Glen Doe

[NH 209 128]–[NH 220 125]

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Introduction

The Glen Doe river section shows the relationships between the Glen Doe Granite Gneiss and the metagabbro and metadolerite intrusions, all of which were emplaced at an early stage in the tectonometamorphic history of the Moine succession. Regionally discordant granite sheets, now represented by granite gneiss, were emplaced into psammitic and pelitic metasediments that lie around the Glenfinnan Group–Loch Eil Group boundary, during Neoproterozoic deformation and amphibolite-facies metamorphism. The granite gneiss in Glen Doe forms part of the most northerly large body of the West Highland Granite Gneiss Suite. Unlike some of the more southerly granite gneiss bodies (see Quoich Spillway and Fassfern to Lochailort Road Cuttings GCR site reports, this chapter), the Glen Doe body lies to the east of the Loch Quoich Line, and has escaped strong Caledonian reworking. Rock *et al.* (1985) demonstrated the tholeiitic nature of the Glen Doe mafic rocks, and Peacock *et al.* (1992) noted that they formed part of a widespread mafic suite. Millar (1990, 1999) showed that the earlier-formed metagabbros and later metadolerites were geochemically related, but were texturally, mineralogically and geochemically distinct. The metadolerites are comparable with intrusions found widely elsewhere in the Moine succession (see Comrie GCR site report, Chapter 6). The rocks in Glen Doe are generally highly deformed by pre-Caledonian structures, but primary igneous intrusive relationships and textures are locally preserved in the mafic bodies.

Peacock (1977) first described the Glen Doe section and interpreted the metagabbro–metadolerite–granite gneiss relationships to infer that two separate generations of mafic rocks were present and that the granite gneiss predated their emplacement (see also Peacock *et al.,* 1992). This work suggested that the granite and early amphibolitic mafic rocks were foliated and metamorphosed during a D1 event, prior to metagabbro intrusion. Soper and Harris (1997) and Millar (1999) rejected this interpretation and attributed the observed relationships to the variable deformation of the different components dependent on their competency and the prevailing metamorphic conditions. They argued for emplacement of the granite gneiss followed closely by intrusion of the meta-dolerites and metagabbros.

Early geochonological work suggested that the Moine succession had been affected by Grenville orogenesis at around 1000 Ma (e.g. Brook *et al.,* 1976; Brewer *et al.,* 1979; Aftalion and van Breemen, 1980), and Millar (1990) interpreted the Glen Doe metabasic rocks as having been emplaced during this event. However, more-recent U-Pb zircon dating has shown that emplacement of the granite gneiss took place at 873 ± 7 Ma (Friend *et al.,* 1997), and zircons from the metagabbros in Glen Doe similarly date their intrusion at 873 ± 6 Ma (Millar, 1999).

Description

The River Doe section exposes the granite gneiss and mafic rocks at a number of readily accessible localities between [NH 209 128] and [NH 225 120] (Figure 8.7). Two distinct types of mafic rocks intrude the granite gneiss here; older coarse-grained metagabbros and later finer-grained metadolerites. Throughout much of the section, both types can be represented by tight to isoclinally folded, pervasively recrystallized hornblende schists (e.g. Locality (Figure 8.7)). However, at some low-strain localities, original intrusive relationships are well preserved in relatively undeformed mafic intrusions.

The best examples of the mafic rocks occur at [NH 2184 1259], where five intrusive phases can be observed in a weakly deformed body exposed in the river bed for some 80 m (Locality 'B', (Figure 8.7)). The bulk of the intrusion is a coarse-grained, hornblende-plagioclase metagabbro (Metagabbro 1) with a relict sub-ophitic texture and locally rhythmic layering on a 5 cm scale. In its central part, the metagabbro contains metre-scale xenoliths of partially melted, unfoliated granite, containing coarse, partly resorbed quartz and feldspar phenocrysts. The xenoliths have similar chemical and isotopic characteristics to the local granite gneiss country rocks. Their lack of foliation implies that they were incorporated into the gabbroic melt before the onset of deformation. The metagabbro shows considerable contamination for several metres around the xenoliths with decreased modal amphibole at the expense of plagioclase and biotite, and local development of garnet. Within the zone of granitic xenoliths, SiO_2 shows an increase from 48% to > 55%, Rb and Ba show elevated values, whereas Sr, Y and Zr are depleted (Peacock *et al.,* 1992; Millar, 1999). A later phase of metagabbro (Metagabbro 2) shows chilled margins against the main body and encloses a xenolith of undeformed, rhythmically layered metagabbro with a well-preserved sub-ophitic texture.

Upstream between Metagabbro 2 and the metabasic-granitic gneiss contact is a zone of complex mixing, where gabbroic rocks pass into irregular masses of quartz-plagioclase-biotite-garnet-hornblende schist. As the contact is approached granitic veinlets derived from local melting of the country rocks are common, and a strong foliation is developed parallel to that in the adjacent granite gneiss. Xenoliths within the mixed zone also carry this fabric, but show no evidence of earlier fabrics. The downstream contact of the metabasic body is faulted but poorly exposed.

A 10 m-thick composite metadolerite dyke, (metadolerites 1 and 2) cuts the metagabbro lithologies described above. The dyke shows chilled fine-grained contact zones against the metagabbro, and dips at 60° towards the southeast, near-perpendicular to the layering in the gabbro. Where an offshoot of the dyke approaches the upstream contact of the mafic body, it also develops a strong foliation, parallel to that in the surrounding metagabbroic rocks (Locality 'B', (Figure 8.7)).

Just upstream from the main metagabbro body, a large boulder and associated outcrops show an undeformed mafic intrusion with finer-grained margins cross-cutting the granite gneiss foliation. Peacock (1977) interpreted the mafic rock to be a metagabbro, thus requiring an additional phase of deformation in the granite gneiss, prior to emplacement of the metagabbro suite. However, thin sections from the 'later metagabbro' show it is a biotite-hornblende microdiorite, a member of the late Caledonian Microdiorite Sub-suite (Millar, 1990).

A number of deformed mafic bodies are exposed in the river section 20–50 m west of the main mafic body described above. These bodies fall into two distinct groups; the majority are fine-grained, garnet-free hornblende schists, chemically and isotopically similar to the undeformed metadolerites (Millar, 1990); less abundant are coarsely foliated, garnetiferous hornblende schists, commonly with a distinctive augen texture, that represent the metagabbros. A typical deformed metagabbro is exposed at [NH 2182 1261]. Peacock (1977) termed these bodies 'rodded hornblende schists' and interpreted them as an early phase of metabasite intrusion, pre-dating emplacement of the undeformed metagabbros and metadolerites.

However, on the basis of their field relationships, and geochemical and isotopic characteristics, Millar (1990) showed that the garnetiferous hornblende schists and metagabbros form part of the same suite. Hence the mafic rocks of Glen Doe form parts of a single suite, characterized by two main types, the earlier metagabbros and the later metadolerites, whose deformational and metamorphic condition are spatially quite varied. Whereas the metadolerites form part of a regional suite (Rock *et al.,* 1985), the large undeformed metagabbros are common only within the Glen Doe Granite Gneiss body, although examples do occur farther north in upper Strathglass (Peacock *et al.,* 1992). Note that the use of the term 'metagabbro' in Peacock *et al.* (1992) refers to all undeformed mafic rocks, whereas here 'metagabbro' refers to the geochemically distinct coarse-grained metabasites, irrespective of their state of deformation.

Relatively undeformed mafic bodies also occur at a number of other localities within Glen Doe, for example, near the small hydro-electric dam at [NH 2107 1270]. However, at [NH 2169 1265] schistose metadolerites are deformed by recumbent isoclinal F2 folds, and in places an S1 fabric in the granite gneiss can be traced around the fold hinges (Figure 8.8). Despite the high tectonic strain and extensive recrystallization of the schistose metadolerites, composite relationships and chilled margins can still be discerned in parts. Recrystallintion during D2 has obliterated the S1 fabric in the schistose metadolerites here, but at [NH 2095 1275] an S1 fabric is still present in the metadolerite (Peacock, 1977). D3 Caledonian upright reworking is limited to open folding and S3 fabrics are rarely present in the Glen Doe mafic rocks.

In addition to the metadolerite intrusions of Glen Doe, Peacock (1977) described an unusual suite of hornblende schists characterized by large garnets up to 4 cm across, the so-called big garnet rock'. These rocks occur close to the boundary between Glenfinnan Group gneissose pelite and Loch Eil Group psammites in the Glen Doe area (Peacock, 1977), at the north-western end of Loch Cluanie (Millar, 1990), and farther north, to the south-east of Loch Beinn a' Mheadhoin (Peacock *et al.,* 1992). Typical examples crop out 200 m south-east of the Glen Doe river section, around [NH 207 126]. The garnets were subjected to a detailed analysis by Zeh and Millar (2001) in order to ascertain their metamorphic history (see 'Introduction', this chapter). It is possible that these coarse garnetiferous hornblende schists represent former volcanic layers or ferruginous, marly beds within the Moine sediments. However, the coarsely garnetiferous hornblende schists are commonly associated with intrusive amphibolites, and they may result from contamination or hybridization of Moine pelites during the syn-metamorphic emplacement of the mafic intrusions.

Minor Caledonian intrusions are rarely exposed within the Glen Doe river section and are generally emplaced within brittle fault-zones. However, microdiorites occur at [NH 2659 1181], [NH 2172 1265] and [NH 2158 1263], associated with faults in the granite gneiss or along a faulted contact between granite gneiss and quartzose psammite. A porphyritic microgranodiorite dyke cuts granite gneiss at [NH 2104 1273].

Interpretation

The field relationships of the mafic intrusive bodies and granite gneiss at Glen Doe are particularly well displayed owing to the low Caledonian strain in this area. The sequence of intrusive events that pre-date the onset of deformation is as follows:

- Emplacement of granite sheets – protolith of the Glen Doe Granite Gneiss.
- Emplacement of gabbro in multiple pulses, incorporating undeformed xenoliths of granite and earlier gabbro pulses. Melting of adjacent country rocks and xenoliths.
- Emplacement of dolerite in multiple pulses.

Emplacement of the Ardgour Granite Gneiss precursor has been dated at 873 ± 7 Ma by the U-Pb TIMS zircon method (Friend *et al.,* 1997) from samples near Glenfinnan. Rogers *et al.* (2001) obtained a similar intrusive age of 870 ± 30 Ma using U-Pb SHRIMP analyses of zircons from the Fort Augustus Granite Gneiss. These two bodies belong to the West Highland Granite Gneiss Suite, and are the oldest intrusive rocks presently dated in the Moine succession. Thus, they provide a minimum age for deposition of this sedimentary sequence.

The metadolerites are geochemically similar to modern Mid-Ocean Ridge Basalt (MORB) in terms of their Nd isotope characteristics and immobile trace-element chemistry (Th, Zr, Hf, Ta, Nb, rare-earth-elements; Millar 1990, 1999). However, mobile elements (Rb, K, Ba, Sr) are strongly enriched, probably by fluid interaction with the adjacent granitic and metasedimentary rocks during metamorphism. The metadolerites contain no primary minerals suitable for U-Pb dating and attempts to date them using Rb-Sr methods have produced only meaningless mixing lines.

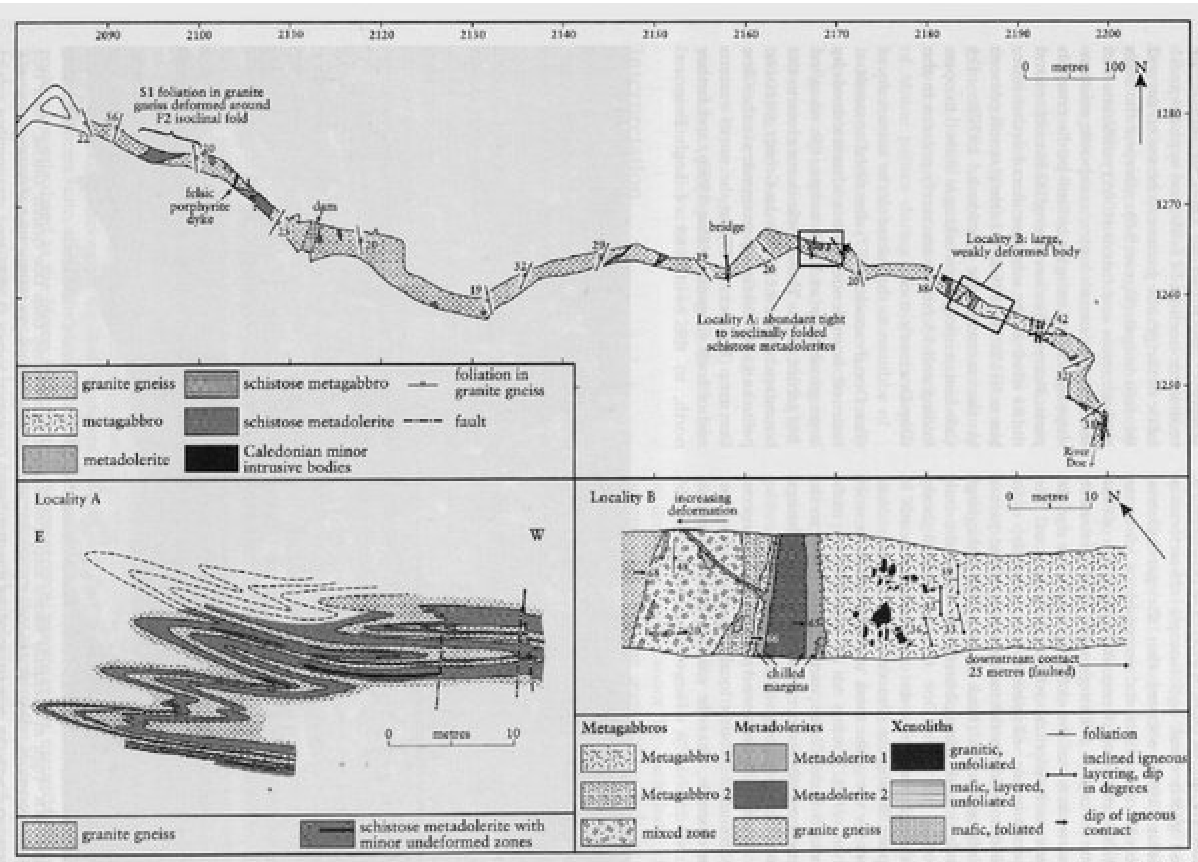
The metagabbros have a more-evolved chemistry, reflecting fractional crystallization of a similar tholeiitic basic magma, mixing with partial melts of the granite gneiss, and interaction with metamorphic fluids. Zircons separated from a sample of schistose metagabbro give a U-Pb TIMS age of 873 ± 6 Ma, interpreted as dating syn-metamorphic emplacement of the metagabbro protolith (Millar, 1999). However, the possibility that the zircons are inherited from granite gneiss and incorporated in the basic melt cannot be excluded. Sr isotope data from the metagabbros indicate a major isotopic disturbance at a later date (Millar 1990).

The field evidence implies emplacement of metagabbro and metadolerite suites occurred shortly after emplacement of the granite gneiss, but prior to the onset of deformation. The data suggest that the mafic suite and granite gneiss suite were emplaced during a single geological event. The MORB-like chemistry of the mafic rocks supports the hypothesis that this bimodal magmatism occurred during a Neoproterozoic extensional event at *c.* 870 Ma. Dalziel and Soper (2001) suggested that such an event may mark the start of the break-up of the Rodinia supercontinent. However, the evidence for a Knoydartian orogenic event (see 'Introduction', this chapter, Strachan *et al.,* 2002a, and Tanner and Evans, 2003) implies that extensional events were followed by orogenic compression and crustal stacking at around 750 Ma.

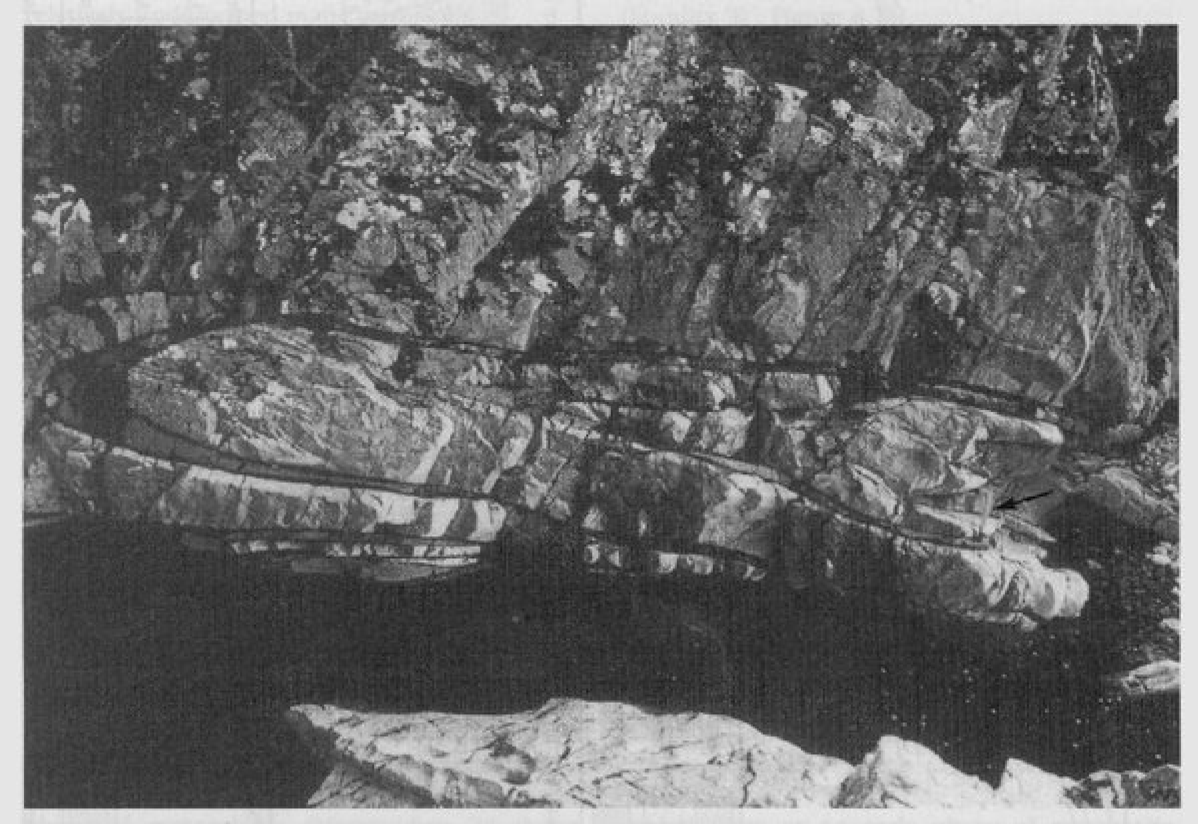
Conclusions

The Glen Doe GCR site contains unrivalled exposures of the relationships between Neoproterozoic granite gneiss, metagabbros and metadolerites that intruded the Moine metasedimentary rocks prior to the onset of orogenic deformation. These relationships are critical to the understanding of the early intrusive, tectonic and metamorphic history of the Moine. The MORB-like geochemical characteristics of the abundant metadolerite dykes are of particular importance, as they suggest emplacement in an extensional environment. Field and geochrono-logical evidence support emplacement of the metabasic rocks at *c.* 870 Ma, effectively coeval with intrusion of the granitic protolith of the West Highland Granite Gneiss Suite. The basic magmatism resulted in high-grade metamorphism and melting of the Moine metasediments at depth that led to formation of the granitic intrusions followed by the development of early metamorphic fabrics. No major fold structures are associated with this early metamorphism in the Glen Doe area: the age of the major isoclinal folds that deform the granite gneiss, the mafic bodies, and the early schistosity remains unconstrained. The Glen Doe GCR site provides evidence for an early attempted break-up of the Rodinia supercontinent and is therefore of international importance.

[References]



(Figure 8.7) Map of the Glen Doe GCR site. (1) Inset Locality A — detail of tight to isoclinally folded amphibolitic mafic dykes. (2) Inset Locality B — detailed map, showing field relationships between different generations of metagabbro, metadolerite and granite gneiss.



(Figure 8.8) Tight to isoclinally folded amphibolitic mafic dykes in the Glen Doe Granite Gneiss, River Doe section [NH 2169 1265]. The hammer (arrowed) is 32 cm long. (Photo: I.L. Millar, British Geological Survey, reproduced with the permission of the Director, British Geological Survey, © NERC.)