Chapter 5 Moine Thrust Belt

Introduction

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The Moine Thrust Belt forms the outer edge of the Caledonian orogenic belt in the northern mainland of Scotland. It separates the poly-deformed and metamorphosed orogenic interior of Moine and Dalradian rocks to the ESE, from the foreland of Lewisian gneisses with their cover of Torridonian and Cambro-Ordovician sedimentary successions to the WNW As such, the thrust belt forms a small segment of the edge of penetrative deformation caused by the Caledonian Orogeny. There are continuations of the belt in northern Greenland and possibly north-west Ireland. The Moine Thrust Belt and its extensions are related to the Scandian (Silurian) phase of the Caledonian Orogeny, which resulted from the collision of Baltica and Avalonia against Laurentia, to which Scotland belonged at the time (see also Chapter 1). In Scotland, the thrust belt runs from the north coast near Whiten Head to Sleat on Skye (Figure 5.1). Northern continuations have been proposed beneath the West Orkney Basin, on the basis of seismic data. To the south of Skye, the thrust belt presumably lies to the east of Lewisian outcrops on the islands of Coll and Tiree but to the west of outcrops of Moine metasedimentary rocks on Ardnamurchan and Mull. Its trace is unclear but traditionally it is inferred to lie beneath the Sound of Iona because the Isle of Iona contains probable Lewisian units. However, these could be part of the Moine Thrust Sheet.

Regardless of the controversies concerning its offshore trace, the Moine Thrust Belt has achieved worldwide importance for the development and testing of key concepts in structural geology. Many geology students are trained here in structural analysis and mapping techniques every year. The landscape is of great beauty as highlighted in guides and booklets (e.g. Mendum *et al.,* 2001; British Geological Survey, 2004d). This introductory section highlights the historical importance of the thrust belt, outlines its broad structural elements and provides a regional framework for the GCR sites. It also emphasizes the variations in the types of structures and their relative importance along the belt.

Historical review

Thrust belts are common components of the outer parts of many of the world's orogenic belts. One of the earliest to be described was the Moine Thrust Belt, following the recognition of large-scale thrust surfaces in the Assynt and Eriboll districts by Callaway (1883) and Lapworth (1883). This work settled a famously acrimonious debate in mid-19th century geology between James Nicol and the Geological Survey as represented by Roderick Murchison and later by Archibald Geikie. Murchison's view was that the rock succession in north-west Scotland was essentially continuous, while Nicol contended it was faulted. Lapworth and Callaway's discoveries rendered the Geological Survey's interpretation untenable and led Geikie, then Director of the Survey, to send his most able geologists to complete a major mapping programme. The results of this awesome task eventually appeared in two ground-breaking publications, the North-west Highlands memoir (Peach *et al.,* 1907) and the special 1-inch geological map of the Assynt district (Geological Survey of Great Britain, 1923). Oldroyd (1990) has provided an entertaining account of these early researches, together with their socio-scientific fallout and subsequent legacy. The significance of the research of Peach *et al.* (1907) is discussed by Butler (2007).

For the following 50 years, geological research within the thrust belt concentrated upon correlating minor structures, particularly folds and planar fabrics, and relating them to the regional geology. Up until the mid-1970s this research attempted to find structural links between the Moine and its underlying thrust belt (e.g. Barber, 1965; Soper and :Wilkinson, 1975). For example, gently inclined and isoclinal to tight folds were linked to a single mylonite-forming event (termed 'D1'). This type of structural analysis received added impetus with the application of radiometric dating techniques to igneous intrusions within the Northern Highlands; these age dates apparently calibrating the relative structural histories built up from field studies (e.g. Woolley, 1970; van Breemen *et al.,* 1979a). A review of the evidence from the igneous rocks in Assynt appears in GCR Volume 17, *Caledonian Igneous Rocks of Great Britain* (Parsons, 1999).

In the late 1970s, renewed interest in the structural evolution of the Moine Thrust Belt was propelled by the application of analytical techniques developed in the foothills of the Rocky Mountains (e.g. Bally *et al.,* 1966; Dahlstrom, 1970) and the Appalachians of North America (Rich, 1934; Milici, 1975). Elliott and Johnson (1980) pioneered this approach in the North-west Highlands. The critical conceptual leap was that thrust belts evolve by individual thrusts growing, linking, moving and then dying. They form in a general foreland-propagating sequence so that higher nappes are carried 'piggy-back' upon lower ones. In the Appalachians, Mitra and Elliott (1980) showed that folds and deformation fabrics could be explained by local thrusting processes rather than by regional tectonic events, prompting a similar re-assessment of minor structures within the North-west Highlands. These new approaches led to a major programme of remapping within the thrust belt, in many cases re-examining, for the first time in a hundred years, the geometrical relationships between thrusts and the sheets that they carry. Much of this work confirmed the ideas of Elliott and Johnson (1980), recognizing in particular that many of the structural complexities and bewildering networks of faults originated from the repetition of individually rather simple geometric elements. However, some parts of the thrust belt show fault geometries that are not predicted by Elliott and Johnson's ideas, particularly extensional structures that cut down the stratigraphical section in the direction of transport (Coward, 1982). Controversy remains as to the larger-scale tectonic significance of these features, in particular whether they accommodated crustal extension, gravitational collapse or even the locally complex effects of purely compressional tectonics (Coward, 1983; Butler, 2004a; Butler *et* al., 2006, 2007; Holdsworth *et al.,* 2007).

The renewed interest in thrust belt structure, particularly in north-west Scotland, came when structural geologists began to relate the deformation recorded by mountain belts to plate-tectonic processes through integrating surface geology with deep seismic reflection profiles (Soper and Barber, 1982; Brewer and Smythe, 1984). Central to this were attempts to quantify the magnitude of horizontal displacements responsible for stacking up piles of thrust sheets, primarily using so-called 'balanced cross-sections' (Dahlstrom, 1969). These constructions are geological profiles drawn parallel to the inferred direction of displacement in such a way that the stratigraphy may be restored graphically to a predicted undeformed state. Although simple palinspastic reconstructions have been made of parts of mountain belts for almost a century, balanced sections are a significant improvement because they attempt to quantify the displacements experienced by all layers, an important part of testing models of structural geometry and evolution for internal consistency. By representing three-dimensional tectonic structure in two-dimensional profiles, balanced cross-sections have a general assumption of plane strain, in that there is no movement of material out of the profile. Notwithstanding this limitation, balanced sections were crucial for providing estimates of almost 60 km for the original width of that part of the Cambro–Ordovician shelf succession now stacked up within the Moine Thrust Belt (Butler and Coward, 1984; Coward, 1985). Estimates for the whole belt suggest some 100 km of sub-horizontal displacement (Elliott and Johnson, 1980). These movements have carried the Moine rocks and the orthotectonic part of the Caledonide Orogen, apparently as a relatively thin sheet, by this amount across the foreland Lewisian gneisses.

The map-scale structural geometry, along with the application of material science methods, provided a springboard for detailed micro-structural studies of fault rocks (e.g. White, 1977; Knipe, 1989). The purpose of these studies was to define better the conditions under which the thrust faults and shear zones developed, and thereby understand how the very large tectonic displacements were accumulated on such relatively narrow features.

A prime reason for the successful mapping of the Moine Thrust Belt, together with its continued popularity as a training ground for students, lies in the well-differentiated lithostratigraphy. The stratigraphy of the Torridonian sedimentary rocks and the nature of the unconformity at the base of the Torridonian is different blocks of Lewisian basement are spectacularly exposed in the GCR site at Slioch—outlined elsewhere in this volume. The Heights of Kinlochewe where it rests upon an irregular land surface with almost 500 m of relief. Regionally the Precambrian rocks are capped by a remarkably planar unconformity which underlies a surprisingly layer-cake succession of Cambro-Ordovician sedimentary rocks (Figure 5.3). The geometry of this unconformity can be appreciated in the Arkle–Foinaven area and at An Teallach. The Cambro-Ordovician succession comprises three distinctive units. The oldest is represented by about 150 m of quartzites (the Eriboll Sandstone Formation), the middle one is a highly differentiated collection of sands, silts and muds capped by clean quartzites (the An t-Sron Formation), and the upper one is a thick (over 1500 m) succession of carbonate rocks (the Durness Group). These units are readily identified, commonly from a great distance, allowing exceptionally complex tectonic interleavings to be unravelled by field geologists. They also provide exposures of thrust and fold structures of unrivalled clarity, well illustrated by the GCR sites in this volume. The *Skolithos* trace fossils in the Eriboll Sandstone Formation are ideal strain markers and have played a key role in the understanding of strain patterns, both in the Eriboll GCR site (e.g. Coward and Kim, 1981), and in thrust belts generally. GCR sites representing the stratigraphy and palaeontology of the Cambro-Ordovician succession are described in the *British Cambrian to Ordovician Stratigraphy* GCR Volume (Rushton *et al.,* 2000).

The Moine Thrust and its mylonites

The Moine Thrust is defined as the tectonic contact along which the Moine metasedimentary rocks, together with the Lewisian basement upon which they were deposited, were carried to the WNW. These units now rest tectonically upon Cambro-Ordovician and Torridonian sedimentary rocks, which in turn overlie Lewisian basement of the foreland (Figure 5.1), (Figure 5.2). The Moine Thrust is characterized by extensive mylonite development in both its footwall and hangingwall; indeed the term 'rnylonite' was first coined by Lapworth (1883) for strongly sheared rocks within the Eriboll GCR site. The resultant mylonite zone varies in thickness from a few metres to several hundred metres. This zone can contain thin mylonite units derived from the different protoliths. The Pipe Rock generates near-monomineralic quartz mylonites and as such it is straightforward to relate the deformed rocks to the protolith type.

In contrast, the protoliths of the common chloritic mylonites and phyllonites can be difficult to correlate, for example, the so-called 'Oystershell Rock' of the Geological Survey (Peach *et al.,* 1907). This crenulated phyllonite is composed chiefly of chlorite, white mica, quartz and feldspar, and contains abundant deformed lensoid quartz veins and segregations from which the rock type gets its name. Evans and White (1984) suggested that it represents strongly deformed and retrogressed Moine psammite and thus has been carried by the Moine Thrust. More recent research has indicated that the protoliths for the 'Oystershell Rock' are Lewisian gneisses (e.g. Holdsworth *et al.,* 2001). However, it is still uncertain whether this lithology was derived from the footwall (as suggested by Holdsworth *et al.,* 2001), the hangingwall, or from Lewisian on either side of the Moine Thrust. These issues become important for defining the position of the Moine Thrust (see Cleft an t-Seabhaig, Faraid Head and Sango Bay GCR site reports, this chapter). A similar problem occurs in the south part of the thrust belt on Skye (Tarskavaig GCR site). Here highly sheared psammites, the Tarskavaig Group, have been variously correlated with the main Moine succession and with the Torridonian units of the foreland.

In general, where the stratigraphical separation across the Moine Thrust is greatest, and particularly when the footwall lies in carbonate rocks of the Durness Group, the mylonite zone is carried on a discrete fault-zone marked by cataclasites (e.g. at the Sango Bay GCR site). Such behaviour, indicating a transition from ductile deformation with relatively high-temperature crystalline plasticity to brittle faulting and fracture processes, is predicted to occur on fault zones that migrate up through the crust (e.g. Sibson, 1983). Evidence for this transition occurs on all sections across the thrust belt. Varied structures and textures are found locally within the deformation zone associated with the Moine Thrust as indicated above, and elsewhere within underlying, later thrusts which stack up the Cambro–Ordovician sedimentary rocks. Thus the Moine Thrust changes its character from place to place. Indeed, the western edge of the Moine outcrop is not everywhere defined by the Moine Thrust; later thrusts and faults, some associated with later basin formation, characterize the boundary of Moine rocks in places. In the Lochalsh area (Figure 5.1), it is commonly difficult to establish whether the western boundary of the Moine outcrop is the Moine Thrust or a late fault contact (e.g. at the Hangman's Bridge and Ard Hill GCR sites).

Classic investigations using the overprinting relationships of structures on an outcrop scale have been used to deduce the relative timing of folding, mylonite formation and movement on localized 'brittle' thrust faults. Working in the Lochalsh district, Johnson (1957) and Barber (1965) considered mylonite formation to be a distinct structural event that could be correlated along the strike of the thrust belt and between different thrust sheets. Soper and Wilkinson (1975) applied the same logic to the Eriboll district, and Elliott and Johnson (1980) retained this approach in the Assynt area. However an alternative philosophy has been adopted, using ideas of cyclic strain localization established for shear zones (e.g. Carreras *et al.,* 1977; Sibson, 1977a; Ramsay, 1980); folding, mylonite formation and localized shearing have been related variously to changes in strain rate and transient perturbations in flow. Therefore, rather than having regional significance or acting as diagnostic markers of particular correlatable events, mylonitization, folding and faulting are envisaged as having occurred sporadically. Consequently, later work in the Eriboll area (e.g. Butler, 1982b; Evans and White, 1984) has assigned only local significance to relative structural chronologies and has argued against regional correlations.

In many places, the Moine Thrust may be shown to pre-date Caledonian structures in its footwall. The best illustrations of these relationships are to be found in the Eriboll and Foinaven GCR sites, locally in the north-east part of the Assynt district (e.g. at the Stack of Glencoul in the Glencoul GCR site) and in the Dundonnell–An Teallach areas. However, in south Assynt (Figure 5.1); e.g. at the Knockan Crag GCR site) the western edge of the Moine outcrop is marked by a low-angle fault, possibly an extensional fault (Coward, 1983), which is demonstrably later than Caledonian thrusts below.

Structural styles within the thrust belt

Cross-sections through thrust belts, including the Moine Thrust Belt, can appear to be frustratingly complex (Figure 5.2). However, careful studies have established that a few simple geometries recur (Figure 5.4), and it is the combination of these 'building blocks' that produces elaborate three-dimensional thrust belt geometries. Individual thrusts can be shown to have complex geometries with layer-parallel segments (termed 'flats') and steeper linking segments (called 'ramps') that cut across layering. Movement up ramp-flat profiles generates folds in the hangingwall strata. Thrusts rarely occur in isolation but rather occur in complex arrays, called 'imbricate zones', in which individual thrusts (ramps) splay upwards from an underlying floor thrust. If these ramps re-combine up-dip onto another major flat (the roof thrust) the entire structure is termed a 'duplex' (Figure 5.4). The essence of these structures was described by Peach *et al.* (1907) and was formalized for the Moine Thrust Belt by Elliott and Johnson (1980). They are generally representative of the fundamental structural geometries that stack up segments of continental crust, particularly during collision orogeny.

Understanding the evolution of thrust systems has always involved deduction of the relative timing of formation of the various thrust faults. Peach *et al.* (1907) decided on balance that structurally higher thrusts (including the Moine Thrust) moved later, truncating imbricate thrusts in their footwall. This 'overstep' model was challenged first by Dallstrom (1970), based on studies in the Canadian Rockies, and in the Moine Thrust Belt by Elliott and Johnson (1980), who argued that thrusts developed strictly from top to bottom. Such has been the influence of this work that this 'piggy-back' thrust model is embedded in the general literature. However, Coward and Butler (Coward, 1983; Butler and Coward, 1984; Butler, 1987) demonstrated that piggy-back thrusting was not universally applicable in the Moine Thrust Belt. Recent studies have shown that within individual duplex systems, the relative order of thrusting is variable with certain limits, leading to a more-general model of synchronous, rather than strictly sequential, thrusting (Butler, 2004a; Butler *et* ed., 2007). Many of the critical locations for these debates lie within the GCR sites described here.

There are several different types of thrust-related structure developed beneath the Moine Thrust. The GCR sites provide an excellent introduction to these variations, which are illustrated on (Figure 5.4). The terms 'thrust sheet' and 'nappe' are virtually synonymous; 'thrust sheet' is herein used for structures that are dominated by brittle thrusting, whereas the term 'nappe' is used for more ductily deformed sheets that are dominant in the southern part of the belt.

Lewisian thrust sheets

Amongst the most striking structures within north-west Scotland are the large thrust sheets that contain Lewisian basement, generally with remnants of the original Cambrian or Torridonian cover. The three most famous of these are prime constituents of GCR sites; the Arnaboll Thrust Sheet at Eriboll and the Glencoul and Ben More thrust sheets of Assynt (Ben More Assynt–Conival–Na Tuadhan GCR site). Other examples are found in the southern part of the thrust belt; the Kinlochewe and Kishorn thrust sheets, which are parts of the Slioch-Heights of Kinlochewe and Cnoc min Broc GCR sites respectively. The thrusts are remarkable in that they appear to have cut through massive, apparently competent gneisses as discrete planes with only a metre or two of associated tectonite (Butler *et al.,* 2006). The Kinlochewe Thrust in the Meall a' Ghiubhais GCR site has similar characteristics but also cuts across irregularities in the Lewisian-Torridonian unconformity.

Imbricate zones

The distinctive and planar-bedded Cambro-Ordovician sedimentary rocks were particularly prone to imbrication by thrusts so that individual units can be repeated many times. In the northern part of the thrust belt (Figure 5.1), the Cambrian quartzites, particularly the Pipe Rock Member, appear to have accommodated many tens of kilometres of shortening (Figure 5.2)b through the formation of duplexes on scales from centimetres to tens of metres (Figure 5.5). This is most clearly demonstrated at the Foinaven GCR site (e.g. Elliott and Johnson, 1980; Butler, 1982b, 2004a), but the Eriboll, Skiag Bridge and Stronchrubie Cliff GCR sites also contain spectacular repetitions of Cambro-Ordovician units. Farther south, for example between Loch Broom and Kinlochewe (including the Càrn na Canaich GCR site), the thrust belt contains very little imbrication. Indeed in many places it consists entirely of the Moine Thrust. However, imbricate zones are present in the Torridon area (Butler *et al.,* 2007) with thick slices containing Torridonian and Cambrian strata, for example at Sgorr Ruadh, as described in the Beinn Liath Mhor GCR site report (this chapter).

Lateral variations in the geometry of thrusts are responsible for major culminations along the thrust belt. The presence of ramps can generate radical variations in the content of individual thrust sheets. Where many imbricate slices are stacked, complex folds and culminations may have been generated within the thrust belt. The Assynt Culmination furnishes the largest example (Figure 5.1). This bulge in the Moine Thrust is formed by laterally restricted thrust sheets of Lewisian basement (the Ben More and Glencoul sheets) together with vast piles of imbricate structures within the Cambro–Ordovician succession. The culmination also includes major intrusions (e.g. the Loch Ailsh Syenitic Pluton; Parsons, 1999) that Elliott and Johnson (1980) suggested were a major cause of the abundant imbrication. The process of culmination formation may be best appreciated on an outcrop scale at Creag Shomhairle in the Foinaven GCR site.

Fold–thrust complexes

Folds may be associated with thrusts simply as a geometric consequence of movement along ramp-flat profiles. These antiformal, so-called 'fault-bend folds' (e.g. Rich, 1934; Suppe, 1983) only develop in the hangingwall (e.g. at Heilam, Eriboll GCR site, see (Figure 5.6)). Examples are also exposed on cliff sections on Foinaven and in the Sgorr Ruadh area (Figure 5.1). However, in many natural examples, folds are interpreted to have initiated as buckles, subsequently being cut through by a thrust (e.g. Fischer and Coward, 1982; Williams and Chapman, 1983). This composite behaviour may be distinguished from simple fault-bend folding by identifying deformation in the footwall to thrusts, particularly large-scale synforms, which form the complementary fold pair to the hangingwall antiforms. Large-scale buckle folds have evolved into thrust sheets as some limbs shear out, generating tight folds carried on thrust-sense shear-zones. In ideal cases, these folds face in the direction of tectonic transport (e.g. Coward and Potts, 1983). This type of behaviour appears to characterize deformation in the southern part of the Moine Thrust Belt. The Kishorn Nappe (Figure 5.1) contains areas of overturned Torridonian sedimentary rocks, which pick out large-scale footwall synclines beneath higher-level thrusts, for example the Lochalsh Syncline that dominates the geology of Sleat and forms one of the largest folds in the thrust belt. Associated with these large folds are widespread schistosities and minor folds, well displayed in the Ard Hill and Carn a' Bhealaich Mhoir GCR sites. This style of broadly distributed deformation is in marked contrast to the Lewisian-cored thrust sheets of central and northern Assynt (Butler *et al.,* 2006). The change in structural style coincides with the presence of a thick Torridonian sedimentary sequence in the southern part of the thrust belt. It apparently indicates that the interface between Torridonian and Lewisian rocks was prone to buckling, perhaps nucleating on preexisting normal faults, whereas the Cambrian-Lewisian unconformity favoured thrust ramps.

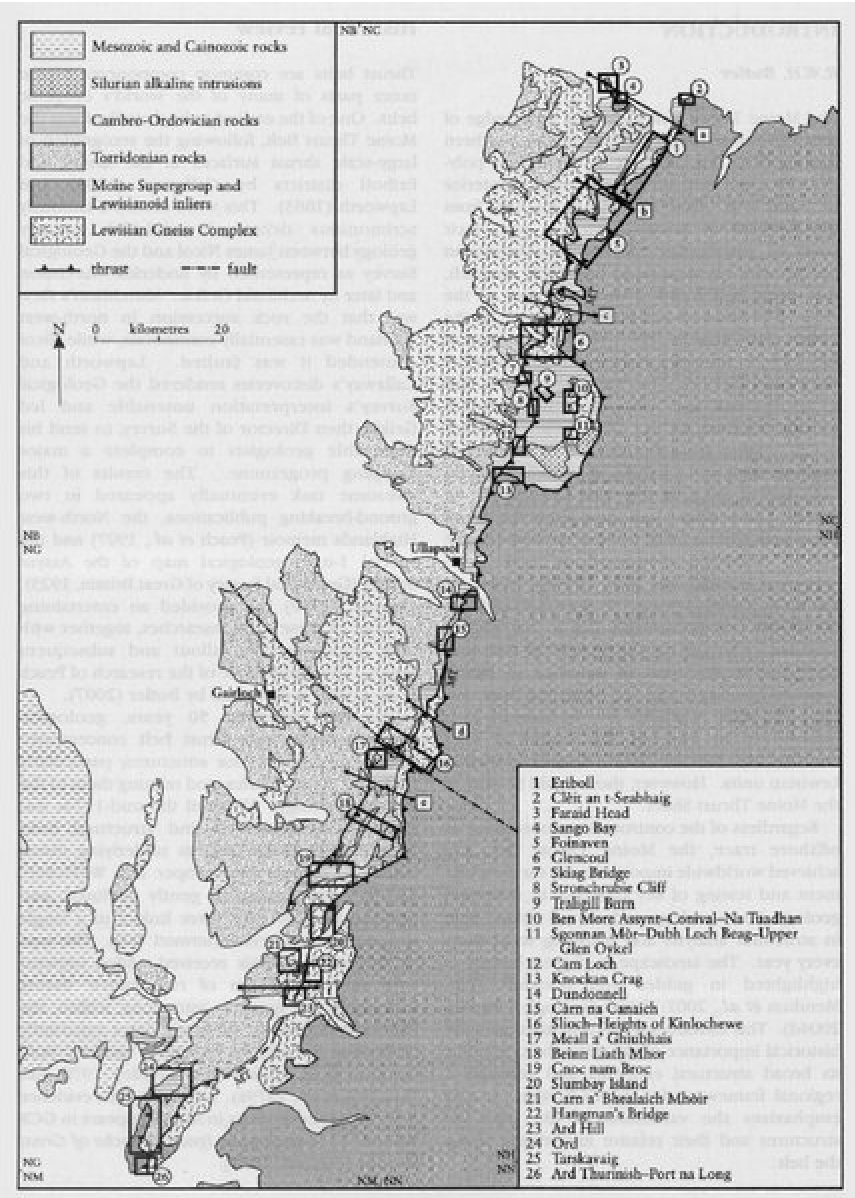
Timing

It is generally accepted that thrust tectonics had ended in north-west Scotland by earliest Devonian times (*c.* 400 Ma), but the evidence for this paradigm is rather sparse. Estimating the timing of displacements within the Moine Thrust Belt relies on radiometric ages from various alkaline igneous intrusions. The Loch Borralan Syenitic Pluton of Assynt, which appears to cut the Ben More Thrust (e.g. Parsons, 1979, 1999), has been dated at 430 ± 4 Ma (van Breemen *et al.,* 1979a). The Loch Ailsh Pluton, which is apparently cut by Caledonian structures (see Ben More Assynt–Conival–Na Tuadhan GCR site report, this chapter), has yielded an age of 439 ± 4 Ma (Halliday *et al.,* 1987). In addition, the Canisp Porphyry sills, which lie in the foreland immediately west of the thrust belt but are absent from the belt itself, have a U-Pb TIMS zircon intrusion age of 437 ± 4.8 Ma (Goodenough *et al.,* 2006). However, direct dating of mylonite formation in the hangingwall to the Moine Thrust implies that ductile movements associated with recrystallization continued until about 410 Ma (Freeman *et al.,* 1998). There are no clear indications from geological relationships of the time of final cessation of movement in northwest Scotland. Although minor intrusions spatially associated with the Loch Borralan Pluton (e.g. the 'nordmarkite' dykes) are found on both sides of the Moine Thrust, no individual intrusions have been found that definitively suture the thrust belt. Neither are there any sedimentary rocks earlier than Triassic age that unconformably overlie the structures.

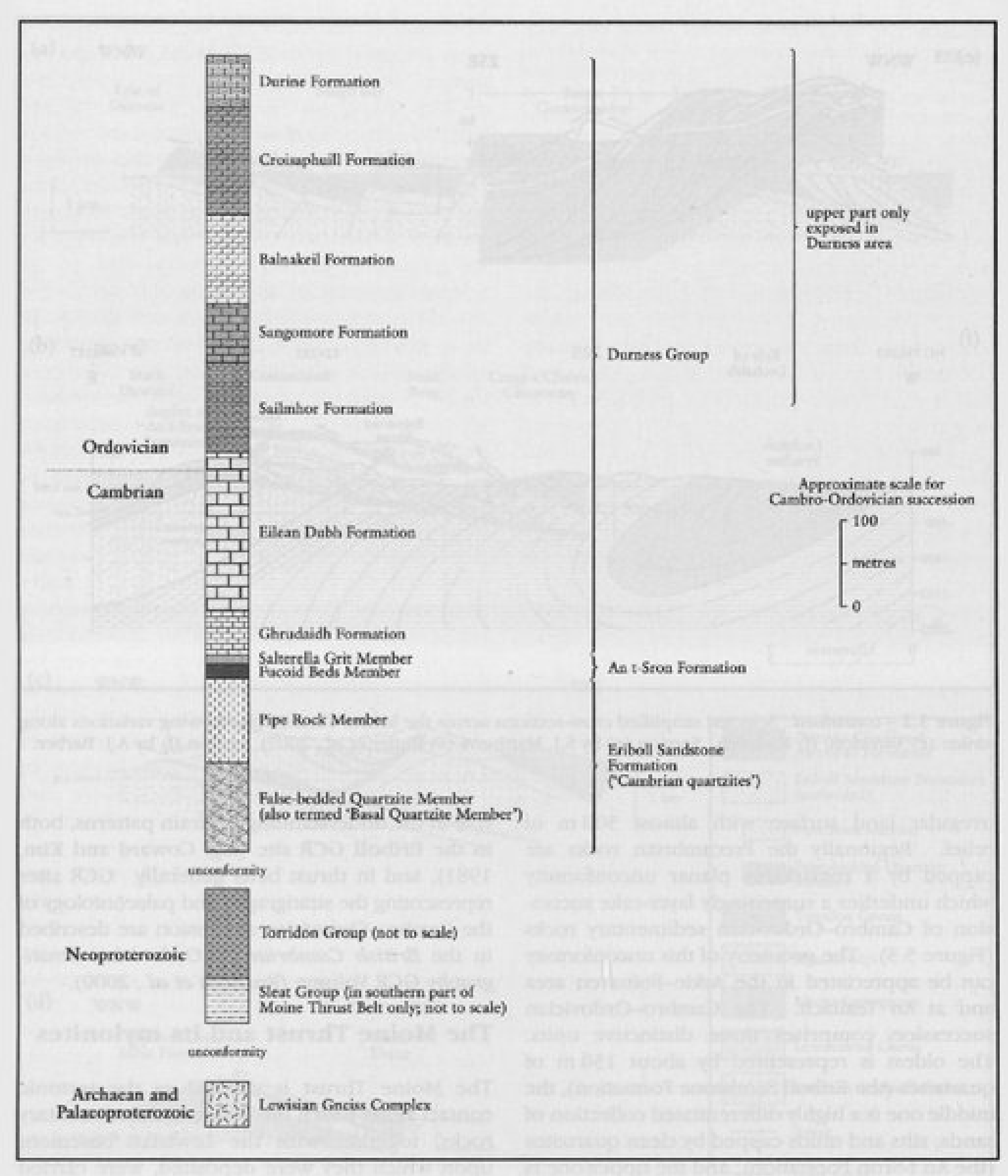
Summary

The Moine Thrust Belt forms the outer, northwest margin to the Scottish Caledonides. As such it provides spectacular examples of the range of structures found with the marginal zone of an orogenic belt. Over 150 years of geological investigation have seen a number of revolutions in the analytical philosophy behind different types of tectonic analysis and interpretation. The international importance of the Moine Thrust Belt is increased by the spectacular nature of outcrops in a region of outstanding natural landscape that provide unparalleled insight into the three-dimensional structure of thrust systems. These locations provide important resources for teaching and for continued research; the region remains a heavily used natural laboratory for testing tectonic models. The GCR sites reflect this history and the range of structures that can be found in thrust belts, both in style and scale. They are described broadly from north to south, starting at Loch Eriboll, the historical site where the 19th century 'Highlands Controversy' was resolved (Lapworth, 1883; Peach *et al.,* 1888).

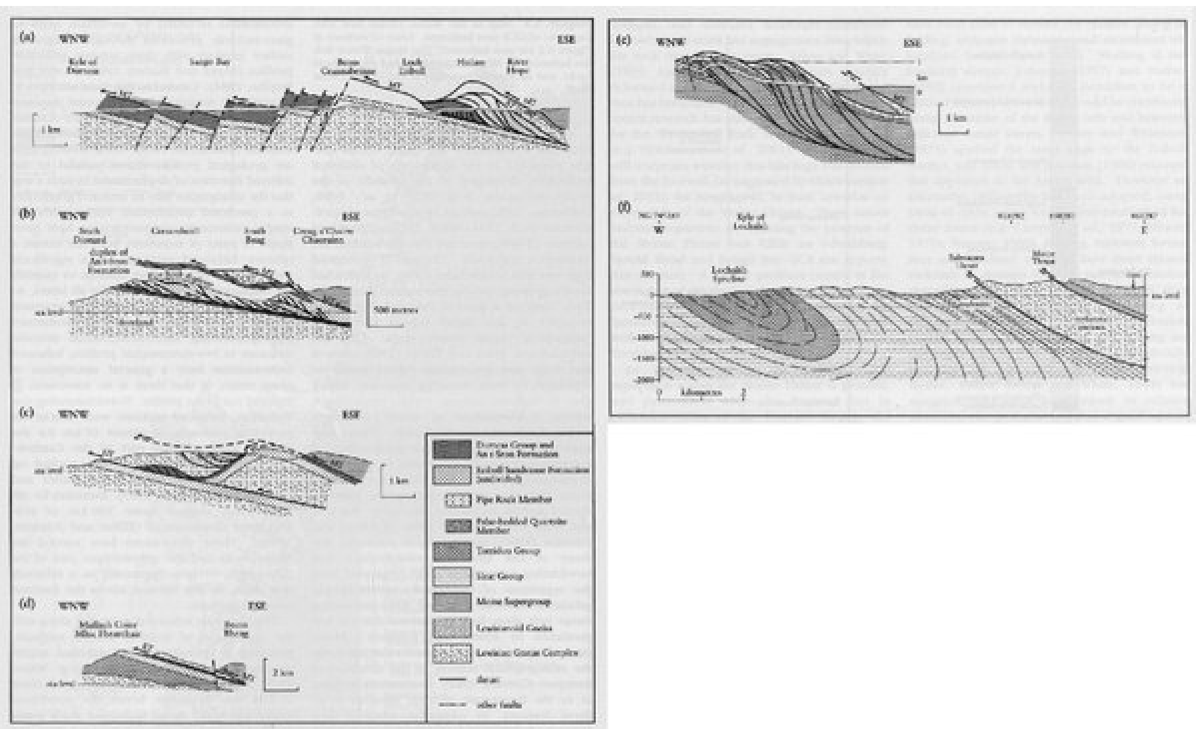
[References](#)



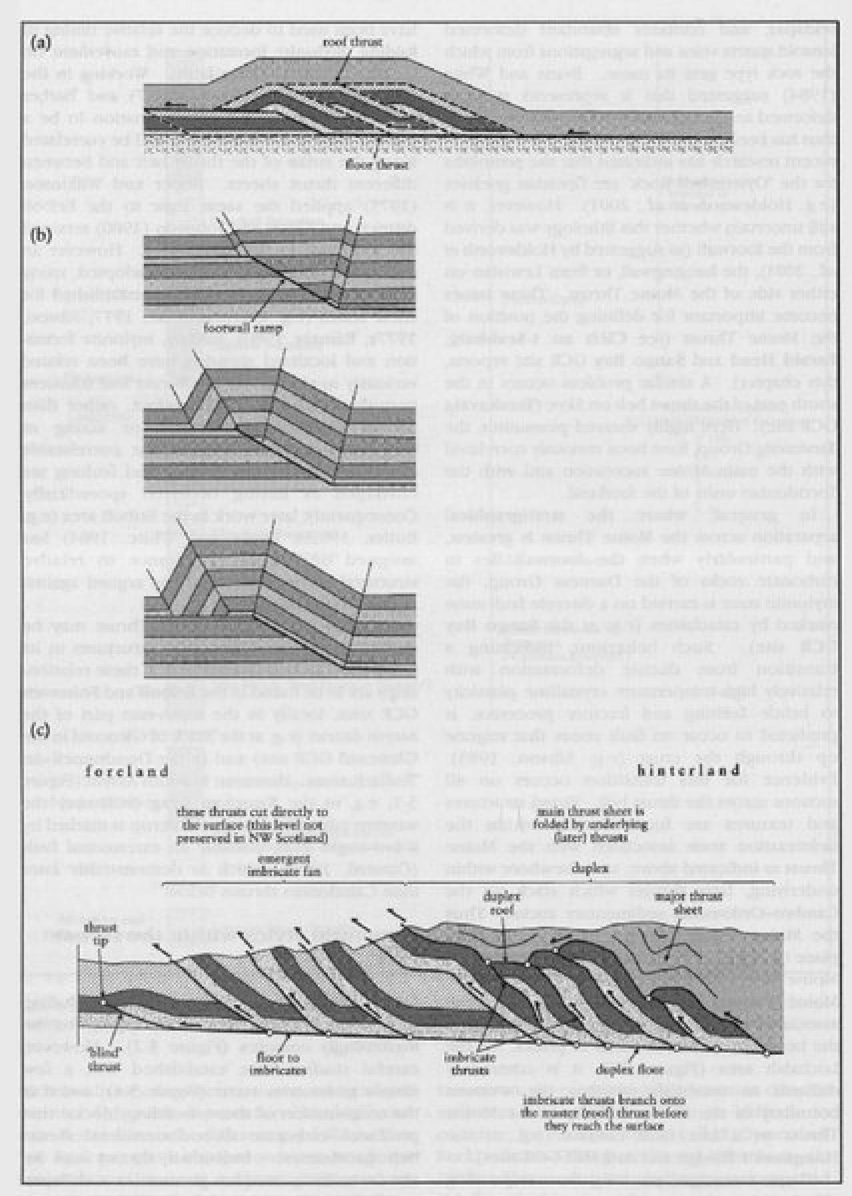
(Figure 5.1) Map of the Moine Thrust Belt with locations of GCR sites indicated. Lines of sections of Figure 5.2 are also indicated. The Moine Thrust Belt lies between the Moine Supergroup and the foreland rocks, and its eastern boundary is the Moine Thrust itself.



(Figure 5.3) Stratigraphical column of Cambro–Ordovician sequence in north-west Scotland. Based on Swett (1969), Prigmore and Rushton (1999)and British Geological Survey (2002).

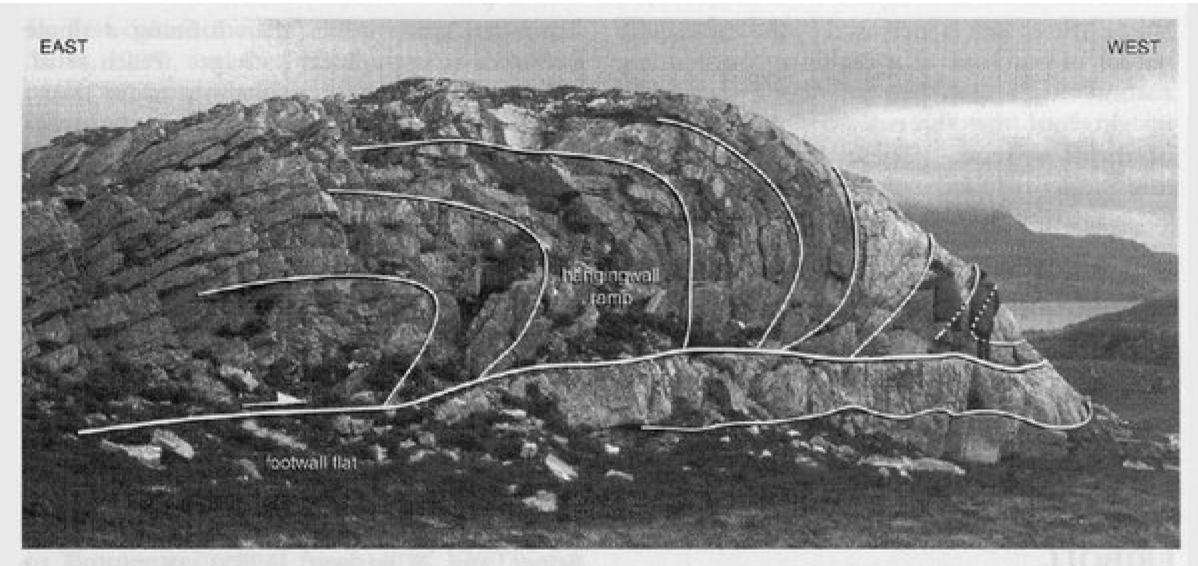


(Figure 5.2) Selected simplified cross-sections across the Moine Thrust Belt, showing variations along strike. MT — Moine Thrust; AT — Arnaboll Thrust; CST: — Creag Shomhairle Thrust; GT — Glencoul Thrust; KT — Kinlochewe Thrust. (a) Arnabol—Durness; (b) Foinaven; (c) north Assynt; (d) An Teallach—Carn na Canaich. Sections (a)—(d) by R.W.H. Butler. Selected simplified cross-sections across the Moine Thrust Belt, showing variations along strike: (e) Torridon; (f) Lochalsh. Section (e) by SJ. Matthews (in Butler et al., 2007), section (f) by AJ. Barber.



(Figure 5.4) Idealized thrust geometries. (a) Idealized duplex (Boyer and Elliott, 1982): three imbricate thrust slices between a roof and a floor thrust. (b) Suppe's model for the development of fault-bend fold in the hangingwall, formed as a thrust sheet climbs up a footwall ramp (after Suppe, 1983). (c) Diagram showing imbricate thrusts, duplex, duplex floor and roof and other thrust geometries.

(Figure 5.5) Example of a single-bed duplex structure developed within the Pipe Rock. This is the Beyond Hope duplex of Bowler (1987), exposed in coastal outcrops south of Whiten Head. (Photo: R.W.H. Butler.)



(Figure 5.6) Small-scale fold-thrust complex in quartzite, Heilam, Eriboll GCR site. (Photo: R.W.H. Butler.)