Letter to the Editors

The editors have received the following communication from N. J. Soper and A. L. Harris.


Highland geology is the subject of renewed debate: were the Moine and Dalradian rocks affected by orogeny during the Proterozoic?

The Morarian orogeny is thought to have affected the Moine rocks to the north of the Great Glen and oldest Dalradian rocks of the Central Highlands at 750 – 850 Ma, based on isotopic dating of supposedly synorogenic or intra-orogenic regional pegmatites and Older Granites such as the Ardgour granite gneiss and the Carn Chuinneag intrusion. The Grampian event has been inferred by Rogers et al. (1989) to have affected the later Dalradian strata before emplacement of the Ben Vuirich intrusion at about 600 Ma. These views have been challenged by Soper and England (1995) on the grounds that an apparently continuous Riphean–Vendian stratigraphical succession is present in the Highlands, indicative of lithospheric extension and thermal recovery, and preserving no orogenic unconformities. Other workers have deliberately discounted Proterozoic orogeny, for example Dewey and Shackleton (1984) in their Grampian synthesis.

An informal meeting was convened in May 1995 in order to re-examine some of the field relationships that are critical to the concept of Proterozoic orogeny. The findings proved to be of such interest, differing in important respects from published interpretations, that a larger group met in May 1996, concentrating on structural relationships of key intrusions in the area north of the Great Glen. Those present in 1995 included A. J. Barber, D. J. Fettes, A. L. Harris, P. D. Ryan and N. J. Soper. The meeting was structured so that agreement was reached as to what had been seen before leaving each locality, independently of interpretation. The group was joined in 1996 by I. W. D. Dalziel, J. F. Dewey, J. Mendum, S. Robertson, M. Smith and D. B. Snyder, with P. J. Carey, M. R. W. Johnson, D. Powell and D. Wilson participating for part of the workshop.

The following notes record the agreed observations, and, it is hoped, a consensus view of the inferences drawn from them.

Ardnish pegmatite

This pegmatite sheet is intruded into Moine rocks of the Morar Group near the western end of the Ardnish peninsula [NM 694813]. The pegmatite was interpreted by Powell et al. (1983) as intruded post-D2, pre-D3, and gave a Rb-Sr muscovite age of 746–776 Ma. It has therefore provided an important line of evidence to support the concept of Proterozoic orogeny in the Moine.

The locality was visited only by the 1995 party, which confirmed that the pegmatite cuts bedding-foliation in the Moine host rocks and is folded by the dominant (the only?) set of folds at the locality, regarded as regional F3. In the axial regions the pegmatite carries a weak S3 fabric. However, it also carries an earlier foliation that is sub-parallel to its margins. This consists of a compositional layering, possibly due to multiple intrusion, and a penetrative fabric defined by mica and feldspar grain-shape orientation. These micas are locally crenulated in S3.

At one point the pegmatite appears at first sight to cut a fold but the geometrical relationships result from the coaxial folding of non-parallel surfaces (Moine bedding-foliation and the pegmatite), as depicted by Powell et al. (1983, fig. 2). Powell et al. regarded the folding of the pegmatite as D3 because the S3 fabric wraps syntectonic garnets in the host Moine rocks, presumed on regional grounds to be syn-D2. However, S3 also deforms the earlier pegmatite foliation and if this is S2, D1 is not represented at the locality.

The pegmatite predates all observed structures and cannot therefore provide evidence of pre-pegmatite orogenic deformation.

The Ardgour gneiss: Glenmoriston

The Ardgour (or West Highland) Granite Gneiss occurs as a number of sheet-like bodies within the Glenfinnan and Loch Eil groups in western Inverness-shire. It was interpreted by Dalziel (1966) as the product of in situ migmatization and metasomatism but by Barr et al. (1985) as a syn-tectonic (implicitly, syn-orogenic) granite produced during high-grade metamorphism and anatexis of the Moine country rocks. A Rb–Sr whole-rock age of 1028 Ma was taken to indicate Grenville orogenic metamorphism of the Moine (Brook et al. 1976), but this proved to be in conflict with Sm–Nd evidence for a Grenville age of the eclogitic sub-Moine basement at Glenelg (Sanders et al. 1984). Friend et al. (in press) report SHRIMP U–Pb zircon data which they interpret as indicating anatexis and formation of the gneiss and associated segregation pegmatites at about 870 Ma.

Both groups examined road cuts on the A887 in Glenmoriston around [NH 240113], where sheets of granitic gneiss are mapped within the Locheil Group of the Moine, in the ‘flat belt’. The flat belt has been interpreted as a zone in which regional D1 and D2 structures in the Moine rocks retain their original recumbent attitude, traditionally thought to be Proterozoic; in contrast to the ‘steep belt’ to the west of the Loch Quoich line, produced by upright Caledonian reworking (Roberts and Harris 1983).

The gneiss is pink, rather fine-grained and homogeneous, and not so conspicuously migmatitic as elsewhere (q.v.). Sheet-like metasomatic intrusions intrude the gneiss and chill against it, and (as seen in road cuts immediately
to the east) also cut the Moine country rocks. Within the gneiss the basic sheets are deformed by very tight recumbent folds, with axial surface foliation that is contiguous with the dominant subhorizontal fabric of the gneiss. These are the earliest structures seen and could be dubbed F1/S1. The sheets also have recumbent folds with more rounded hinges that refold and crenulate ‘S1’ in their hinge zones; these could be called F2, although it is equally possible that the observed structures were generated by continuous, progressive deformation.

The foliation in the gneiss is clearly composite, with evidence of progressive reworking of the subhorizontal fabric. The folds in the basic sheets within the gneiss presumably relate to the curvilinear D1/D2 folds in the Lochiel Moine described by Holdsworth and Roberts (1984). These authors are coy about D1, referring to ‘sparse intrafolial isoclines’, the dominant folds being D2. Regardless of uncertainty about the status of D1, the evidence is that the gneiss and basic sheets share the deformation of the Moine country rocks. The observed sequence is:

(1) Deposition of the Lochiel Group
(2) Emplacement of the granitic protolith of the Ardgour gneiss
(3) Intrusion of the basic sheets
(4) D1/D2 ('flat belt') deformation
(5) Upright reworking (not seen at the outcrops described)

There is no evidence to deny a Proterozoic age for events 1–3 and a Palaeozoic age for 4 and 5.

Metabasite intrusions: Glen Doe

In the nearby River Doe section, around [NH 219125], composite tholeiitic metabasite sheets intrude the gneiss. The section was examined by the 1995 party and two members (M.R.W.J. and I.W.D.D.) of the 1996 group. Peacock (1977) described xenoliths of ‘basic schist’ within sub-ophitic garnetiferous metagabbro, inferring two intrusive episodes, pre-D1 and post-D1/pre-D2.

The visiting group interpreted the xenolith fabric as a primary igneous feature. There was no evidence that the basic sheets had been emplaced later than any observed deformation of the gneiss. Acid xenoliths were thought by Peacock to be hornfelsed gneiss, but as no relic gneissic fabric is present they could represent remelted gneiss protolith (possible back-veining of the basic sheets by the gneiss was noted in the road cut).

Numerous chills of gabbro on gabbro were seen but no consistent direction of younging could be inferred. At the margin of the main body, thin sheets of garnetiferous metagabbro are present in the gneiss, both rocks sharing a common foliation parallel to the contacts.

The following inferences are permitted:

(1) the MORB chemistry and sheeted geometry of the metabasite intrusions suggest significant lithospheric extension;
(2) high heat flow during extension, perhaps enhanced by advective heat from the basic intrusives, may have been responsible for generation of the gneiss protolith by anatexis; however, the basic rocks cut the gneiss and could be much younger;
(3) gneissification of the granitic protolith post-dates the basic magmatism.

It subsequently transpired that I. L. Millar has established an identical chronology from a comprehensive re-examination of Moine–gneiss–metabasite relationships in the area (Millar 1990).

Ardgour gneiss: Glenfinnan

The A830 road section through the Moine Supergroup is described in Excursions 3 and 4 in the Moine Guide (Allison et al. 1988). Locality 10, Excursion 3 [NM 916802] is the source of zircon samples from the gneiss dated by Friend et al. (in press) as described above.

The foliation is steeply inclined, as a result of ‘D3’ upright reworking of recumbent D1/D2 structures. No clear evidence was seen of structures that could be unambiguously designated D1. At the sampled locality the gneiss contains leucosome blebs, interpreted by Dalziel (1966, plate 2.1) as F2 fold cores isolated during intense D2 reworking. (R. A. Strachan subsequently pointed out that D2 sensu Dalziel is D3 sensu the Moine Guide). The dated zircons come from both the gneiss and the leucosome segregations.

The following interpretation is possible.

(A) The gneiss protolith was generated and reworked with the formation of segregation pegmatites in one continuous process at c. 870 Ma (which could be called D1 and might be extensional) and subsequently deformed by D2 and D3.

However, the combined evidence from Glenfinnan, Glen Moriston and Glen Doe favours an alternative.

(B) The protolith was generated and emplaced (in an extensional regime?) at c. 870 Ma, was then intruded by basic sheets, and subsequently reworked and migmatized during D1/D2, all the products being later deformed by D3.

Carn Chuinneag

The Carn Chuinneag and Inchbae gneissic granitoids are intruded into the Morar Group Moine of Easter Ross. They have well developed contact aureoles and the former has a riebeckite-bearing facies with local aegerine. Rh–Sr whole-rock and bulk fraction zircon studies suggested an emplacement age of about 560 Ma, subsequently supported by four near-concordant U–Pb SHRIMP zircon ages in the range 540–620 Ma (Pidgeon and Compston 1992).

Shepherd (1973) interpreted the intrusions as emplaced post-D1, pre-D2 in the structural sequence, the inference being that D1 is Proterozoic. The dominant structure is D2 which consists of folds with a congruous L–S fabric that affects both the country rocks and intrusions, strongly rodding and foliating the latter. The D1 structure consists of a bedding-parallel foliation in micaceous lithologies, designated S1’ by Shepherd and correlated with a fabric
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was also speculation as to why Shepherd should have assigned the dominant linear fabric to D1 (Shepherd 1973, fig. 4) and the dominant planar fabric to D2, in what is clearly a pervasive L-S fabric associated with regional folding.

Conclusions

(1) No firm evidence was seen around the Ardnish pegmatite, Ardgour gneiss or Carn Chuinneag granite that the Moine country rocks had undergone orogenic deformation before or during emplacement of these Proterozoic intrusions.

(2) Evidence from the Carn Chuinneag aureole establishes that the Moine country rocks in this area had not been pervasively deformed before intrusion during the Vendian.

Speculations

(1) In discussion, the party favoured an extensional environment for these intrusions and the regional metasite suites. Isotopic dating suggests two periods of extension-related magmatism, at about 800–870 Ma and 600 Ma, the latter Iapetan.

(2) Evidence for a regional, pervasive and separately identifiable D1 tectonic event in the Loch Eil and Glenfinnan groups is tenuous.

(3) There was discussion about the length of time that the Moine rocks could remain deeply buried, if orogenically deformed in the Proterozoic. It was suggested that a mid-Ordovician age for the D1/D2 recumbent folding and ‘Taconic’ arc accretion event, the latter to Baltica collision.

It was concluded that there is no evidence to support a pre-granite pervasive deformation of the Moine country rocks, and observations 6 & 7 appear to rule it out.

Examination was also made of a locality in Abhainn na Glasa [SO1785] described by Harker (1970) as showing pre-hornfels folding. The fold proved to be a late flexure. Water-washed exposures nearby show delicate sedimentary structures mentioned above.

There was discussion about the reality of D1, and the origin of the S1 bedding-parallel fabric – a problem not unique to Carn Chuinneag. A mimetically-enhanced sedimentary and/or compaction fabric was suggested. There was also speculation as to why Shepherd should have described as axial planar to rare folds that he designated D1. There is also a grain-alignment lineation assigned to D1 but this is described as coaxial with the dominant folds, D2 (Shepherd 1973, fig 3).

Two traverses were made to establish what structures and fabrics are cut by the Carn Chuinneag intrusion. One was led by D. Wilson in Kildermorie Forest where the southern contact is exposed between [NH 464794] and [454784]. The other was in upper Strathcarron to examine a well exposed section in the Garbh Allt near Sallachy [490876] described by Shepherd (1973, fig. 9) where several granite apophyses cut the contact hornfelses. The following observations and inferences were made.

(1) The granite cuts bedding and the bedding-parallel fabric in the country rocks.

(2) There is evidence for syn-emplacement deformation, for example granite veins axial planar to small folds in the hornfels, and shear zones oblique to F2.

(3) Younging reversals in the Garbh Allt, used by Shepherd to infer D1 folding cut by granite sheets were verified, but since S2 faces consistently across them (with one doubtful exception), it was thought that they are likely to be F2 structures.

(4) The prominent folds (‘D2’) deform bedding in the Moine country rocks, crenulate the bedding-parallel fabric, and transpose and wrap contact andalusite and garnet. No F1–F2 interference was observed.

(5) The D2 L–S fabric rods and foliates the granite, crossing intrusive contacts. It is the dominant tectonic fabric in the area, but it appears to have been depicted as D1 in figure 4b of Shepherd (1973). It is consistent in style and orientation with that associated with the Sgurr Beag slide zone.

(6) Xenoliths enclosed in foliated granite are foliated oblique to bedding, those in unfoliated granite display only bedding.

(7) In the hornfelses, delicate sedimentary structures are preserved, including ripple cross-lamination, small slump folds and sedimentary dykelets still normal to bedding.

J.F.D. reported that subsequent examination of thin sections of the hornfels from both the northern and southern contacts showed contact garnet and andalusite to be earlier than the first muscovite/biotite-defined fabric, which is strongly crenulated. The garnets have a spongy texture, include unoriented quartz and feldspar grains, and contain no hint of a pre-garnet fabric.

References


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