Chapter 8 Moine (South)

Introduction

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The southern Moine area stretches from Loch Hourn and Glen Moriston in the north, southwestwards to Ardnamurchan and the Sound of Mull, where Palaeogene mafic lavas and intrusions overlie and intrude the Moine rocks. A small enclave of Moine rocks occurs in the south-west part of Mull adjacent to the Ross of Mull Granite Pluton. The Great Glen Fault bounds the area to the south-east, and to the west the Moine Thrust Belt lies offshore. The northern boundary of the area extends as far north as Cluanie and Glen Affric to include all the outcrops of the West Highland Granite Gneiss Suite (Figure 8.1). The area encompasses the mountainous watershed region of Inverness-shire and the north part of Argyllshire with numerous summits exceeding 900 m. Lower hilly areas and more-rolling, partly forested country occurs near to the Great Glen, on the Ardnamurchan peninsula, and in Morvern in the south.

The main features of the geology of the southern Moine area are the distinctive tripartite division of the Moine Supergroup into the Morar, Glenfinnan and Loch Eil groups, the presence of the West Highland Granite Gneiss Suite, and the overall structural pattern, dominated by the central 'Steep Belt' and the Sgurr Beag Thrust. The 'Steep Belt' is an area of complex, superimposed folding mainly affecting interbanded pelitic and psammitic rocks of the Glenfinnan Group that forms a central NE-trending spine to the region. It is an area of rugged, rocky and grassy mountains transected by roughly east–west breaches, which are infilled by Loch Quoich in the north, Loch Shiel in the centre, and Loch Sunart in the south. The Loch Eil–Loch Ailort transect provides a major through route from Fort William to Mallaig (Figure 8.1), (Figure 8.2); see Fassfern to Lochailort Road Cuttings GCR site report, this chapter). The Sgurr Beag Thrust separates the Sgurr Beag Nappe above, from the Moine and Knoydart nappes below (Figure 8.1). Glenfinnan Group and Loch Eil Group rocks lie within the Sgurr Beag Nappe. Lewisianoid inliers are restricted to the Morar area where they occur mainly in thrust sheets and lenses. The Moine rocks contain evidence of Neoproterozoic deformation and metamorphism, with the Grampian and possibly Scandian orogenic episodes superimposed on the earlier pattern. The igneous history of this area is varied and spans a long time-period. The oldest elements are the granite precursors of the West Highland Granite Gneiss Suite and early gabbro and dolerite bodies, emplaced at *c.* 870 Ma (Friend *et al.,* 1997; Millar, 1999; Rogers *et al.,* 2001). Pegmatitic granite and leucotonalite vein-complexes give isotopic ages between 784 Ma and 827 Ma (Rogers *et al.,* 1998), compatible with their formation during a Neoproterozoic Knoydartian tectonometamorphic event. The foliated Glendessarry Syenite was intruded during the Grampian Event at *c.* 456 Ma (van Breemen *et al.,* 1979b). Deformed gabbro-diorite intrusions in Glen Scaddle, dated at *c.* 426 Ma (Strachan and Evans, 2008), and in Glen Loy, are in part sheared and amphibolitized, attesting to Scandian orogenic activity. The final phases of the Caledonian Orogeny in the late Silurian were marked by the emplacement of numerous acid to intermediate intrusions. The Strontian, Cluanie and Ross of Mull plutons and the Clunes Tonalite are the major bodies. Minor intrusions include abundant microdiorite sheets and dykes, granitic vein-complexes, porphyritic microgranodiorite dykes, appinitic intrusions, and rare lamprophyre dykes.

History of research

The early workers of the Geological Survey moved down the Moine Thrust Belt to Lochalsh and Skye in the late 19th century (see Chapter 5), and it was only in the 1920s that the Survey commenced mapping in the southern Moine area. The complex nature of the geology, the wet weather, and the difficult nature of the ground made progress slow, particularly in the more-remote mountainous parts of the area. Work continued intermittingly from the 1950s to the 1980s, and the final 1:50 000 sheet, Sheet 73W (Invermoriston), was published in 1995 (British Geological Survey, 1995). However, much of the southern Moine area has no memoir coverage.

During the Second World War, the Knoydart Mica Mine was described by Kennedy *et al.* (1943) and shortly afterwards went in production. The mica was used for furnace windows and electrical components.

Academic work, commonly PhD studies involving detailed mapping, focused on the southern Moine area from the mid-1950s onwards. An early group, from Imperial College, London, included P.S. Simony, J.S. Spring and P.W.G. Tanner, who worked in Kintail and Knoydart and linked with Ramsay's work in the Glenelg area (see 'Introduction', Chapter 7). Another group at the University of Edinburgh, supervised by M.R.W. Johnson, included I.W.D. Dalziel, G.C. Clark, R.L. Brown and J.B. Howkins, who worked in the Glenfinnan–Loch Ailort area. D. Powell, R. St J. Lambert and A.B. Poole were other significant contributors to these field-based studies, notably in the Morar-Lochailort area. D. Barr, B.H. O'Brien, A.M. Roberts and P.A. Rathbone from Liverpool University were supervised by A.L. Harris and carried out work on the southern Moine area. Other notable PhD work was carried out by R.A. Strachan in the Glenfinnan–Loch Eil area and by N.R.W. Glendinning in the western Moine; both studies contributed significantly to our understanding of the sedimentary environments during deposition of the Moine Supergroup (Strachan, 1985, 1986; Glendinning, 1988).

Based on their Geological Survey mapping, Richey and Kennedy (1939) suggested a tripartite division of the structurally and stratigraphically lowest Moine rocks, now termed the 'Morar Group', into Lower and Upper Psammite 'groups' separated by a 'Striped and Pelitic Group'. They also recognized an underlying 'Sub-Moine' succession that included orthogneisses (Lewisianoid inliers) and veined and schistose semipelites, pelites and psammites in which bedding was difficult to discern. Kennedy (1955) subsequently revised the structural interpretation significantly, and postulated that the coherently bedded Moine rocks formed the Morar Nappe, which was folded by the later Morar Antiform to give a 'window' into the lower succession. He recognized that the Lower Psammite and parts of the Moine succession were duplicated in the structurally lower rocks and argued that Lewisianoid gneiss was present. When Kennedy presented his model, there was considerable discussion as to the nature of the 'Lewisianoid' gneiss inliers, the possible correlations with the Glenelg area, and the wider tectonic interpretations of the postulated tectonic (?Grampian and Scandian) events. Kennedy's interpretations, both in Morar and on the wider scale, were not well received, but there was little discussion of the structural detail and nature and position of the slide or thrust boundaries of the different elements. Lambert (1958) later argued that the Moine–Sub-Moine boundary was in fact a gradational metamorphic boundary, but it was the detailed work of Ramsay and Spring (1962) in Knoydart, Poole (1966) in North Morar, and Powell (1966) in Morar and Lochailort, that determined the nature of the structural boundaries and detailed stratigraphy. This work, combined with the publication of Sheet 61 (Arisaig) (Institute of Geological Sciences, 1971), enabled more-coherent interpretations of the Morar Group rocks to be made by Poole and Spring (1974) and Powell (1974). It was recognized that the Lewisianoid rocks lay either in thrust contact with the adjacent Moine succession, or in the cores of tight to isoclinal folds.

The recognition of the Sgurr Beag Thrust, a shear zone that separates the Morar and Glenfinnan groups (Tanner *et al.,* 1970; Tanner, 1971; Rathbone and Harris, 1979; Powell *et al.,* 1981) proved to be a key in the understanding of the regional overall structure of the Moine succession. The Quoich (or Loch Quoich) Line that marks the eastern margin of the central 'Steep Belt' and broadly coincides with the south-eastern boundary of the Glenfinnan Group, was first recognized by Clifford (1957), but its overall significance was recognized by Roberts and Harris (1983) and Strachan (1985).

The origin of the West Highland Granite Gneiss Suite, a series of granite gneiss bodies that occur mainly along the Glenfinnan Group–Loch Eil Group boundary, has been controversial. Bailey and Maufe (1916) interpreted the southernmost body, the Ardgour Granite Gneiss, as a deformed, pre-metamorphic intrusion. Harry (1954) and Dalziel (1966) suggested that the Ardgour body formed *in situ* by K-metasomatism of Moine sediments during high-grade metamorphism. Mercy (1963) suggested that the Ardgour Granite Gneiss could have a magmatic origin. On the basis of geochemical data, Gould (1966) concluded that it has a uniform granitic composition, distinct from the adjacent Moine metasediments, and was intruded as an Al-undersaturated magma which incorporated metasedimentary material from the Moine rocks at depth. Barr *et al.* (1985) re-investigated the granite gneiss occurrences in the North-west Highlands and concluded that they represent a series of deformed and metamorphosed intrusive granite sheets. The relationship of the granite gneiss with associated metagabbro bodies at Glen Doe was first studied by Peacock (1977), but it was Millar's work (1990, 1999) that showed the intimate relationship between the two suites of rocks and suggested that the granite gneiss and the metagabbro were part of a bimodal, rift-related suite of magmatic rocks (see Glen Doe GCR site report, this chapter).

Some of the earliest geochronological work was by Giletti *et al.* (1961), who pioneered Rb-Sr dating on micas from the Knoydart Mica Mine and Sgurr Breac, obtaining ages between 690 Ma and 750 Ma (see Knoydart Mica Mine GCR site report, this chapter). This work gave the first hint of Neoproterozoic tectonothermal events within the Moine outcrop, and the character and significance of the 'Knoydartian' and 'Morarian' events has proved controversial ever since. Similar Neoproterozoic ages were soon obtained from muscovites in pegmatites elsewhere in the Moine area (Long and Lambert, 1963; van Breemen *et al.,* 1974; Piasecki and van Breemen, 1983; Powell *et al.,* 1983). More-accurate U-Pb monazite and zircon dating (van Breemen *et al.,* 1974, 1978; Rogers *et al.,* 1998) from many of these pegmatite bodies has confirmed their Neoproterozoic ages, with the pegmatites thought to be pre- or syn-D2. Dating on other rocks has also yielded Neoproterozoic ages: Vance *et al.* (1998) obtained Sm-Nd ages of 823 Ma and 788 Ma from garnets in the Morar Petite, and Tanner and Evans (2003) obtained a U-Pb TIMS age of 737 ± 5 Ma from titanite in calc-silicate rocks in the upper part of the Morar Group.

The early geochronological work on members of the West Highland Granite Gneiss Suite gave contradictory results (Brook *et al.,* 1976; Aftalion and van Breemen, 1980). More recently, U-Pb dating of zircons has concluded that the original granite intrusion occurred at *c.* 873 Ma (Friend *et al.,* 1997; Rogers *et al.,* 2001). Millar (1999) also obtained an 873 ± 6 Ma emplacement age from a metagabbro at Glen Doe, where the mafic rocks clearly cut the granite gneiss. Most authors now accept that this *c.* 870 Ma event was extensional. Several authors (Dalziel and Soper, 2001; Ryan and Soper, 2001) argued that all the Neoproterozoic tectonothermal events could be explained by extensional events. However, recent studies that combined isotopic dating with metamorphic petrology (e.g. Vance *et al.,* 1998; Zeh and Millar, 2001; Tanner and Evans, 2003) appear to show that the 'Knoydartian' and 'Morarian' events were contractional orogenic events. One puzzling aspect of these Neoproterozoic events is that elsewhere in the region there is no evidence of orogenic events of comparable age, and Scotland was, at the time, probably situated in the middle of the Rodinia supercontinent. The nature and extent of these pre-Caledonian orogenic events remains somewhat unclear (e.g. see Oliver, 2002).

Geological history

The geological history of the southern Moine area has many similarities with the central and northern Moine areas. The dominantly arenaceous Moine succession was deposited in early Neoproterozoic times in a wide shallow fluviatile and marine basin whose basement was composed of Lewisianoid rocks. In the southern Moine outcrop, the basement-cover relationship is only exposed in the Morar area. Pelitic and semipelitic units representing mud and silt deposition are found within the lower Morar Group rocks, but are more abundant in the overlying Glenfinnan Group. The upper Loch Eil Group is dominated by psammites derived from mature marine sands. Studies of detrital zircons suggest that the Moine sands were derived from the Grenville Belt and Canadian Shield areas (Friend *et al.,* 2003).

Granite sheets were intruded into the Moine succession during the early Neoproterozoic at *c.* 870 Ma (Friend *et al.,* 1997), followed closely by gabbro and dolerite intrusions (Millar, 1999). These elements were all deformed and metamorphosed during the Knoydartian event (*c.* 820–730 Ma). Recent isotopic dating and metamorphic studies suggest that this was an orogenic event that resulted in compressional stacking of the succession (Vance *et al.,* 1998; Zeh and Millar, 2001; Tanner and Evans, 2003; see North Morar GCR site report, this chapter). It is unclear whether this Knoydartian event also resulted in the formation of the distinct Moine, Knoydart and Sgurr Beag nappes. A considerable time-gap followed before the rocks were reworked during the early Ordovician Grampian Event of the Caledonian Orogeny. This event refolded the earlier structures and also resulted in metamorphism to middle-amphibolite facies, though probably at lower pressures than those prevailing during the earlier Knoydartian event. The reworking occurred mainly within the 'Steep Belt' in Glenfinnan Group rocks, with deformation and metamorphism occurring coeval with the intrusion of the Glendessarry Syenite at 456 Ma. Isotopic work has so far provided little evidence of the Scandian Event in the southern Moine area, but Strachan *et* al. (2002a) assigned the main Caledonian reworking to this event. These authors interpret the thrust geometry in the southern Moine succession as part of a coherent foreland-propagating sequence linked to the Moine Thrust Belt and draw analogies with the structural sequence in Sutherland. Following Scandian deformation, a period of strong uplift occurred in late Silurian time, accompanied by intrusion of the gabbro, tonalite and granodiorite plutons and related minor intrusions. Devonian sandstones and conglomerates were probably deposited on parts of the southern Moine area following the major period of uplift, particularly along the Great Glen, but only small remnants. are now preserved (Stoker, 1983).

Main lithologies

Lewisianoid inliers

Lewisianoid rocks are found locally as thrust-bounded lenticular sheets in the immediate hangingwall of the Sgurr Beag Thrust (see Kinloch Hourn GCR site report, this chapter). However, their main occurrence in the Moine (South) area is in the central part of the Morar Antiform associated with the lower part of the Morar Group succession. Here, Lewisianoid gneisses are found in the cores of tight to isoclinal anticlinal infolds (Powell, 1974) and possibly also occur as thrust sheets (Kennedy, 1955). The gneisses are typically layered felsic and mafic orthogneisses. The interlayered hornblendic material, epidotic and pyritic nature of the gneisses, and the occurrence of mafic and ultramafic pods, are characteristic features of Lewisianoid inliers (see North Morar GCR site report, this chapter). Their complex history is represented by several phases of mafic intrusion and by different generations of quartz-feldspar pegmatite veins. The thickness of the gneissic layering ranges from several metres, down to a few millimetres where the rocks have been highly sheared during the Knoydartian or Caledonian orogenic events.

Moine-Lewisianoid relationships are not as clear in the southern Moine area as farther north. Basal Moine conglomerates are absent and the Moine-Lewisianoid contacts are commonly the sites of ductile thrusting (see Kinloch Hourn and North Morar GCR site reports, this chapter). Where the basal contact of the Moine succession is seen in its relatively unmodified state in Morar, the thinly interbedded psammites, semipelites and pelites of the Basal Pelite Formation appear to lie with marked unconformity on the Lewisianoid gneisses.

Moine Supergroup

The overall stratigraphy of the Moine rocks broadly youngs from basal units in the west to the highest units in the east. Three tectono-stratigraphical divisions of the Moine succession were first recognized in the southern Moine area (Johnstone *et al.,* 1969), and these divisions are now formally termed the 'Morar Group', the 'Glenfinnan Group' and the 'Loch Eil Group' (Holdsworth *et al.,* 1994). However, relationships between the three groups are partly tectonic and their regional lateral extent, and internal facies variations still remain surprisingly poorly known. The A830 road sections between Corpach and Arisaig constitute the type area for the Moine stratigraphy (see Fassfern to Lochailort Road Cuttings GCR site report, this chapter). The Morar Group consists predominantly of psammite, with subordinate pelite + semipelite formations. Glenfinnan Group rocks consist mainly of interlayered psammite, semipelite and pelite, but in parts major gneissose semipelite + pelite formations, locally thick psammite units, and small amphibolite bodies occur. The Loch Eil Group rocks are dominantly psammites. The stratigraphical successions and constituent formations are summarized in (Figure 8.3).

The Morar Group–Glenfinnan Group boundary is normally marked by the Sgurr Beag Thrust with the Glenfinnan Group and Loch Eil Group rocks forming the overlying Sgurr Beag Nappe. However, on the Ross of Mull a stratigraphical transition, albeit considerably deformed, is recorded (Holdsworth *et al.,* 1987). Glendinning (1988) noted that the Upper Morar Psammite Formation contained more-semipelitic units and became thinner towards its eastwards limit around Loch Eilt, suggesting a possible facies change south-eastwards into Glenfinnan Group lithologies. Facies changes are well documented at the Glenfinnan Group-Loch Eil Group boundary, with transitional sequences noted by Roberts and Harris (1983), Strachan (1985), and Peacock *et al.* (1992). In the southern Moine area this boundary corresponds with the Quoich Line, a major monoform that separates the 'Steep Belt' to the north-west from the 'Flat Belt' to the south-east.

The Moine rocks represent a sequence of fluviatile and marine sands, silts and muds laid down in a wide shallow basin. Glendinning (1988) documented the sedimentology of the Upper Morar Psammite and concluded that the formation represented a mainly tidal shelf deposit with proximal and minor fluvial sands prograding northwards over more-distal sands, silts and muds. Cross-bedding foresets indicate that tidal currents were predominantly towards the NNE. Recent work by Bonsor and Prave (2008) has re-interpreted the sedimentological features as indicating an alluvial braidplain environment of deposition. Farther east, Strachan (1986) also suggested that the Loch Eil Group psammites were of shallow-marine origin. Soper *et al.* (1998) erected a model for Moine deposition in two E-facing half-graben basins. They suggested that the Morar Group formed as a predominantly rift succession in a more westerly basin, passing upwards and laterally eastwards into the Glenfinnan Group rocks that represented a thermal subsidence phase. The Loch Eil

Group rocks represented a further phase of rifting with Lewianoid rocks effectively forming a basement high underlying the 'Steep Belt' to the west of the basin-bounding fault.

The provenance of the Moine succession has been addressed by U-Pb dating of detrital zircons and inherited detrital zircon cores from igneous rocks (Friend *et* ed., 1997, 2003; Peters *et al.,* 2001; Rogers *et ed.,* 2001; Cawood *et al.,* 2004). The detrital zircon data seem coherent for the whole succession. Archaean zircons are rare; significant age clusters occur at *c.* 1800–1600 Ma, *c.* 1500 Ma and *c.* 1100–980 Ma. The most obvious source of suitable granitoid rocks would be the Labradorian terrain of Canada or the Gothian terrain of Scandinavia with input from the Grenville Orogen (Cawood *et* ed., 2004). The youngest detrital grain so far dated yielded an age of 980 ± 4 Ma (Peters *et* al., 2001), bracketing deposition of the Moine succession between 980 Ma and the intrusion of the granite gneiss protolith at 873 Ma.

Morar Group

The Morar Group contains a basal semipelitic unit and two main psammitic units separated by an intervening semipelitic and pelitic unit. The rocks have been metamorphosed to greenschist-and amphibolite-facies with a marked rise in metamorphic grade south-eastwards. In the lower-grade parts of the psammitic units, abundant sedimentary structures occur, including cross-bedding, slump- and load-structures, lenticular rippled sandstone beds, local erosional surfaces and rare shrinkage cracks (Richey and Kennedy, 1939; Glendinning, 1988). (Figure 8.4) shows the distribution of the stratigraphical units of the Morar Group in Knoydart, Morar and Ardnamurchan. The Morar Group is described in detail in the North Morar GCR site report (this chapter).

The lowest unit, the Basal Pelite Formation, is a thin unit that mantles the Lewisianoid rocks in Morar and Knoydart. It consists of thinly layered, schistose, muscovite-biotite-semipelite and pelite, with some psammite beds and abundant quartz veins and pods. The formation is more psammite-rich near its top and passes upwards into the Lower Morar Psammite Formation. This consists of thin- to thick-bedded psammites with subordinate semipelites. The psammites are locally pebbly and contain heavy-mineral bands in the lower part. Cross-bedding is common throughout, and ubiquitous in the upper part. In the upper part of the formation calc-silicate ribs are present and semipelite units more abundant. In Knoydart, the Lower Morar Psammite Formation can be divided into three separate formations, the Arnisdale Psammite Formation, the Rubha Ruadh Semipelite Formation, and the Barrisdale Psammite Formation (Ramsay and Spring, 1962; see (Figure 7.3), Chapter 7).

The Lower Morar Psammite Formation passes with rapid transition up into the Morar Pelite Formation, formerly known as the 'Striped and Pelitic 'Group'' (Richey and Kennedy, 1939) or 'Morar Schist Formation' (Johnstone and Mykura, 1989). In its type area this formation has three component elements. A lower, grey, laminated and layered semipelite and psammite unit is succeeded by a central schistose garnetiferous pelite and semipelite unit, which in turn is overlain by a rhythmically layered pelite, semipelite and psammite unit. Calc-silicate ribs are very abundant in the central and upper parts of the formation. The Morar Pelite Formation is equivalent to the Ladhar Bheinn Pelite of Ramsay and Spring (1962) that dominates in Knoydart (see (Figure 7.3), Chapter 7, and (Figure 8.3)). In the Kinloch Hourn area, pelitic units in the formation become more psammitic northwards (Tanner *et al.,* 1970). South from Kinloch Hourn, a *c.* 150 m transitional unit, termed the 'Aonach Sgoilte Psammite Formation', occurs between the Morar Pelite Formation and the overlying Upper Morar Psammite Formation (Ramsay and Spring, 1962; Holdsworth *et al.,* 1994). This unit consists mainly of intercalated pelite, semipelite, and micacous and siliceous psammites, with abundant calc-silicate ribs. The psammite component increases upwards and its upper part consists of feldspathic and siliceous psammites with thin pelitic partings. Soper *et al.* (1998) and Strachan *et al.* (2002a) considered this unit to be laterally equivalent to the Upper Morar Psammite Formation, but this interpretation is not followed here.

The Upper Morar Psammite Formation consists of thin- to thick-bedded feldspathic psammites, commonly pebbly and with heavy-mineral bands. Subsidiary semipelite beds and calc-silicate ribs are common. The formation shows excellent examples of bipolar cross-bedding, complex sand-wave structures, and gravel-lag deposits (Glendinning, 1988; Bonsor and Prave, 2008; see also the Eilean Mòr and Camas Choire Mhuilinn GCR site report, this chapter). Soft-sediment load structures are common in the thicker western parts of its outcrop.

On the Ross of Mull, the Lower Shiaba Psammite, the Shiaba Pelite and the Upper Shiaba Psammite are correlated with the Lower Morar Psammite, the Morar Pelite and the Upper Morar Psammite formations respectively (Holdsworth *et al.,* 1987, 1994; (Figure 8.3)).

Glenfinnan Group

The stratigraphy of the Glenfinnan Group rocks is less well defined and documented than that of the Morar Group, but is generally characterized by laterally more-variable semipelitic and pelitic units that are susceptible to migmatization. Structural dislocations and large- and small-scale complex folding are generally present. Together with original facies changes these give rise to a complex package in which the original stratigraphical template is very difficult to restore. An attempt has been made to collate the various local stratigraphies and suggest correlations (Figure 8.3), but this inevitably differs from Holdsworth *et al.* (1994) and earlier attempts (e.g. Roberts *et al.,* 1987).

Near Kinloch Hourn, the Reidh Psammite Formation, a gneissose and locally migmatitic psammite unit containing small lenses of Lewisianoid gneiss, occurs immediately above the Sgurr Beag Thrust (Tanner, 1971; Roberts *et ed.,* 1987). However, its outcrop extends only some 5–6km to the south, the unit being cut out just north of Loch Quoich. The psammite passes eastwards with rapid transition into the Lochailort Pelite Formation (Sgurr Beag Pelite Formation farther north), a thick, gneissose, locally garnetiferous, layered semipelite and pelite unit, with subsidiary psammite layers (Brown *et al.,* 1970). Small amphibolite lenses and calc-silicate ribs are present. The Lochailort Pelite stretches from Kinloch Hourn southwards in the immediate hangingwall of the Sgurr Beag Thrust as far as Moidart, where it contains several distinct psammite units (Brown *et al.,* 1970). Between Loch Moidart and Loch Sunart two units appear to lie stratigraphically beneath the Lochailort Pelite Formation but still within the Sgurr Beag Nappe. These are the Salen Pelite Formation and the Resipol Striped Formation (formerly Assemblage') (Figure 8.3). The Salen Pelite Formation is mainly a gneissose pelite and semipelite, with an apparent stratigraphical transition up into the overlying striped gneissose psammites, semipelites and pelites of the Resipol Striped Formation (Roberts *et al.,* 1987). Individual pelite units, one *c.* 200 m thick, can be traced north from Resipol to central Moidart, where they appear to merge with the Lochailort Petite outcrop. In Mull a psammite, gneissose pelite and quartzite unit, the Lagan Mor Formation, is interpreted to represent a sedimentary transition from Morar Group to Glenfinnan Group rocks. The overlying Scoor Pelitic Gneiss Formation, a gneissose garnetiferous pelite and semipelite with abundant calc-silicate lenses, is probably laterally equivalent to either the Salen Petite Formation or the Lochailort Pelite Formation (Figure 8.3).

In Moidart the Lochailort Pelite is overlain by the Beinn Gaire Psammite Formation, a *c.* 650 m-thick psammite unit with garnetiferous semipelite and pelite interbeds and minor calc-silicate ribs and heavy-mineral bands (Brown *et at,* 1970). The psammite unit thins northwards, and in eastern Morar and the Glenfinnan area the Lochailort Pelite Formation is directly overlain by the Beinn an Tuim Striped Schist Formation (Dalziel, 1966), which passes northeast along strike into the Quoich Banded Formation (Roberts and Harris, 1983). These units consist of thinly interlayered psammite, semipelite and pelite with some thicker gneissose pelite and siliceous psammite units also present. Locally, massive lenticular quartzite units are present. This is the archetypal Glenfinnan Group lithology and normally shows a wide range of fold structures. The equivalent unit on Mull, the Ardalanish Striped and Banded Formation, a sequence of interbedded semipelite, pelite and micaceous psammite with abundant calc-silicate lenses, and amphibolite pods in its upper part, forms the bulk of the Glenfinnan Group succession and is the youngest unit exposed. However, on the mainland the Druim na Saille Pelite Formation, a thick gneissose, partly migmatitic, garnetiferous pelite and semipelite unit with patches of oligoclase-rich gneisses overlies the Beinn an Tuim Striped Schist in Ardgour (Dalziel, 1966). Amphibolite lenses and calc-silicate ribs are common in both these units.

Farther north in the eastern part of the 'Steep Belt' around Glen Dessarry and Loch Quoich, are extensive outcrops of the Quoich Banded Formation (Roberts and Harris, 1983), which along strike in Glendessarry were termed the 'Strathan Striped Schists and Quartzite' (Roberts *et al.,* 1984). The overlying Quoich Pelite Formation, a thick gneissose garnetiferous pelite and semipelite unit with amphibolite pods, but lacking calc-silicate lenses, can also be traced south into Glen Dessarry, where it is termed the 'Fraoch Bheinn Pelite Formation' (Roberts *et al.,* 1984). Roberts *et al.* (1983) initially correlated these upper Glenfinnan Group formations with the Beinn an Tuim Striped Schist and Druim na Saille Pelite formations respectively. Subsequently, Roberts *et al.* (1987) correlated the Quoich Banded Formation with the Reidh Psammite and Resipol Striped formations, and the Quoich Pelite and Fraoch Bheinn Petite formations with the

Lochailort Pelite Formation (see also Holdsworth *et al.,* 1994). The early correlations (as shown on (Figure 8.3)) give a more-coherent regional pattern and are preferred here.

Between Loch Arkaig and Loch Lochy, adjacent to the Great Glen Fault, within an area dominated by Loch Eil Group rocks, an anti-formal inlier exposes migmatitic interlayered psammites and semipelites with abundant calc-silicate layers and lenses. These are termed the Achnacarry Striped Formation' and are interpreted as Glenfinnan Group rocks (see Eas Chia-Aig Waterfalls GCR site report, this chapter). Lithologically and structurally they are equivalent to the Achnaconeran Striped Formation of the Moine Central area that occurs extensively farther north-east in Glen Moriston and Glen Urquhart.

Loch Eil Group

The Loch Eil Group is the youngest group of the Moine succession and is dominated by psammites. In many areas it is not divided into component formations, but where detailed work has been carried out, individual psammite and quartzite units have been delineated. The total thickness is estimated to be 4–5km (Strachan, 1985; Soper *et al.,* 1998). It consists mainly of feldspathic and siliceous psammites, with subsidiary micaceous psammite and semipelite interbeds and abundant calc-silicate rock lenses. Sedimentary structures are common, notably cross-bedding, but small-scale grading, convolute bedding, and ripple-lamination are also present (Strachan, 1985). Although the Loch Eil Group rocks are typically rather monotonous (e.g. Dalziel, 1966), in parts lenticular quartzite and feldspathic quartzite units up to 1500 m thick can be recognized (Stoker, 1983; Strachan, 1985). In addition around Loch a' Chrathaich, north of Glen Moriston, May and Highton (1997) mapped out three discrete semipelite units up to 100 m thick in the psammite sequence. In Glen Moriston it is suggested that the Loch Eil Group psammites may pass laterally and transitionally into the underlying Achnaconeran Striped Formation at their eastern margin (May and Highton, 1997).

At the western end of Loch Eil, the Glenfinnan Group-Loch Eil Group boundary is transitional from pelite to psammite over only 2–3m (Strachan, 1985). The state of strain is generally low here and cross-bedding has been recorded within 5 m of the contact. In many places members of the West Highland Granite Gneiss Suite occur along the Glenfinnan Group-Loch Eil Group boundary and hence obscure contact relationships (see for instance the Quoich Spillway GCR site report, this chapter). Nevertheless, transitional units have been recognized in several places. In the Quoich Dam area, transitional units are the Lower Garry Psammite Formation and the Gany Banded Formation (Roberts and Harris, 1983). The Lower Garry Psammite Formation contains excellent cross-beds, slump-folding and pebbly layers, admirably exposed in Coir' an t-Seasgaich [NH 077 035]. The overlying Garry Banded Formation consists of some 200 m of psammite, quartzite, gneissose pelite and semipelite inter-layered on the scale of 10 cm to 1 m. The Quoich Granite Gneiss separates the two formations and all the units contain concordant to locally discordant amphibolite sheets or dykes. The Loch Eil Group Upper Garry Psammite Formation, which consists of feldspathic and siliceous psammite with subordinate semipelite and pelite and calc-silicate lenticles, overlies the Garry Banded Formation. Sedimentary structures are present locally. When traced eastwards the Upper Garry Psammite and Lower Garry Psammite appear to converge to become a single unit.

Between Glen Dessarry, Loch Affric and Loch Loyne, the distinction between the Glenfinnan and Loch Eil groups is unclear. Around Loch Cluanie, Peacock *et al.* (1992) placed the Glenfinnan Group-Loch Eil Group boundary at the highest pelite unit or at the granite gneiss boundary. Thus, the psammite units of the Loch Loyne–Loch Cluanie areas were tentatively attributed to the Glenfinnan Group. However, to the south these psammites patently correlate with the Lower Gany Psammite of the Loch Eil Group and possibly also with the Garry Banded Formation. The 'Cluanie' psammites contain some pebbly layers, locally spectacular cross-bedding, magnetite-rich heavy-mineral bands and abundant calc-silicate lenticles. They are partly gneissose and are interlayered with subsidiary semipelite and pelite, which in places form discrete units (Roberts *et al.,* 1987; Peacock *et al.,* 1992). A similar problem occurs with the rocks that occupy the core of the F3 Glendessarry/Gleouraich Synform, which stretches some 40 km NNE from Glen Dessarry to Glen Affric. Surrounding the Glendessarry Syenite in the south are the psammites of the Loch Arkaig Psammite Formation, interpreted by Roberts *et al.* (1984) as the lower member of the Loch Eil Group. Farther north, between Loch Quoich and Glen Affric, the thick Easter Glen Quoich Psammite Formation occurs in the same synform. It consists of feldspathic and micaceous psammite with subsidiary semipelite and petite units. Quartzite layers are common and calc-silicate lenses are found in parts. In Glen Affric, a prominent quartzite is developed at the base. Although correlations have been made with the Loch Eil Group, the lithologies of the Easter Glen Quoich Psammite are atypical and show more similarites with the Glenfinnan Group sequence. The structure is complex with possible early (D1?) shear-zone dislocations, D2 and D3 thrusting and folding; in concert with sedimentary fades changes these may be responsible for the occurrence of the Glenfinnan Group psammites within the synform.

Neoproterozoic intrusive rocks

Several suites of intrusive rocks are found in the Moine (South) area, notably members of the West Highland Granite Gneiss Suite and meta-dolerites and metagabbros. Their distribution is shown in (Figure 8.1). These intrusive sheets and dykes were emplaced prior to the earliest deformation, and U-Pb zircon age dating has shown that both granitic and mafic bodies were intruded at *c.* 873 Ma (Friend *et al.,* 1997; Millar, 1999).

West Highland Granite Gneiss Suite

In the Moine (South) area thick sheets of deformed and locally migmatitic granitic gneiss, collectively known as the 'West Highland Granite Gneiss Suite', form disconnected but clearly related outcrops (Johnstone and Mykura, 1989). The sheets are concentrated along the Quoich Line around the Glenfinnan Group–Loch Ell Group boundary. Individual occurrences are termed the Ardgour (Sgurr Domhaill)', 'Sgitrr Mhurlagain', 'Quoich', 'Glen Doe' and 'Fort Augustus' granite gneisses. Its occurrence is described in the Fassfern to Lochailort Road Cuttings, Quoich Spillway and Glen Doe GCR site reports (this chapter). Sheets vary in thickness from < 1 m to over 1.4 km for the main Ardgour Granite Gneiss body. The granitic gneiss normally shows sharp contacts with the adjacent Moine rocks and locally contains metasedimentary xenoliths. The sheets are normally concordant with the bedding and main foliation, but its mapped outcrop shows that regionally it cuts across parts of the Moine stratigraphy (Figure 8.1). Granite gneiss sheets are commonly interleaved on a metre-scale with the Moine metasedimentary lithologies, particularly around the margins of the thicker sheets, for example west of Ceannacroc Lodge at [NH 202 106]. Examples of cross-cutting relationships occur in Glen Garry at [NH 134 028] (Peacock *et al.,* 1992).

The granite gneiss is a monzogranite consisting essentially of quartz, plagioclase feldspar (oligoclase), potash feldspar (perthitic rnicrocline) and biotite, with minor garnets (< 0.5 mm) and muscovite and accessory apatite, zircon, titanite and magnetite/ilmenite (May and Highton, 1997). Veins of leucogranite and quartz-feldspar pegmatite are present locally. There are abundant quartz, quartz-feldspar and granitic segregation veins with marginal biotite selvedges. These veins, together with aligned biotite and mafic aggregates, define an S1 gneissose foliation. This is folded by tight to isoclinal F2 folds, which also affect the larger sheets of granitic gneiss. The gneiss generally also contains a locally strong S2 foliation, which is typically composite with the earlier Si. The granite gneiss represents an early sheeted intrusion into the Moine succession that predated the main deformation and metamorphic episodes.

The geochemistry of the West Highland Granite Gneiss Suite classifies it as an S-type peraluminous granite, consistent with derivation by partial melting of semipelitic Moine rocks at deeper crustal levels (e.g. Gould, 1966; Barr *et al., 1985;* May and Highton, 1997). U-Pb zircon SHRIMP and TIMS studies have determined an emplacement age of the Ardgour and Fort Augustus granite gneiss bodies at 873 ± 7 Ma (Friend *et al.,* 1997) and 870 ± 30 Ma (Rogers *et al.*, 2001) respectively. Rogers *et al.* (2001) also obtained a 470 ± 2 Ma titanite age from the Fort Augustus body, interpreted as reflecting a Grampian metamorphic overprint.

Metadolerites and metagabbros

As in the northern and central Moine areas, mafic dykes or sheets, intruded prior to deformation and metamorphism, are locally common and form swarms in parts of the Moine (South) area. They are now largely amphibolites but were originally mainly dolerite sheets. Rarely, the mafic bodies still show doleritic textures. Particular concentrations occur along the Quoich Line, and in the eastern outcrop of the Loch Eil Group outcrop (May and Highton, 1997). Amphibolite lenses are also scattered throughout the Glenfinnan Group outcrop. They are generally schistose and garnetiferous, typically with biotite-rich margins, particularly in the pelitic lithologies.

In thin section the amphibolites consist of green-brown to blue-green hornblende, plagioclase (oligoclase to andesine) and quartz, with subsidiary titanite, epidote, biotite, garnet and ilmenite. Garnets locally range up to several centimetres across and tend to overgrow the earlier fabrics in the amphibolites. In parts the amphibolites are retrogressed to biotite-rich mafic schist.

Metagabbros typically form pods and lenticular sheets from < 1 m to some 20 m thick. They are only abundant in Glen Doe in upper Glen Moriston, where they intrude the Glen Doe Granite Gneiss. The critical relationships between the granite gneiss and the several distinct intrusive phases of the metagabbro and metadolerite are described in detail in the Glen Doe GCR site report (this chapter). The geochemistry of the metagabbros and meta-dolerites shows that they are tholeiitic and overlap with Mid-Ocean Ridge Basalts (Peacock *et al.,* 1992; Millar, 1999). The metagabbros also show evidence of contamination by granite or metasedimentary rocks (Millar, 1999). Zircons from the metagabbro have been dated by U-Pb TIMS method at *c.* 873 Ma (Millar, 1999). Although it is possible that the zircons originated from the nearby granite gneiss, the date is interpreted as an emplacement date of the metagabbro, implying that the protoliths of granite gneiss and the metagabbro were intruded essentially contemporaneously. This is supported by field relationships at Glen Doe (see GCR site report, this chapter) and at Quoich Spillway, where a xenolith of Moine metasedimentary rock in the Quoich Granite Gneiss contains hornblende schist. If the 873 Ma age obtained from zircons from the metamorphic segregations in the granite gneiss at Glenfinnan also reflects the formation of the main foliation (Barr *et ed.,* 1985; Friend *et al.,* 1997), then a metamorphic event must have occurred immediately following emplacement of the granite and mafic bodies.

Pegmatites

Pegmatite bodies are abundant within semipelitic and pelitic rocks of the Morar Group and Glenfinnan Group. They range from single pegmatitic granite veins (e.g. at Ardnish peninsula, Loch Ailort), to zones of pegmatite pods as at Knoydart Mica Mine (see GCR site report, this chapter), and areas of extensive pegmatite veining (e.g. Sgurr Breac, North Morar). Although pegmatite generation undoubtedly related to several different orogenic events, early isotopic dating by Giletti *et al.* (1961) and Long and Lambert (1963) showed that several of the pegmatites were of Precambrian age. Rb-Sr muscovite ages of 690–750 Ma from these pegmatites were interpreted as indicating the age of metamorphism in the Moine rocks. Isotopic dating using the Rh-Sr mica and U-Pb zircon and monazite systems has confirmed their Neoproterozoic age and suggested that the pegmatites are mostly related to a Knoydartian tectonometamorphic event (van Breemen *et al.,* 1974; Powell *et* al., 1983; Rogers *et al.,* 1998). Rogers *et al.* (1998) obtained U-Pb TIMS monazite ages of 827 ± 2 Ma and 784 ± 1 Ma from the Ardnish and Sgurr Breac pegmatites respectively. These ages appear to link to Sm-Nd garnet ages of 820–790 Ma that Vance *et al.* (1998) obtained from the Morar Pelite Formation.

Notable Neoproterozoic pegmatite occurrences have been described at Knoydart, Sgurr Breac, Kinloch Hourn, Ardnish and Loch Eilt in the Moine (South) area, and except for Ardnish they are described in the relevant GCR site reports. Although these larger pegmatite bodies are granitic, the more-abundant smaller segregation veins are commonly leucotonalitic (formely termed 'trondhjemite'). Johnstone and Mykura (1989) assigned these pegmatitic leucotonalite bodies to the Loch Shiel Migmatite Complex and showed that they related to their parent lithology and reflected the metamorphic grade of the host rocks. Prominent large masses occur immediately east and south-east of the head of Loch Morar [NM 880 903]; on Beinn Gharbh and Sgurr an Ursainn [NM 880 870]; on Meall a' Choire Dhuibh [NM 923 984] at the head of Loch Quoich; and on Beinn Odhar Mor [NM 851 791], south-west of Glenfinnan (Figure 8.1). Some of these segregation veins and related larger pegmatitic leucotonalite bodies may be of Neoproterozoic age, but most are probably of Ordovician age. They relate spatially to the zone of sillimanite-grade metamorphism that accompanied the Grampian Event in the Glenfinnan Group and upper Morar Group rocks of the 'Steep Belt'.

Caledonian intrusions

Caledonian intrusions range from major plutons to dyke swarms and from mafic to felsic; some were deformed during the Caledonian Orogeny, others are undeformed. The structures in the igneous bodies, their mutual relationships, and their emplacement ages, allow documentation of the different stages of the Caledonian Orogeny in the North-west Highlands. The distribution of the major plutons, granitic vein-complexes, and microdiorite and porphyritic microgranodiorite (the 'Main Felsic Porphyrites') dykes and sheets is shown on (Figure 8.5). Johnstone and Mykura (1989) give good summaries of the different intrusive elements, and Strachan *et al.* (2002a) provide a more-recent review Stephenson *et at.* (1999) described some of the major intrusions in the GCR Volume *Caledonian Igneous Rocks of Great Britain,* and

Smith (1979) provided a summary of the minor intrusions of the Northern Highlands.

Major intrusions

The Glendessarry Syenite has been dated at 456 ± 5 Ma (U-Pb zircon, van Breemen et ed., 1979b). It consists of an outer mafic syenite and a younger, inner felsic syenite (Richardson, 1968; Fowler, 1992). The syenite has a strong, steeply SW-plunging lineation (L3). There are several large pelite and metalimestone xenoliths in the syenite and patches of pegmatitic granite. The pelitic xenoliths locally contain sillimanite and kyanite. Other xenoliths contain tight minor folds. The xenoliths cannot be matched with the surrounding psammite envelope, which was assigned by Roberts *et al.* (1984) to the Loch Arkaig Formation (Loch Eil Group). The intrusion is interpreted as an original sheet-like body now occupying the core of a curvilinear F3 synform (Roberts *et al.,* 1984; Johnstone and Mykura, 1989).

The Glen Scaddle Intrusion and petrologically related Glen Loy intrusions together with the Clunes Tonalite, lie adjacent to the Great Glen. The Glen Scaddle (6.5 km x 3 km) and adjacent Glen Muic intrusions in Ardgour consist of gabbros and subsidiary diorites with varying degrees of amphibolitization (Dreyer, 1940). The lithologies are locally appinitic and have transitional complex marginal phases. They are variably sheared with fine-grained amphibolite developed in the shear zones. Loch Eil Group :gneissose feldspathic psammite and semipelite surround the intrusions with transitional igneous-sedimentary 'hybrid' rocks commonly present. The intrusions contain xenoliths of graphitic pelite, psammite, metalimestone and calc-silicate rock with some small pods of serpentinite (Johnstone and Mykura, 1989). Stoker (1983) noted that the intrusion lay in the core of the Glen Scaddle Synform and its internal foliation generally lay sub-parallel to local 'F2' fold axial planes. However, the accompanying coarse lineation lay consistently at a high angle to 'F2' fold axes and related 12' lineations in the adjacent Moine rocks. Stoker agreed with Dreyer (1940) that contact metamorphic diopside, sillimanite and cordierite in the country rocks overprint the regional metamorphic mineralogy, which he attributed to a 'D1' episode. Thus, Stoker (1983) interpreted the intrusions as pre-'D2' in age. However, the intrusions appear to have only undergone partial structural and metamorphic modification internally, and a U-Pb TIMS zircon age of 426 ± 3.2 Ma for the intrusion of the Glen Scaddle metagabbro obtained by Strachan and Evans (2008) suggests that the deformation and metamorphism were coeval with major movements along the Great Glen Fault and may relate to the Scandian Event. Hence, emplacement appears to post-date the main D2 deformation and metamorphic events seen elsewhere in the Moine outcrop. Strachan and Evans (2008) propose that the deformation in the intrusion relates to the main upright 'Steep Belt' folding, normally termed 'D3', and that this event is Scandian in age.

The Glen Loy Complex (5 km x 3.5 km) lies farther north in Lochaber and consists of hornblende gabbro, with appinitic and dioritic variants (Johnstone and Mykura, 1989). The gabbro body is unfoliated and shows igneous compositional layering. Rarely xenoliths of hornfelsed garnet-cordierite-staurolite-bearing pelite are present. The surrounding Loch Eil Group psammites are veined, hornfelsed, metasomatized and locally contain sillimanite.

Thick masses of pegmatitic granite cross-cut the southern part of the gabbro and the adjacent psammites. Dykes and sheets of the late Silurian Microdiorite Sub-suite and granitic veins of the Banavie Vein-Complex both transect the Glen thy Complex. Regional dips in the adjacent Loch Eil Group psammites suggest that the complex lies in a synform. No age dating has yet been undertaken on this body.

The Clunes Tonalite forms a roughly triangular-shaped body (4 km x 2.3 km) above Loch Lochy, adjacent to the Great Glen Fault. The tonalite is generally homogeneous, but with variable biotite and hornblende content. Where biotite-rich, a steep SW-dipping planar foliation is dominant; where hornblende is present, plagioclase and hornblende form the prominent shallow NW- or SE-plunging lineation. Stewart *et al.* (2001) interpreted the internal fabrics to result from deformation during emplacement, linked to sinistral movements on the Great Glen Fault. They obtained a U-Pb zircon TIMS age of 427.8 ± 1.9 Ma, which they interpreted as dating emplacement of the intrusion.

The Strontian Pluton forms a teardrop-shaped outcrop some 26 km long immediately northwest of the Great Glen Fault in Morvern and Ardgour (Sabine, 1963, and Loch Sunart GCR site report in Stephenson *et al.*, 1999). It consists of an outer hornblende granodiorite phase (the Loch Sunart Granodiorite), dated at 425 ± 3 Ma (Rogers and Dunning, 1991) and an inner biotite granodiorite and granite phase (the Glen Sanda Granodiorite Intrusion-swarm), dated at 418 ± 1 Ma (Paterson *et al.,* 1993). The pluton has a 3 km-wide sillimanite-bearing thermal aureole whose mineralogy indicates that the outer phases of the pluton were intruded at pressures of around 4 kbar (Ashworth and Tyler, 1983). The pattern of the pre-consolidation foliation has been interpreted to imply that the pluton was emplaced during both sinistral and dextral movements along the Great Glen Fault (Hutton, 1988).

The undeformed Ross of Mull Granite Pluton forms a broadly ovoid outcrop some 10.5 km x 6.5 km at the south-western extremity of the mainland part of North-west Highlands (Bailey and Anderson, 1925; Zaniewski *et al.,* 2006). The Cnoc Mor to Rubh' Ardalanish GCR site report in Stephenson *et* al. (1999) described the intrusion itself, whereas the thermal aureole of the pluton is described in the Ardalanish Bay GCR site report in this chapter. The outer parts of the pluton consist of muscovite-biotite granite, but this grades inwards to a potash-feldspar-phyric granite locally with minor diorite enclaves. Its eastern margin is a sheeted complex of granite and Moine rocks. Moine xenoliths are abundant in the pluton and a ghost Moine stratigraphy is readily traceable (Holdsworth *et al.,* 1987). The aureole, which reaches over 500 m wide, contains all three aluminosilicates, but not all at the same locality. Halliday *et al.* (1979) obtained an Rb-Sr mineral-whole-rock age of 414 ± 3 Ma for the outer biotite granite, but this is thought to date uplift rather than emplacement.

The Cluanie Granodiorite Pluton is an undeformed, 'keyhole-shaped' pluton some 7 km long and 4 km wide, centred on the eastern part of Loch Cluanie (Figure 8.5). It consists essentially of hornblende granodiorite with varying amounts of megacrystic potash feldspar. Non-megacrystic granodiorite occurs marginal to the eastern and southern contacts. Along the eastern contact, aplitic granite, leucogranite and quartz-feldspar pegmatite veins are abundant (Leedal, 1952; Peacock *et al.,* 1992). The contacts with the adjacent Moine rocks are sharp, locally discordant, and normally dip moderately to steeply outwards from the pluton. Evidence of stoping and roof pendants has been recognized, for example on Creag na Mairt [NH 175 115] (Peacock *et al.,* 1992). The intrusion has been dated at *c.* 417 Ma (Pidgeon and Aftalion, 1978), but Powell *et* al. (1983) reported an age of 425 ± 4 Ma, which corresponds with other members of the Argyll and Northern Highlands Suite. This older age would also accord with the observations that sheets and dykes of the regionally extensive Microdiorite Sub-suite cross-cut the Cluanie Pluton (Peacock *et al.,* 1992), but pre-date the Strontian Pluton. These relationships imply that the intrusion of the main granodiorite plutons and the dykes and sheets of the Microdiorite Sub-suite are closely related and probably late Silurian in age.

Minor intrusions

A summary listing of the Caledonian and later minor intrusions in the central and southern Moine areas is shown in (Table 7.1) (Chapter 7). In the Moine (South) area there are notable concentrations of granitic vein-complexes, microdiorite sheets and dykes, appinitic rocks, and porphyritic microdiorite dykes. In addition there are numerous Permian-Carboniferous dykes and irregular intrusions, and abundant Palaeogene mafic dykes. Note that for the purpose of clarity the minor intrusions are omitted from (Figure 8.1) and from many of the individual GCR site figures. (Figure 8.5) attempts to portray the distribution of the more-abundant dyke-swarms and intrusions. Their importance is that they record the waning phases of the Caledonian Orogeny and provide evidence of the post-orogenic pattern of uplift (see ((Table 7.1)), Chapter 7).

Within the gneissose to migmatitic semipelitic and pelitic units of the Moine succession, quartz and quartz-feldspar pegmatite veining is normally developed. The veins and pods are mainly leucotonalite (quartz-oligoclase feldspar-biotite), although locally they are granitic. In parts of the Glenfinnan Group, the veining forms lit-par-lit migmatites (see Johnstone and Mykura, 1989), and locally areas of pegmatitic leucotonalite veining are extensive (e.g. in Ile Choire at the head of Loch Morar). The occurrence of leucotonalite veining clearly reflects the middle amphibolite-facies metamorphic grade and semipelitic nature of the host Moine rocks and relates to the penetrative D2 and D3 deformations. As noted above, the age of pegmatitic veining is not always clear as appropriate metamorphic conditions were attained in both Neoproterozoic and Ordovician times, and thus it is difficult to assess the relative ages of the pegmatite bodies at outcrop. Although the Neoproterozoic veins are commonly more pervasively foliated and finer grained than their later Ordovician relatives, even the later pegmatitic granite veins show some folding and internal fabrics. However, the larger Caledonian pegmatites commonly cross-cut earlier quartz and quartz-feldspar pegmatite veins and schistosities that relate to the D2 deformation.

The Silurian granite vein-complexes (see (Table 7.1)) range markedly in size, with the Glen Garry Vein-Complex covering some 300 km^2, whereas the Loch Arkaig and Mallie complexes cover only some 40 km^2 and 20 km^2 respectively (Figure 8.5). Small granodiorite bodies are present in many complexes, implying the presence of plutons or magmatic sources at depth. Lithologically the veins and sheets range from quartz-diorite to granite and leucogranite and texturally from aplitic to medium-grained and pegmatitic. The Glen Garry Vein-Complex consists mainly of granodiorite veins and larger bodies, but shows a range from quartz-diorite to leucogranite. The veins cross-cut the microdiorite dykes and sheets, both foliated and unfoliated, but some veins are cross-cut by porphyritic microgranodiorite dykes (formerly termed 'Main Felsic Porphyrites'). The Loch Eil, Loch Arkaig and Mallie vein-complexes are granitic with veining of variable density. Their granitic veins are cross-cut by foliated microdiorites. The Banavie Vein-Complex consists of granite and pegmatitic leucogranite veins and masses. The pegmatitic leucogranite veins are cross-cut by microdiorite sheets and dykes and may well be an extension of the Loch Eil or Loch Arkaig complexes. In contrast the red granite veins are later as they cross-cut the microdiorites.

Intrusions of the Microdiorite Sub-suite are wide-ranging in the Cluanie and Glen Moriston area and farther south (Smith, 1979). They form generally SE-dipping sheets, and their igneous mineralogy consists of zoned andesine and hornblende (commonly forming phenocrysts) with biotite and subordinate interstitial quartz and potash feldspar. They cross-cut the Cluanie Pluton, but are commonly sheared and carry a strong marginal or at times penetrative schistosity or foliation. Talbot (1983) suggested that some earlier members of the sub-suite were folded (e.g. by Glenfinnan and at Loch Sunart) and that intrusion may have overlapped with the F3 deformation episode. However, their generally discordant contacts, fine-grained margins and geochemical coherence suggest that is unlikely unless the D3 deformation is Scandian (see 'Metamorphism and isotopic dating', below). May and Highton (1997) recognized an earlier foliated and later non-foliated swarm of microdiorites in the Invermoriston district, but showed that their geochemistry is similar. Between Loch Arkaig and Loch Garry the microdiorites have crenulated margins and feldspar phenocrysts are flattened and recrystallized and thin pegmatite veins tightly folded within the sheets. The pattern of metamorphic assemblages in the microdiorite sheets and dykes ranges from greenschist-to lower-amphibolite-facies reflecting the amount of uplift since their intrusion. In the western fringe to the Moine (South) area the microdiorites either show unmodified igneous assemblages, or have recrystallized under greenschist-facies conditions. Albite, pale-green muscovite, actinolite, epidote and carbonate minerals are developed. In most of the area the microdiorites have recrystallized under lower amphibolite-facies conditions giving the typical mineral assemblage: oligoclase ($An_{20–30}$), green hornblende, biotite and sphene. The porphyritic microgranodiorites (formerly 'Main Felsic Porphyrites') show a similar pattern but are restricted to a central 7–20 km-wide zone that stretches south-west from the Cluanie Pluton to Loch Shiel and the Sound of Mull at Loch Aline ((Figure 8.5); Johnstone and Mykura, 1989). In the Invermoriston district May and Highton (1997) described a continuum from mafic microdiorites dominated by green-brown hornblende with rare relict clinopyroxene through to granodiorites dominated by andesine and oligoclase.

The Appinite Suite has petrological and geochemical affinities with the Microdiorite Sub-suite, but the main concentrations of appinitic diorite and related ultramafic bodies apparently relate to the Strontian and Cluanie plutons. Fowler and Henney (1996) interpreted the suite to represent a primary shoshonitic magma of mantle derivation, linked closely to the calc-alkaline plutons. In places appinites cluster near major faults or are associated with breccia pipes, for example in Glen Garry (May and Highton, 1997).

Dykes of the Lamprophyre Sub-Suite (formerly 'Minette Suite') trend predominantly east–west and consist mainly of minette with augite and biotite phenocrysts. The southern edge of the Ratagain Dioritic-syenitic Pluton extends south into Knoydart and prominent individual dykes are found on the Ardnish peninsula (Loch Ailort) and in Moidart. The lamprophyres cut the Strontian and Ross of Mull plutons and are an important marker in the structural sequence.

Quartz-dolerite dykes and small bosses of Permo-Carboniferous age occur locally in the southern Moine area. More abundant are similar-age camptonite and subsidiary monchiquite dykes that Rock (1983) separated into three major swarms (Morar, Eil-Arlcaig, and Ardgour) and a minor swarm (Iona-Ross of Mull). Basalt and dolerite dykes of the North British Palaeogene Dyke Suite are also common. These dykes are typically up to 10 m wide and normally trend north-west; the majority belong to the Mull, Muck-Ardnamurchan, and Skye swarms.

Structure

Structural models for the southern Moine area divide the overall Moine succession into three major nappes, the Moine, Knoydart and Sgurr Beag nappes in structurally ascending order (Barr *et al.,* 1986). The Sgurr Beag Nappe can be divided into a western 'Steep Belt', where the structural pattern is dominated by upright F3 folding, and an eastern 'Flat Belt', where D3 deformation is generally much weaker and the overall bedding and foliation are normally gently dipping. The 'Steep Belt' corresponds roughly with the outcrop of Glenfinnan Group rocks and the 'Flat Belt' with the outcrop of Loch Eil Group rocks.

Although structural patterns have been mapped and structural chronologies recognized widely across the Moine outcrop, it is not a simple matter to translate the structural picture from one area to another. Powell (1974) correlated his stratigraphy and structure from the Morar-Loch Eilt area with that from the Kinloch Hourn (Tanner, 1971) and Moidart-Ardgour (Brown *et al.,* 1970) areas, showing that there was broad agreement on the nature of the main deformation phases D1, D2 and D3. However, even with the acquisition of considerable geochronological data over the past 30 years the age and tectonic significance of the different deformation phases still remain unclear. The main D2 phase has been variously ascribed to the Knoydartian (720–800 Ma), or Grampian (490–450 Ma) events. Similarly, the D3 phase has been attributed to either the Grampian Event or the Scandian (440–420 Ma) Event (see Strachan *et al.,* 2002a for recent summary).

D1 deformation

As in the Moine rocks farther north, this episode is manifest mainly as a bedding-parallel foliation. Tight to isoclinal, minor F1 folds have only been confirmed where they are refolded by F2, resulting in F1–F2 fold interference patterns. However, D1 is deemed partially responsible for interleaving of Lewisianoid basement and Moine cover rocks in the Morar region. Although thrust structures of D2 age can be identified readily in parts of the southern Moine area, D2 structures are locally seen to fold Lewisianoid-Moine contacts or pre-existing tight to isoclinal folds. In these circumstances the Lewisianoid rocks have been portrayed either as thrust sheets of basement or as isoclinal F1 fold cores. The best examples occur in the Morar Antiform and farther east around Ardnamurrach (see North Morar GCR site report, this chapter). Powell (1974) noted that if the Lewisianoid rocks at Ardnamurrach do lie in a fold core, this core is itself isoclinally folded and the whole structure refolded by D2 folds. This seems unlikely and a combination of D1 thrusting and localized F1 and F2 folding would explain the observed relationships somewhat better. Similarly, the presence of shear zones in the Morar Antiform would explain the primary basement-cover interleaving more simply. However, farther north by Attadale on Loch Hourn, Ramsay (1957b) described the extensive refolding of early F1 isoclines involving Lewisianoid basement and Moine cover (see Rubha Camas na Cailinn GCR site report, Chapter 7). O'Brien (1981) also described tight to isoclinal F1 folds and associated muscovite-rich platy zones from low-strain areas in psammitic units of the Morar Group in Ardnamurchan.

In other areas the D1 event does not seem to have resulted in major folding, but it probably marks a time of movement along some of the main shear-zones in the Moine succession, particularly in the Glenfinnan Group rocks. The accompanying metamorphic conditions are difficult to ascertain; in the Morar area they probably attained upper-greenschist or lower-amphibolite facies (see 'Metamorphism and isotopic dating', below).

D2 deformation and the Sgurr Beag Thrust

As in the Moine (North) and Moine (Central) areas, the D2 deformation phase resulted in the most pervasive structures in the Moine and Lewisianoid rocks. Minor and major folds, related mineral lineations, and a prominent foliation are all common. Peak-metamorphic minerals define the foliation and commonly the L2 lineation, which is generally parallel to F2 minor fold axes. Hence the D2 deformation and main metamorphic mineralogy appear to be closely related. Quartz, quartzofeldspathic and leucotonalite veins have been generated widely during the D2 deformation episode.

Generally, F2 folds are tight with a well-developed axial-planar foliation (S2), and range in amplitude and wavelength from a few millimetres to several kilometres. Although they are the most significant and abundant structures in the area, the overall outcrop pattern is normally strongly controlled by F3 folds. The S2 foliation is typically a penetrative cleavage or schistosity, in most F2 fold hinges it is manifest as a new discordant mica fabric. However, in some pelitic rocks S2 forms a crenulation cleavage affecting S1 and the bedding fabric. S2 mostly dips moderately to steeply east to south-east, except where refolded by F3 or later folding (Brown *et al.,* 1970; Powell, 1974). In Morar and in the 'Flat Belt', S2 dips are typically gentle and F2 fold-axis orientations are variable but mostly plunge gently to moderately northwards and southwards, dependent on later folding. F2 folds in the 'Steep Belt' are commonly reclined and their axial orientations are very variable. Around Kinloch Bourn, F2 axes consistently plunge to the south-east and SSE.

D1–D2 relationships are well seen at Glen Doe (see GCR site report, this chapter), where amphibolitic mafic sheets have intruded the Glen Doe Granite Gneiss. F2 recumbent folds, with a prominent axial-planar penetrative schistosity (S2), fold an earlier S1 foliation in the gneissose granite and S1 schistosity in the amphibolites (Millar, 1999).

The main thrusts, such as the Sgurr Beag Thrust and the Knoydart Thrust are attributed primarily to D2. The largest structural dislocation in the southern Moine area is the Sgurr Beag Thrust, originally recognized and mapped by Tanner (1971) in the Kinloch Bourn area and featured in the Kinloch Houm and Lochailort GCR sites. The thrust consistently separates Morar Group rocks in the footwall from Glenfinnan Group rocks in the hangingwall, and over considerable distances its trace is parallel to stratigraphical boundaries. Locally, however, formations are truncated, such as the Reidh Psammite Formation in the hangingwall south of Kinloch Bourn. As noted above, near Loch Sunart the Salen Pelite and Resipol Striped formations in the footwall appear also to be truncated by a lateral ramp of the Sgurr Beag Thrust (Roberts *et al.,* 1987).

The Sgurr Beag Thrust is marked by a zone of increasing ductile strain, tens to hundreds of metres wide (Rathbone and Harris, 1979), and by Kinloch Bourn small lenses of Lewisianoid gneisses mark its position. Both major and minor F3 folds fold the trace of the Sgurr Beag Thrust, most notably the Glenshian Synform and Loch Eilt Antiform in the Loch Eilt–Loch Morar area. Although the Sgurr Beag Thrust is contiguous with minor D2 structures and is generally regarded as a dominantly D2 structure, Powell *et al.* (1981) showed that the regional metamorphic zonation was disrupted by late-stage (i.e. Caledonian) translation across the thrust and attributed this movement to the regional D3 episode. Baird (1982) documented the F3 fold pattern around Lochailort and showed that the thrust appeared to relate to D3 strain patterns and F3 fold geometry. However, he also noted that the thrust truncated the axial planes of significant F3 folds (e.g. the Ranochan Synform), and suggested that thrust movement outlasted the D3 event. Structural and metamorphic considerations suggest that thrust movement must have occurred along a relatively low-angle structure that dipped gently eastwards (Powell *et al.,* 1981; Barr *et al.,* 1986). The age of the Sgurr Beag Thrust and its relationship to peak metamorphism has long been a contentious issue. The thrust has been inferred to have been generated before (Tanner, 1971), coeval with (Powell *et al.,* 1981; Tanner and Evans, 2003), or after (Baird, 1982; Rathbone *et al.,* 1983) peak metamorphism. Its age has been variously interpreted to be Caledonian (Barr *et al.,* 1986) or Knoydartian (Piasecki and van Breemen, 1983; Tanner and Evans, 2003). It seems clear that the Sgurr Beag Thrust is the site of early ductile displacement of considerable magnitude followed by more-defined ductile thrusting that relates to the Caledonian deformation episodes.

The Knoydart Thrust emplaces higher metamorphic grade rocks over lower-grade rocks, but the Morar Group stratigraphy can be matched across the structure, implying that only a moderate amount of translation has occurred (Barr *et al.,* 1986). The trace of the Knoydart Thrust south of Loch nan Uamh is somewhat speculative, but further discrete thrusts are present in the underlying Moine Nappe in North Morar (see GCR site report, this chapter), and thrusts or dislocations also occur in the Morar Group succession farther south in Moidart and Ardnamurchan (O'Brien, 1981). In the Moine (Central) area, large Lewisianoid inliers commonly occur in the hangingwall of the main thrusts. However, except along the Sgurr Beag Thrust by Kinloch Hourn and in the Morar Antiform, Lewisianoid inliers are absent from the Moine (South) area.

D3 deformation

F3 structures vary from centimetre- to kilometre-scale, open to tight folds that control much of the overall outcrop pattern of the Moine succession. Locally, a penetrative or crenulation cleavage (S3) is developed, best seen in fold hinge zones, dependent on the degree of D3 strain and the lithology. D3 structures formed under lower- to upper-amphibolite-facies conditions, commonly accompanied by formation of quartz-feldspar pegmatite segregations, locally emplaced preferentially along F3 fold axial planes. In places, F3 folds are associated with shear zones, but in most areas the F3 structures fold the major D2 shear-zones, at least locally. Brown *et al.* (1970) showed a western front of F3 major folding stretching north from the western end of Loch Moidart to Loch Ailort. Examples of D2 structures folded by F3 folds are abundant throughout the area. Good examples of D2–D3 fold interference patterns are described and illustrated in the Kinloch Hourn, North Morar, and Fassfern to Lochailort Road Cuttings GCR site reports (this chapter). F3 fold axes are locally curvilinear on a small- to medium-scale, reflecting D3 strain variations and the complex F2 and earlier geometry.

The large-scale periclinal Morar Antiform dominates the structural pattern in the Morar area (see North Morar GCR site report, this chapter). The antiform folds the lower part of the Morar Group succession and the inthrust and folded lenticular Lewisianoid gneiss inliers. Regionally, the antiform appears to be a simple structure but in reality it has a complex profile. Normally it has been interpreted as a major F3 fold (Poole and Spring, 1974), but Powell (1974) attributed its formation to D2 on the basis of its associated minor structures and the overall structural geometry, whereas Tanner (1971) attributed related folds to F4 (although confusingly, he termed them 'F3'). Kennedy (1955) documented the main lineation pattern (L2), which apparently pre-dates the antiform. Although most authors have interpreted the overall periclinal Morar Antiform as an F3 structure, the presence of thrust and folded Lewisianoid rocks suggests that it may also represent an earlier structural culmination. Corresponding synforms (Ladhar Bheinn/Ben Sgriol Synform) and antiforms occur to the east, and offset antiformal structures lie to the north (Loch Hourn Antiform) and to the south.

D4 and later phases

Within the Moine succession are identifiable phases of late-stage open to close folds, commonly termed 'F4'. The folding and related cleavages and lineations are variably developed and confined to specific areas. In some semipelitic and pelitic units, S4 crenulation cleavages are developed. Biotite has recrystallized in the S4 cleavages, suggesting that metamorphic conditions were at least at greenschist facies. Powell (1974) recognized a phase of open folding with related subvertical crenulation cleavage development in Knoydart, Morar and Lochailort, here tentatively re-assigned to D4. Note that Powell (1974) correlated his F4 folds with the similarly orientated NNW-trending F3 folds of Tanner (1971) around Kinloch Hourn. In Ardnamurchan, conjugate sets of F4 folds occur (Powell, 1974; O'Brien, 1985).

Brown *et at.* (1970) described F4 open folding and localized S4 crenulation cleavage development in the 'Steep Belt' near Loch Shiel, but F4 folds are difficult to distinguish here as they are effectively coplanar with the F3 and earlier structures. In contrast, Strachan (1985) recognized open to close F4 folds with sub-vertical N-trending axial planes in Loch Eil Group rocks around Loch Eil itself. Here the F4 folds refold earlier F3 folds and control the outcrop pattern in the Loch Eil Group rocks of the 'Flat Belt'.

NW-trending open F4 folds and related crenulation cleavages in pelitic lithologies occur close to the Cluanie Pluton and possibly relate to its intrusion (Peacock *et al.,* 1992). Steeply dipping ENE- and E-trending open F4 folds, locally associated with a prominent S4 crenulation cleavage, also refold D3 and earlier structures in Glen Affric.

Strachan (1985) also recognized a later set of NW-trending open F5 folds that warp and refold earlier structures near Kinlocheil. The fold axes plunge gently east or south-east and have sub-vertical axial planes that trend north-west. Only minor local late-stage monoclines, box folds and kink bands are recorded in the platy psammitic Moine rocks of the Ross of Mull (Holdsworth *et al.,* 1987). No obvious mineral growth is associated with these structures.

Metamorphism and isotopic dating

In their summaries of the metamorphic facies in the Moine succession, Winchester (1974) and Fettes *et al.* (1985) showed that the metamorphic pattern in the Moine outcrop is complex, both in time and space. The metamorphic grade has been determined either by Barrovian index minerals in the relatively sparsely distributed pelitic lithologies (e.g. garnet, kyanite, sillimanite) or by the mineralogy of calc-silicate lithologies (Kennedy, 1949; Tanner and Evans, 2003). Although several distinct phases of metamorphism are superimposed (Lambert *et al.,* 1969; Powell *et al.,* 1981), in general the metamorphic grade increases from greenschist facies in the west to middle- and locally upper-amphibolite facies in the central and eastern parts of the Moine (South) area (Figure 8.6). The lowest-grade, greenschist-facies metamorphic rocks occur in the south-western part of Ardnamurchan. Most of Morar, western Knoydart, and western Ardnamurchan lie in the epidote-amphibolite facies (garnet, biotite grade). Farther east are lower- and middle-amphibolite-facies rocks (kyanite grade), with distinct jumps in metamorphic grade apparently corresponding to the Knoydart and Sgurr Beag thrusts (Powell *et al.,* 1981; Barr *et al.,* 1986). The highest grades are reached in the Glenfinnan–Ardgour area where middle amphibolite-facies assemblages (silli-manite grade) and gneissose pelites are present. The metamorphic grade falls off again eastwards over much of the 'Flat Belt', but this appears to be a result of late-stage retrogression superimposed on earlier higher-grade assemblages.

Isotopic age dating of metamorphic minerals and detailed microprobe studies has only recently revealed a clearer picture of the metamorphic history. Vance *et al.* (1998) obtained Sm-Nd ages from zoned garnets in schistose pelites in the Morar–Lochailort area. The garnet cores gave ages of 814–823 Ma and the middle zone of a large garnet from Polnish gave an age of 788 ± 4 Ma. Unfortunately, they were unable to date the narrow outermost garnet zone. Vance *et al.* (1998) used geobarometry to conclude that garnet growth commenced between D1 and D2 under pressures of 5 kbar and temperatures of 540° C, with pressures eventually rising to over 11 kbar and temperatures to over 700° C.

In large garnets from the 'big garnet' rock from the Glenfinnan Group in Glen Doe, Zeh and Millar (2001) recognized four distinct compositional phases, each containing varied mineral inclusions. Detailed studies of the garnet and included mineral compositions revealed a complex P-T history. The data suggested that the P and T conditions for the four phases were 4–6kbar, 55W-560° C; 6–8.5 kbar, 56W-575° C; 5–8kbar, 640° C; and 5 kbar at 670° C. The oldest, relatively low-pressure phase is compatible with crustal extension or contact metamorphism and may relate to the *c.* 870 Ma intrusion of the West Highland Granite Gneiss Suite. The higher-pressure phase 2 implies crustal stacking and rotational strain and probably relates to the D2 deformation phase. Phase 3, again compressional, followed a cooling and uplift event and the last stage showed final heating. The Caledonian late-stage retrogression is recorded only as crack infillings in the garnet. Epidote, chlorite, calcite, plagioclase and magnetite are recorded as inclusion phases in the garnet.

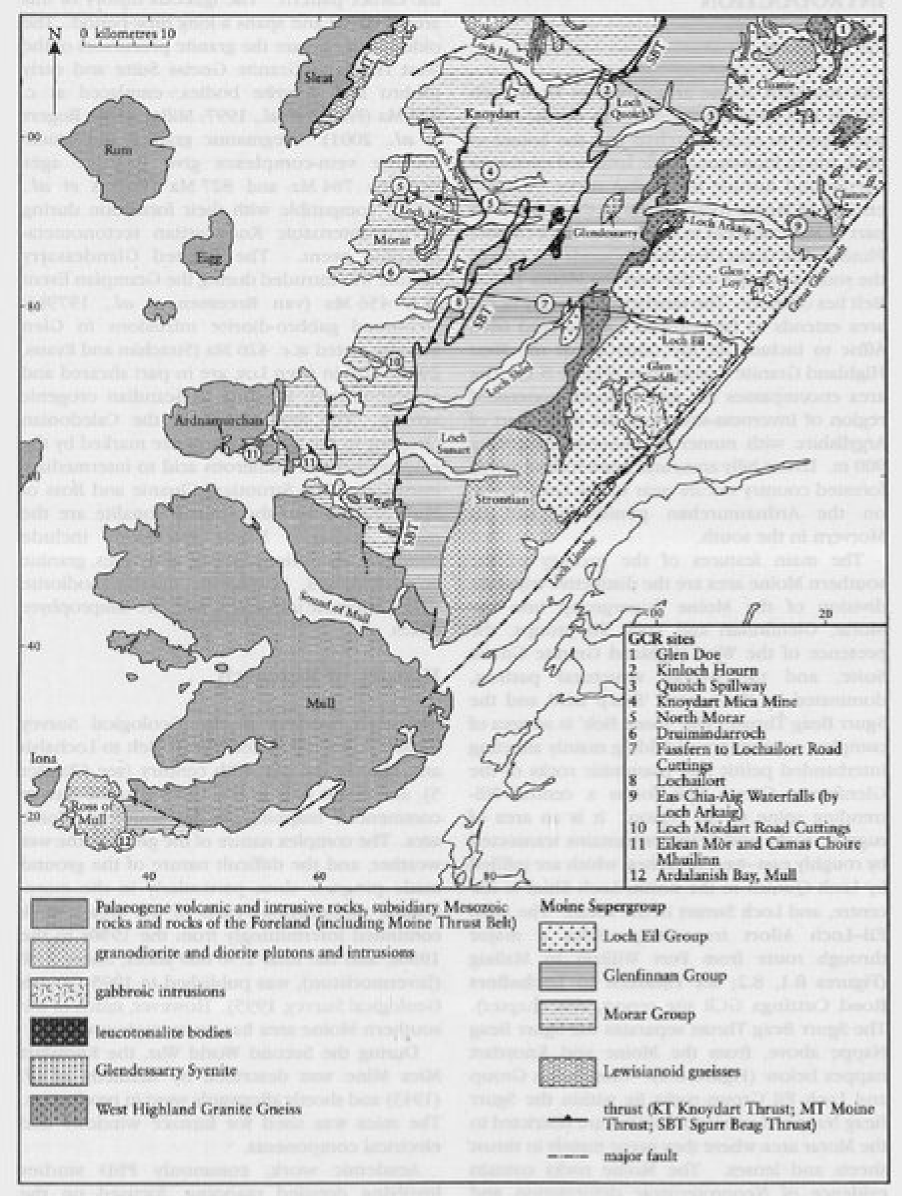
Tanner and Evans (2003) dated metamorphic titanites from calc-silicate layers in the Morar Pelite Formation near Loch Eilt at 737 ± 5 Ma and 751 ± 14 Ma (U-Pb TIMS). They argued that the titanite was part of the peak metamorphic assemblage in the Morar Group rocks immediately beneath the Sgurr Beag Thrust. The bytownite/anorthite + hornblende assemblages in these rocks formed under middle amphibolite-facies conditions (moderate P, T of *c.* 660° C). Together with ages of pegmatites from Loch Eilt (van Breemen *et al.,* 1978), Sgurr Breac and Knoydart (Rogers *et al.,* 1998), these ages imply that the main metamorphic episode in the Moine rocks of Morar occurred around 750 Ma. Later Grampian and possible Scandian metamorphic events are superimposed on this earlier pattern. The garnet studies of Zeh and Millar (2001) and a zircon U-Pb TIMS age date of 727 ± 6 Ma from migmatitic rocks in Glen Urquhart (Emery *et al.,* 2004) suggest that this event also affected Glenfinnan Group and Loch Eil Group rocks.

Grampian metamorphic events are signified by a U-Pb titanite age of 470 ± 2 Ma from the Fort Augustus Granite Gneiss at Ton a' Choiltreich (Rogers *et al.,* 2001) and a U-Pb monazite age of 455 ± 3 Ma from the corresponding Ardgour Granite Gneiss at Glenfinnan (Aftalion and van Breemen, 1980). The *c.* 456 Ma Glendessarry Syenite (van Breemen *et al.,* 1979b) was intruded just prior to D3 deformation. Rb-Sr mica and U-Pb zircon ages from pegmatites around Loch Eilt also give Ordovician ages ranging from 445–470 Ma (van Breemen *et al.,* 1974).

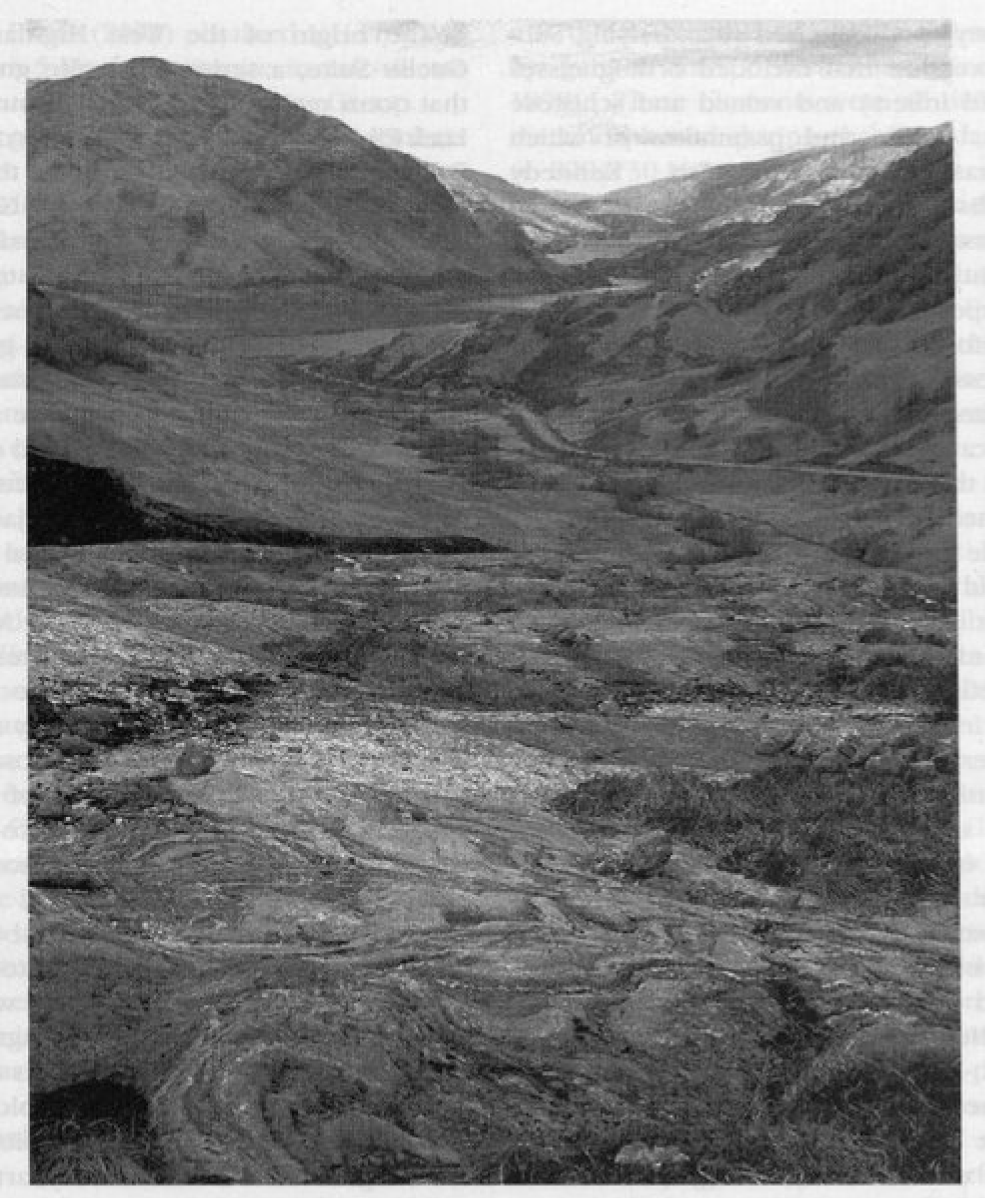
Strachan *et al.* (2002a) has argued that by analogy with the Northern Highlands, where penetrative Scandian deformation strongly affects rocks west of the Naver Thurst Zone, the D3 deformation in the 'Steep Belt' is also Scandian in age (440–425 Ma). This would also agree with Barr *et al.* (1986) who envisaged the internal deformation of the Moine succession and the main thrusting along the Moine Thrust Belt as coeval. However, the current geochronological data in the Moine (South) area favour a Grampian age for the D3 deformation with possibly a localized Scandian deformational and metamorphic overprint. This problem is discussed more fully in the 'Introduction' to Chapter 7 and in the Meall an t-Sithe and Creag Rainich GCR site report (Chapter 7).

The Silurian-age microdiorite sheets provide information about the last phase of metamorphism. Igneous mineralogies and greeschist-facies mineralogies (albite-green mica-actinolite-epidote + carbonate) are present in western Morar, but east of a line from Salen to Kinloch Hourn, lower amphibolite-facies mineralogies (oligoclase-green hornblende-biotite-titanite) are preserved in the deformed microdiorite sheets. Hornblende + biotite fabrics accompanied normally by a down-dip lineation are present in these deformed sheets, and locally, a crenulation cleavage is developed (Smith, 1979). Talbot (1983) described their locally folded nature in parts of the 'Steep Belt', and concluded that the earliest members were emplaced prior to the conclusion of D3 deformation. However, most microdiorite sheets undoubtedly cross-cut the F3 folds and record only the waning phases of the Scandian deformation and metamorphism.

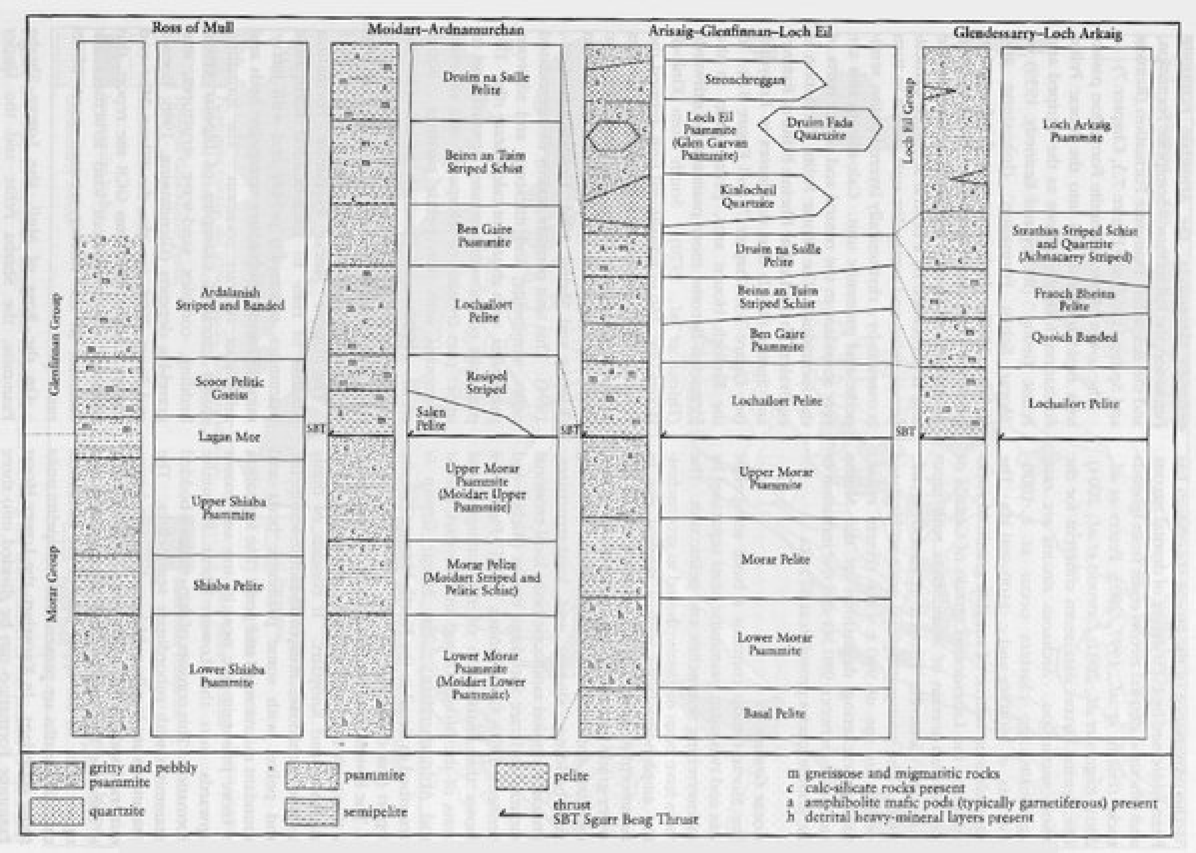
[References](#)



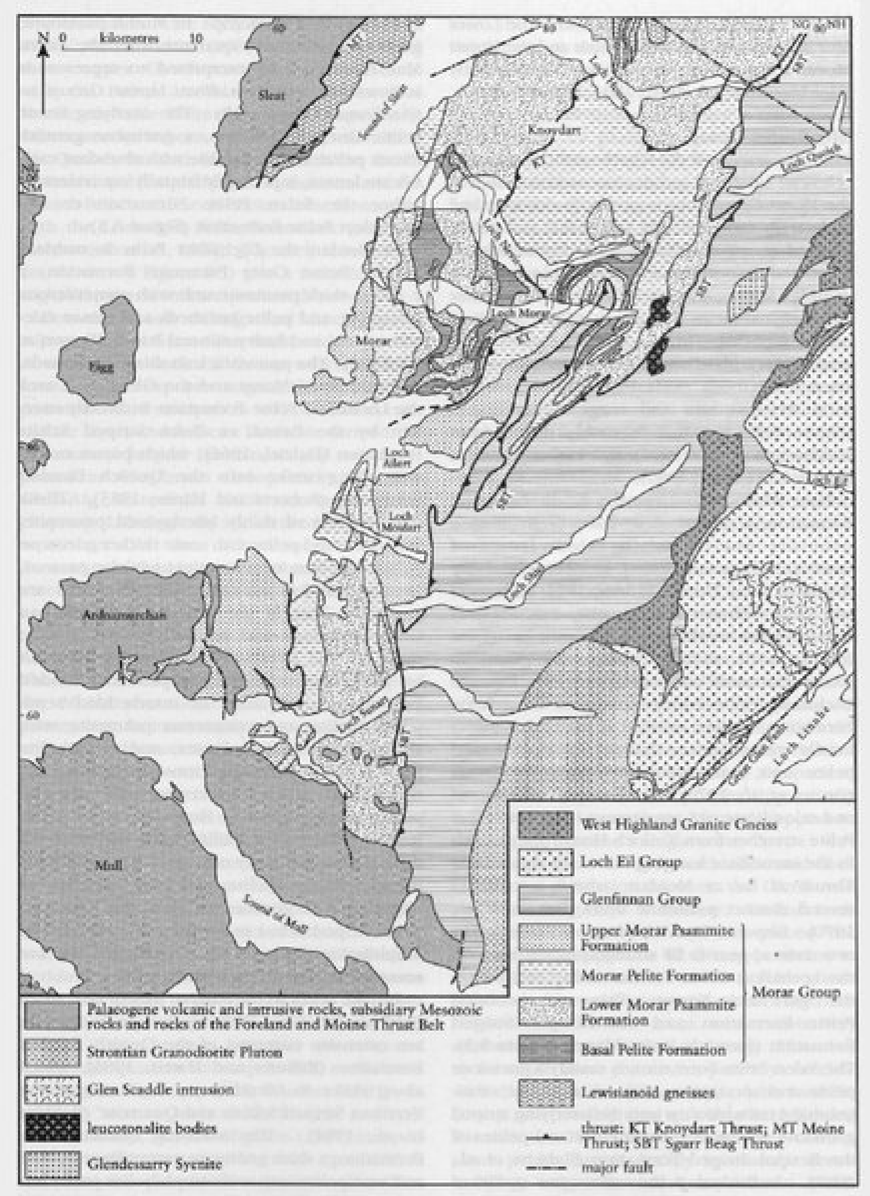
(Figure 8.1) Simplified geological map of the Moine (South) area, showing the location of the GCR sites.



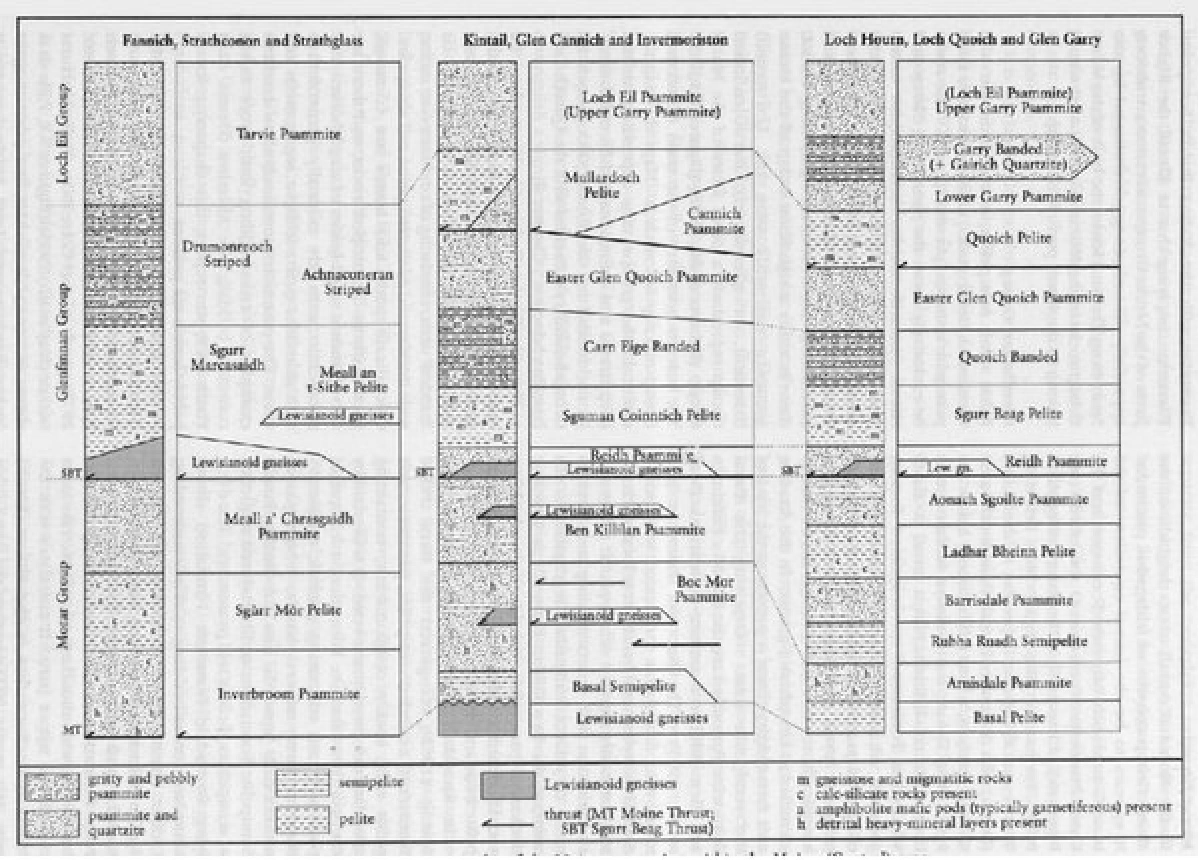
(Figure 8.2) View westwards to Loch Eilt from The Muidhe [NM 857 815]. In the foreground glaciated slabs show complex folded Glenfinnan Group pelitic and psammitic rocks cross-cut by thick pegmatitic veins that are themselves folded. The craggy and mainly grassy hills are typical of the 'Steep Belt'. (Photo: J.R. Mendum, British Geological Survey, reproduced with the permission of the director, British Geological Survey, © NERC.)



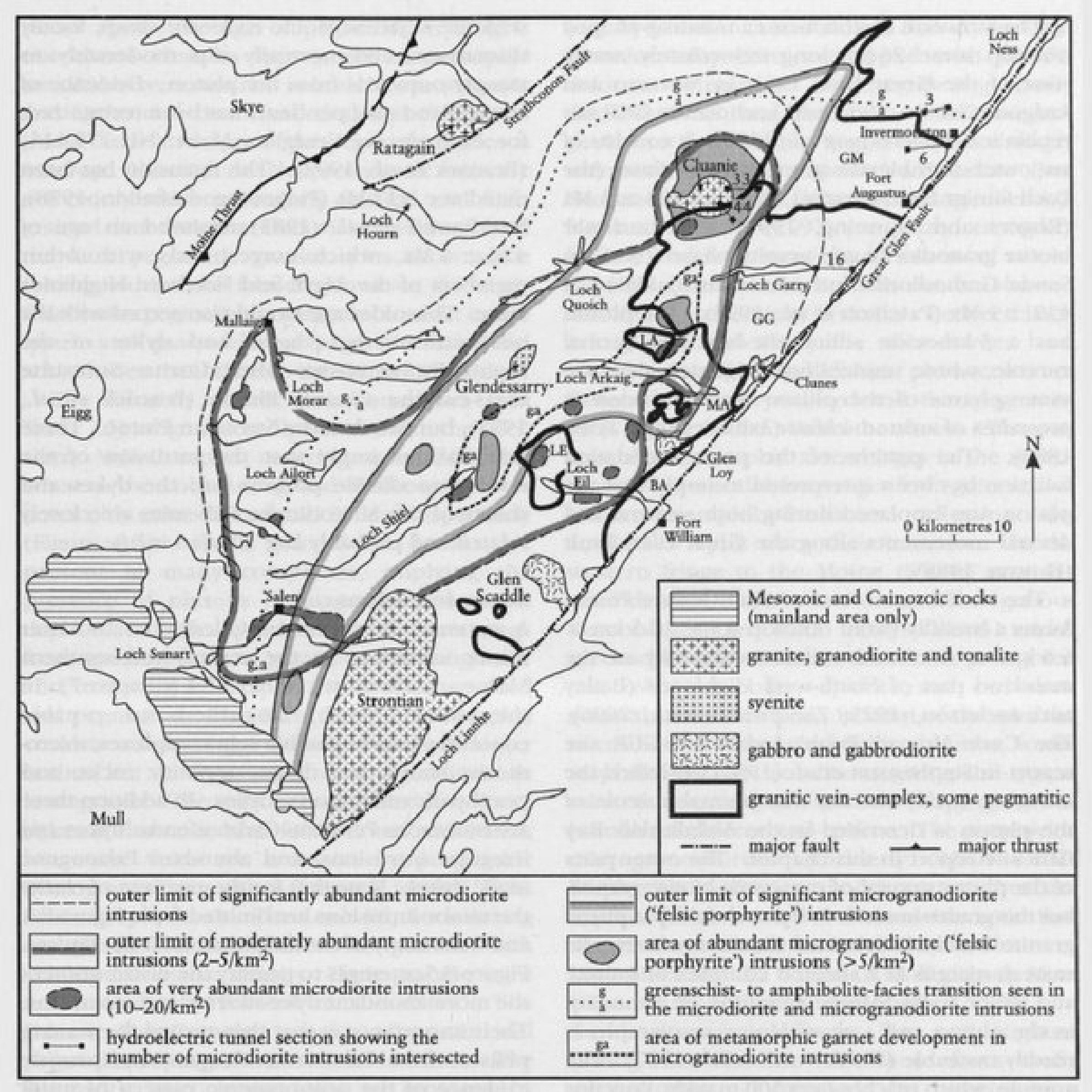
(Figure 8.3) Tectonostratigraphy of the Moine succession within the Moine (South) area, showing the main formations.



(Figure 8.4) Map of Knoydart, Morar and Ardnamurchan showing the distribution of formations of the Morar Group.



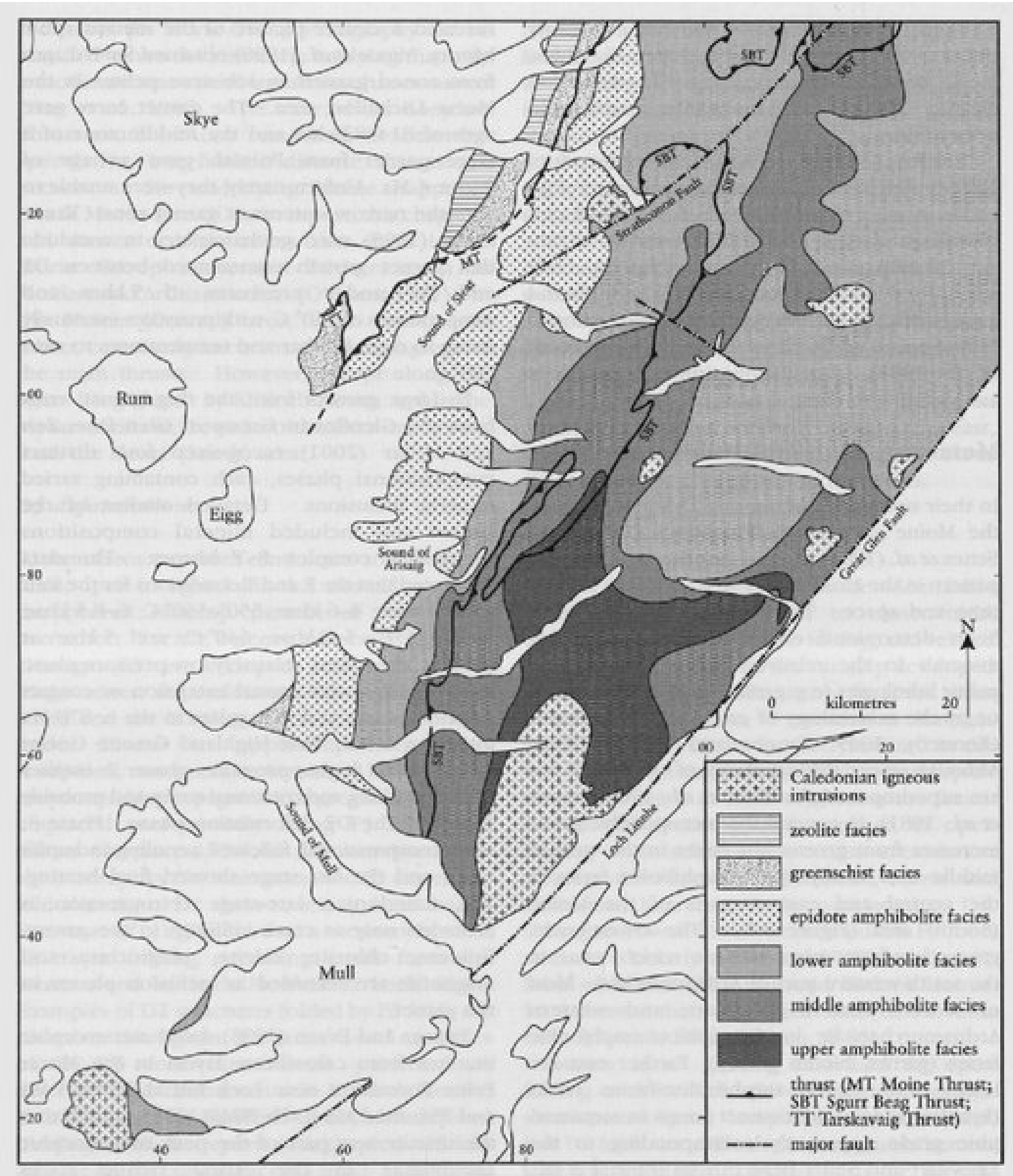
(Figure 7.3) Tectonostratigraphy of the Moine succession within the Moine (Central) area.



(Figure 8.5) Map showing the Caledonian major and minor intrusions. Granitic vein-complexes: Ba — Banavie; GG — Glen Garry; GM — Glen Moriston; LA — Loch Arkaig; LE — Loch Eil; MA — Maine.

Ramsay, 1960, 1963		Barber and May, 1976		May *et al.*, 1993		Tobisch *et al.*, 1970	
Moine & Lewisianoid rocks: Glenelg–Arnisdale area		**Western unit of Glenelg–Attadale Lewisianoid inlier**		**Moine rocks of Killilan Forest (Sheet 72W, Kintail)**		**Moine rocks:– Glen Affric to Strathconon**	
		$D6_L$	Monoclinal folding.			Affric	Open to close, minor and medium-scale folding. Axial planes swing in strike from east in Glen Strathfarrar to NNE in Glen Affric and are subvertical or dip steeply south.
D4	Conjugate minor folds adjacent to Moine Thrust.	$D5_L$	Minor folding in Thrust Belt and Moine succession.				
		$D4_L$	Mylonitization and ESE-plunging lineation.				
D3	Open to tight major and minor folding. N-trending axial planes. Low plunge. Coaxial crenulations.			$D3_M$	Major folding with SE-plunging axes.	Monar	Open to tight major and minor folding on NE-trending axial planes. Related schistosity and crenulation cleavage. Axial plunge commonly to the south-west but locally variable.
						Orrin	Open to tight, rarely isoclinal, major and minor folding. Local axial-plane schistosity and segregations. Gently to steeply W- and SW-plunging axes and lineation. Confined to upper parts of Glens Cannich, Strathfarrar and Orrin.
			Growth of hornblende porphyroblasts.			Strathfarrar	Tight to isoclinal major folds. Axial planes strike north to north-west and axes dip steeply north and south. Confined to middle part of Glen Strathfarrar.
D2	Tight major and minor folding and penetrative axial-plane schistosity.	$D3_L$	SE-plunging folds and rodding.	$D2_M$	Reclined folding with ESE- to SE-trending mineral lineation and rodding. Major sliding and stacking of thrust sheets. Development of flaggy zones and mylonites in the west. Migmatization of the Boc Mor Psammite and formation of the quartz-biotite rock in some slide zones. Amphibolite-facies metamorphism.	Cannich	Tight to isoclinal major and minor folding. Penetrative axial-planar schistosity trends north-east and dips south-east. Axial plunges tend to be steep but are rather variable in orientation. Moderate south-west plunge is common. Amphibolite-facies metamorphism.
D1	Tight to isoclinal, major and minor folds. Interleaving of Lewisianoid and Moine rocks.	$D2_L$	NE-plunging minor folds and rodding abundant. Moderately SE-dipping axial-plane foliation.				
		$D1_L$	Interbanding of Moine and Lewisian.	$D1_M$	Minor isoclinal folding with axial-plane schistosity and rodding lineation. Amphibolite-facies metamorphism.	Pre-Cannich	Tight to isoclinal minor folding. Bedding-parallel schistosity. Intersection lineation. Amphibolite-facies metamorphism.

Deformation sequences in the Moine (Central) area. Note that the structural events do not correlate simply across different areas.



(Figure 8.6) Map of the metamorphic zones of the Moine (South) and Moine (Central) areas. After Fettes et al. (1985).