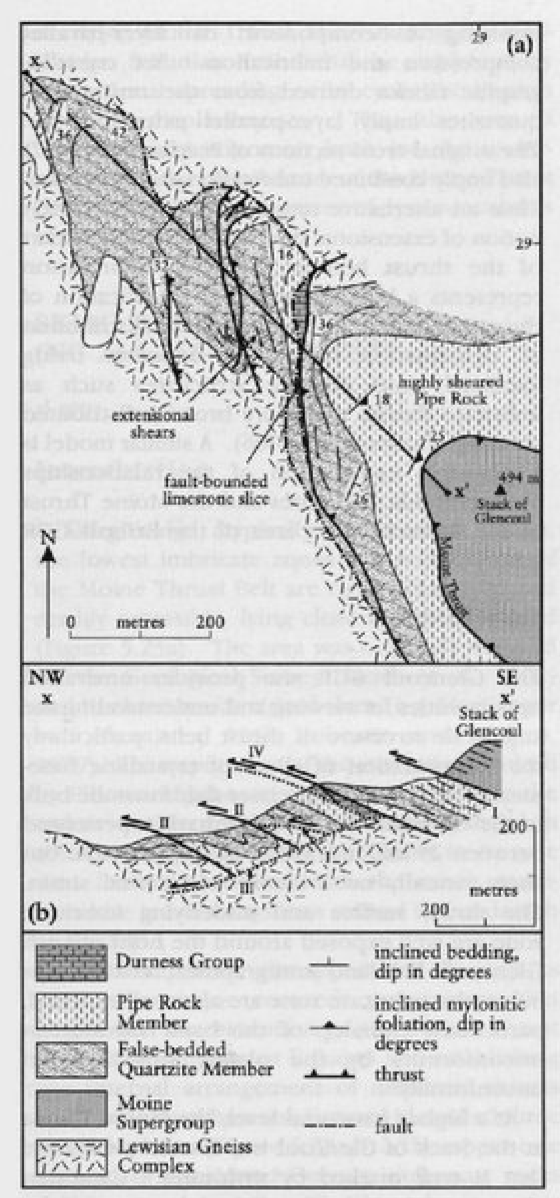
References



(Figure 5.20) The Glencoul Thrust on Beinn Aird da Loch, from the south-west side of Loch Glencoul. Lewisian gneiss has been thrust over cliffs of Cambrian quartzite. Compare with cross-section shown in Figure 5.2 lb. (Photo: R.W.H. Butler.)



(Figure 5.21) Geological relationships at the Glencoul GCR site. (a) Map of the area around Loch Glencoul (modified after Peach et al., 1907; Coward et al., 1980; British Geological Survey, 2007). (b) Schematic cross-section through the Moine Thrust Belt on Beinn Aird da Loch (vertical and horizontal scales equal and as (a)).



(Figure 5.22) (a) Map of the ground to the west of the Stack of Glencoul see Figure 5.21 a based on remap-ping by the author. (b) Schematic cross-section (x-x') through the map area of (a) showing the relationships between layer extensional (dotted) and contractional (solid) faults. These are grouped and numbered in the inferred order of displacement (I-1V in time). The relative timing of the Moine Thrust is uncertain but it probably moved broadly simultaneously with these other shearing deformations.