LOCH SUNART

A. J. Highton

OS Grid Reference: NM776607–NM872593

Introduction

The Strontian pluton (MacGregor and Kennedy, 1932; Sabine, 1963) occurs on the NW side of the Great Glen Fault and is assigned to the Argyll and Northern Highlands Suite of late Caledonian granitic intrusions on the basis of its geochemical and isotopic characteristics (Halliday, 1984). The pluton falls into the category of ‘forceful' intrusions, thought to have emplaced by diapirism (Read, 1961). As a means of pluton emplacement this mechanism is questionable, and alternative solutions have been presented (Hutton, 1988b). The Loch Sunart GCR site presents a cross section through the northern part of the Strontian pluton. Significant features include evidence for intrusion of basic magma contemporaneous with pluton emplacement, and fabrics resulting from syn-emplacement deformation.

The pluton extends over an area of some 200 km² in a N–S-trending outcrop from the NW shores of Loch Linnhe to the southern slopes of Meall a' Ghruith (822 653). It comprises:

1. an outer hornblende-biotite granodiorite facies, with porphyritic and non-porphyritic variants (‘tonalite' and ‘granodiorite' of early workers)

2. an inner biotite granodiorite (‘biotite granite' or ‘adamellite' of early workers) that extends eastwards as a vein complex cross-cutting the metasedimentary envelope (Figure8.7).

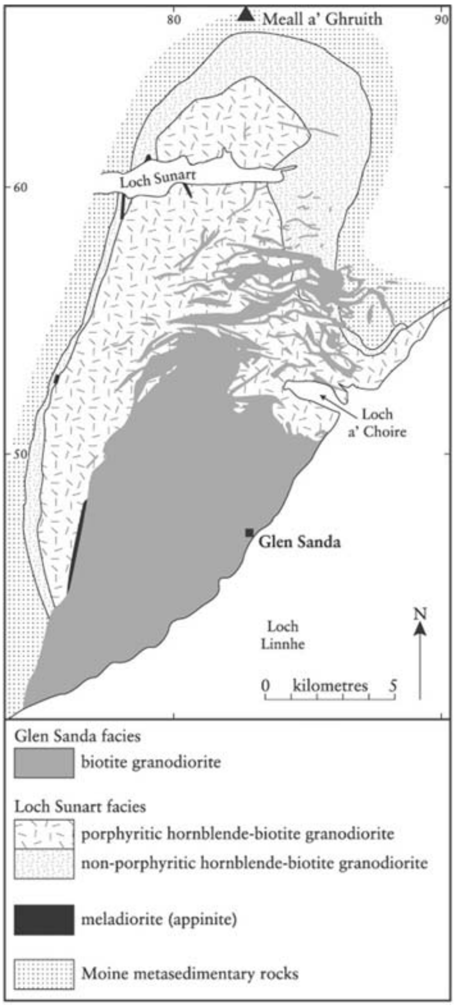

Figure 8.7: Map showing the distribution of facies within the Strontian pluton, adapted from Sabine (1963).

These are referred to respectively as the Loch Sunart granodiorite and Glen Sanda granodiorite facies (Paterson *et al*., 1992a, 1992b). Mafic enclaves, including some large bodies of appinitic meladiorite, are common in both facies (Holden, 1987). Although previously dated at 435 ± 10 Ma (Pidgeon and Aftalion, 1978), recent zircon studies give an emplacement age of 425 ± 3 Ma for the hornblende-biotite granodiorite (Rogers and Dunning, 1991) and 418 ± 1 Ma for the biotite granodiorite facies (Paterson *et al*., 1993). The latter facies, however, has a significant inherited zircon component (Paterson *et al*., 1992a, 1992b).

The envelope consists of middle to upper amphibolite facies metasedimentary rocks of the Glenfinnan and Loch Eil groups of the Moine Supergroup. A 3 km-wide high-grade, sillimanite-bearing thermal aureole encloses the pluton, from which Tyler and Ashworth (1982) derived a pressure estimate of 4 kbar. Along its northern contact, the pluton truncates the outcrop of the Precambrian West Highland Granite Gneiss (Barr *et al*., 1985; Friend *et al*., 1997), while the Great Glen Fault terminates the south-eastern boundary of the intrusion. Kennedy (1946) regarded the Strontian outcrops and those at Foyers on the SE side of the fault as part of the same pluton, separated by a 105 km sinistral displacement. There are significant similarities in terms of lithologies, enclave populations, emplacement and synplutonic deformational histories, and both were intruded at corresponding crustal levels of *c*. 13 km (Tyler and Ashworth, 1983). However, geochemical and isotopic evidence (Marston, 1971; Pankhurst, 1979; Hamilton *et al*., 1983; Halliday, 1984), geophysical constraints (Ahmad, 1967; Torsvik, 1984) and structural interpretations (Munro, 1973) have since demonstrated that this correlation is unlikely.

The pluton and country rocks are cross cut by Permian age ENE-trending camptonite dykes and quartz-dolerite plugs (Rock, 1983), and by later basic intrusions of Palaeogene age.

Description

The GCR site comprises a west to east traverse, including road cuttings, shoreline exposures along both sides of Loch Sunart, and the hills to the south of Glen Tarbert (Figure8.8). It lies within the Loch Sunart facies of the Strontian pluton, which contains abundant mafic enclaves, and is cross-cut by veins of the Glen Sanda facies.

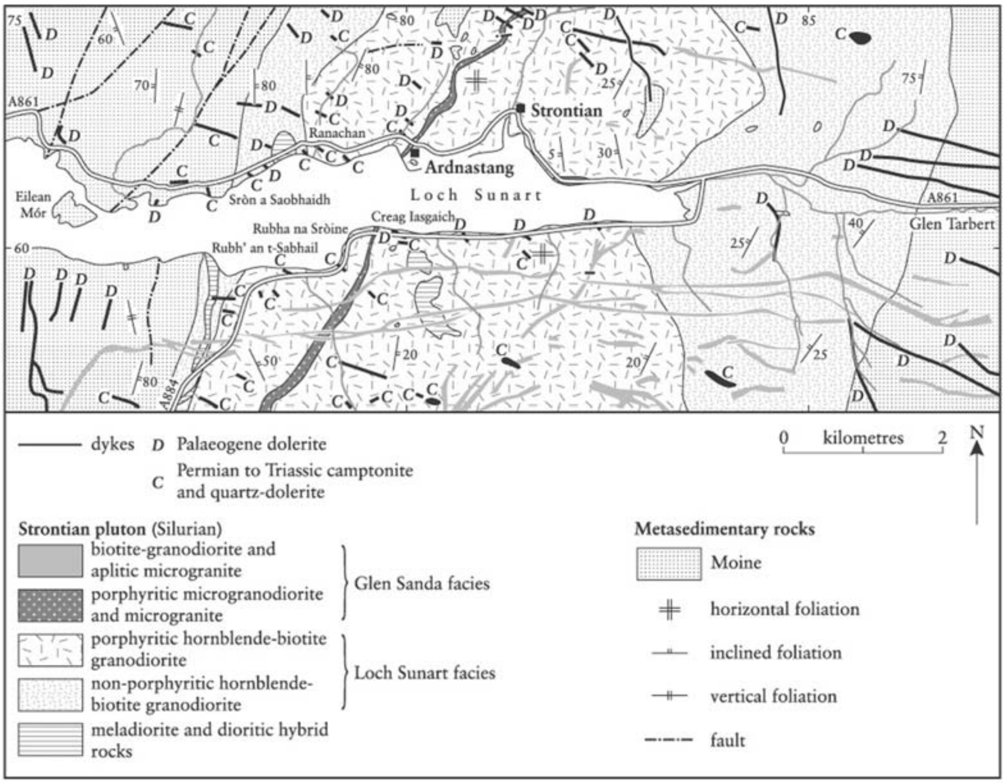

Figure 8.8: Map of the area around the Loch Sunart GCR site, Strontian pluton, adapted from BGS sheets 52E and 53.

Margin and envelope

To the east of Sròn na Saobhaidh, the western contact of the pluton is steeply inclined against interlayered psammites and semipelites. Here, extensive recrystallization and a cordierite–K-feldspar assemblage represent the highest grade within the aureole. Sillimanite forms felts or less commonly coarse crystals, with cordierite, garnet and K-feldspar overgrowing the regional gneissose foliation. A migmatitic overprint, in the form of granitic segregation, disrupts the regional metamorphic fabrics within 500 m of the contact, but is absent from rocks west of Eilean Mór.

Loch Sunart facies

At the outer margin of the pluton, this hornblende-biotite granodiorite is a medium- to coarse-grained, strong to moderately foliated non-porphyritic variant. Adjacent to the western contact aplitic microgranite veins and partially assimilated country rock xenoliths are numerous. The western contact between the outer non-porphyritic and inner porphyritic variant is transitional over a few metres, marked by the incoming of feldspar mesocrysts. On the south shore of Loch Sunart this boundary is partly obscured by a meladioritic intrusion, that is chilled against the non-porphyritic facies. The inner granodiorite is characterized by variably abundant pink microperthitic K-feldspar megacrysts (up to 2 cm long) and plagioclase phenocryts (up to 1 cm long). Both lithologies contain prominent phenocryst of pink-brown titanite up to 0.5 cm long.

A weak to strong foliation defined by the alignment of the ferromagnesian minerals and plagioclase, is present throughout most of the site. The foliation dips inwards, flattening towards the centre of the intrusion. It decreases in intensity away from the margins, and in the porphyritic facies, is often overgrown by the K-feldspar megacrysts. Abundant mafic-rich enclaves have regular ellipsoidal or lenticular shapes, flattened in the plane of the foliation. However, there is no evidence of any significant deformation or recrystallization of either the fabric-defining minerals or the interstitial quartz and K-feldspar in the granodiorites.

Meladioritic bodies and mafic microgranular enclaves

Of principal interest in the GCR site are numerous mafic-rich enclaves, prevalent within the Loch Sunart facies. These take the form of large meladiorite bodies, smaller microdioritic inclusions and amphibole-rich clots. Three large lenticular steep-sided bodies crop out at Ranachan, Rubh' an t-Sabhail and Rubha na Sròine (Figure8.8). Their contacts with the host granodiorite have irregular lobate forms, with globular mafic detachments. Fine-grained, (?)chilled, margins are common, in which the ferromagnesian minerals have skeletal or crudely radial forms (7941 6016; 7852 6107). All show compositional zoning outwards from coarse-grained meladiorite to finer-grained heterogeneous, variably plagioclase-phyric, hybrid leucodiorites. The latter often enclose mafic-rich fragments. The hybrid marginal rocks are commonly either veined by the host granodiorite or net-veined by microgranitic pegmatite segregations. In hybrid rocks at the margin of the Rubh' an t-Sabhail body, the pervasive mineral fabric is refracted from the host granodiorite into the appinitic xenolith.

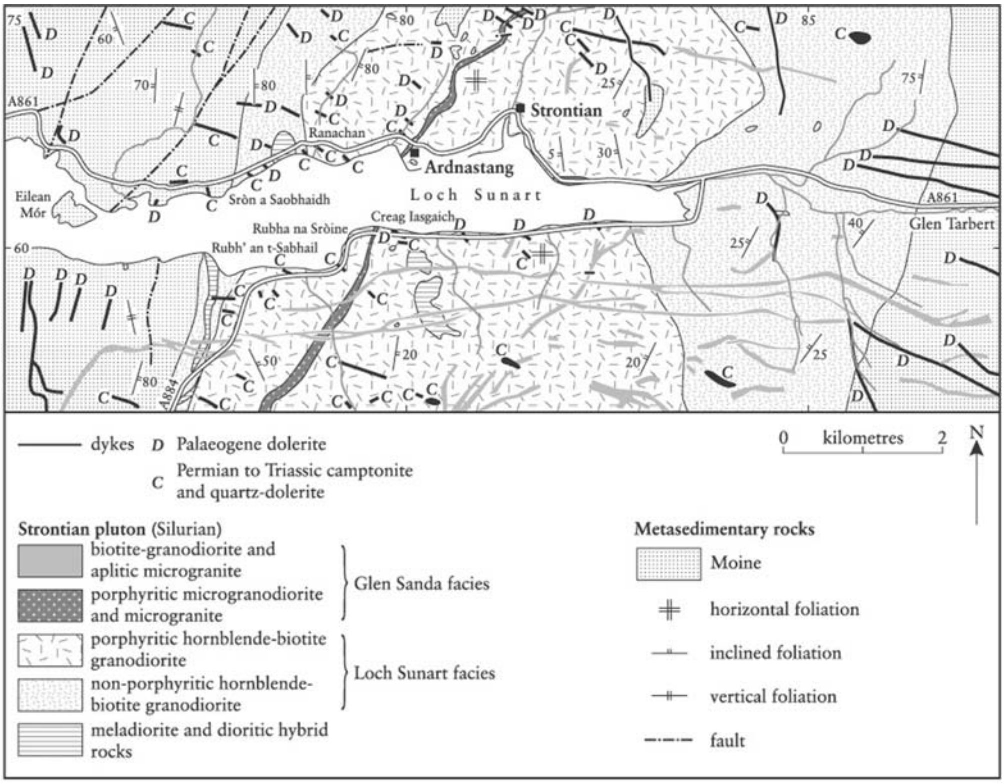

Figure 8.8: Map of the area around the Loch Sunart GCR site, Strontian pluton, adapted from BGS sheets 52E and 53.

Mafic microgranular enclaves are abundant, forming trains of ellipsoidal fragments aligned parallel to the foliation fabric in the granodiorite host (Figure8.9). The enclaves are predominantly hornblende-plagioclase quartz-diorites, and rarely porphyritic tonalites. The non-porphyritic granodiorite contains numerous amphibole-titanite-rich clots, up to 8 mm in diameter. Compositional zoning is common from marginal intergrowths of hornblende, biotite and plagioclase, enclosing largely monomineralic cores of actinolitic amphibole.

Figure 8.9: Mafic microgranular enclaves (MME) in porphyritic biotite granodiorite of the Strontian pluton, Rubh' an Torr-mholaich, Loch Sunart (NM 8133 6015). (Photo: BGS no. C4000.)

Minor intrusions of porphyritic microgranodiorite/granite

Rocks of the Loch Sunart facies and meladiorite bodies are cut by NE-trending sheets and/or dykes of compositionally heterogeneous porphyritic microgranodiorite and microgranite (Figure 8.8). A *c*. 20 m-wide intrusion crops out on both shores of Loch Sunart, to the west of Ardnastang and at Creag Iasgaich on the south shore. The intrusion contains both microdiorite and foliated mafic-rich microgranular enclaves, in varying stages of assimilation. Feldspar mesocrysts overgrow contacts between the hybrid rocks and enclaves.

Glen Sanda facies

This facies is not well represented within the GCR site (Figure8.8), but sheets and dykes of a pink-grey, medium-grained biotite granodiorite extend northwards as far as Loch Sunart and Glen Tarbert. These sheets are mostly parallel sided, with sharp angular contacts; they contain xenoliths of hornblende-biotite granodiorite and lack the foliation that is ubiquitous in the earlier facies. They are variably feldspar-phyric, with pale-pink euhedral phenocrysts of plagioclase (up to 5 mm) enclosed by irregular white rims of albite and poikilitic mesocrysts of K-feldspar (up to 8 mm). Biotite is the predominant mafic mineral (with hornblende rare), but forms less than 10% of the rock.

Interpretation

The Strontian pluton contains two distinct facies, a hornblende-biotite granodiorite and a biotite granodiorite. A two-stage emplacement model has been suggested, with intrusion of the Loch Sunart followed by the Glen Sanda body (Munro, 1965, 1973). Sabine (1963) described the pluton as funnel shaped. Munro (1965) ascribed this form to initial intrusion of a stock-like mass centred in the southern part of the pluton. On reaching the level of emplacement, the magma body expanded laterally in a northerly direction, forcibly distending into the country rock envelope. The internal foliation in the Loch Sunart body was interpreted as a magmatic flow pattern, formed during forceful intrusion (MacGregor and Kennedy, 1932; Sabine, 1963; Munro, 1965). The Glen Sanda intrusion was seen as a later stock, with an apparently brittle mode of intrusion with stoping and sheeting, reflecting emplacement at a higher crustal level than the Loch Sunart intrusion (Munro, 1965). A considerable time gap was invoked to accommodate the apparent uplift, and current geochronology separates the intrusions by approximately 7 Ma. Given the estimated emplacement level of the Loch Sunart body at 14 km, an uplift rate in excess of 1 km per Ma would be necessary to accommodate the high level of intrusion implied for the Glen Sanda body.

More recent studies suggest that the internal foliation in the Loch Sunart facies is a pre-full crystallization fabric, rather than magmatic flow, with the highest strains occurring towards the margins of the pluton (Hutton, 1988a, 1988b). Minerals both defining the fabric and filling the interstices show little evidence of recrystallization. Hence, the foliation in the northern part of the pluton is not a high temperature solid-state tectonic fabric, but reflects the impositon of strain upon an inward accreting crystal framework. Crystal plastic strain fabrics are present in the hornblende-biotite granodiorite elsewhere in the pluton, adjacent to the western boundary with the biotite granodiorite intrusion (Hutton, 1988b). This is an indication of continuing imposition of strain after local consolidation. The variation in orientation of the foliation within the northern part of the pluton (well illustrated within the GCR site), coupled with asymetric vein shear-sense indicators (seen elsewhere), was interpreted by Hutton (1988b) as consistent with a southerly directed listric extension at the time of emplacement, rather than with diapirism or ballooning. Space created during this deformation, at the extensional termination of a dextral shear splay of the Great Glen Fault, allowed the intrusion of the later biotite granodiorite (Hutton, 1988a, 1988b).

Mafic-rich enclaves are common inclusions within ‘I-type' granitic intrusions, and are abundant within the Strontian pluton. They have been interpreted as disrupted precursor ‘appinite' and microdiorite intrusions (MacGregor and Kennedy, 1932; Sabine, 1963). However, recent studies suggest that the enclaves represent synplutonic basaltic intrusions and autoliths, which have mantle isotopic signatures (Holden, 1987; Holden *et al*., 1987; Holden *et al*., 1991; Stephens *et al*., 1991). Interaction of these hydrous basic melts with the host granitic magma has given rise to the dioritic hybrids (Holden *et al*., 1987). The lobate margins to most of the enclaves are indicative of liquid–liquid contacts, with the fine-grained edges representing quenching against a lower temperature host granitic magma. The liquid–chill contacts with differing granitic facies implies episodic intrusion of basic magma throughout pluton emplacement.

Castro and Stephens (1992) suggested that the amphibole-rich clots formed as reaction products between pyroxene and the host magma. The source of the pyroxene is equivocal. They may either represent phenocrysts from the basic magma dispersed during mingling with granodioritic magma, or they may have been derived from the source as restite. The granoblastic textures within the clots might favour a restite origin.

Conclusions

The Loch Sunart GCR site represents one of the finest examples worldwide of mid-crustal pluton emplacement. Fabrics and textures of the pluton clearly demonstrate the effect of active shearing during intrusion and crystallization of magma, which here was probably contemporaneous with movement within the Great Glen Fault system. The site is equally important in demonstrating succinctly the interaction of contemporaneous basic and granodioritic magmas during pluton emplacement, and also the incorporation of residual unmelted material from the source area (restite). The occurrence of basic rocks in all the granodioritic facies points to the continuous availibility of basic magma throughout the emplacement history of the pluton.

Reference list

Ahmad, M. U. (1967) Some geophysical observations on the Great Glen Fault. *Nature*, **213**, 275–77.
Barr, D., Roberts, A. M., Highton, A. J., Parson, L. M. and Harris, A. L. (1985) Structural setting and geochronological significance of the West Highland Granitic Gneiss, a deformed early granite within Proterozoic, Moine rocks of NW Scotland. *Journal of the Geological Society of London*, **142**, 663–76.
Castro, A. and Stephens, W. E. (1992) Amphibole polycrystalline clots in calc-alkaline granitic rocks and their enclaves. *Canadian Mineralogist*, **30**, 1093–112.
Friend, C. R. L., Kinney, P. D., Rogers, G., Strachan, R. A. and Patterson, B. A. (1997) U-Pb zircon geochronological evidence for Neoproterozoic events in the Glenfinnan Group (Moine Supergroup): the formation of the Ardgour granite gneiss, north-west Scotland. *Contributions to Mineralogy and Petrology*, **128**, 101–13.
Halliday, A. N. (1984) Coupled Sm-Nd and U-Pb systematics in late Caldedonian granites and the basement under Northern Britain. *Nature*, **307**, 229–33.
Hamilton, P. J., O'Nions, R. K. and Pankhurst, R. J. (1983) Isotopic evidence for the provenance of some Caledonian granites. *Nature*, **287**, 279–84.
Holden, P. (1987) Source and equilibration studies of Scottish Caledonian xenolith suites. Unpublished PhD thesis, University of St Andrews.
Holden, P., Halliday, A. N. and Stephens, W. E. (1987) Neodymium and strontium isotope content of microdiorite enclaves point to mantle input to granitoid production. *Nature*, **330**, 53–6.
Holden, P., Halliday, A. N., Stephens, W. E. and Henney, P. J. (1991) Chemical and isotopic evidence for major mass transfer between mafic enclaves and felsic magma. *Chemical Geology*, **92**, 135–52.
Hutton, D. H. W. (1988a) Granite emplacement mechanisms and tectonic controls: inferences from deformation studies. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **79**, 245–55.
Hutton, D. H. W. (1988b) Igneous emplacement in a shear zone termination; the biotite granite at Strontian. *Geological Society of America Bulletin*, **100**, 1392–99.
Kennedy, W. Q. (1946) The Great Glen Fault. *Quarterly Journal of the Geological Society of London*, **102**, 41–76.
MacGregor, A. G. and Kennedy, W. Q. (1932) The Morvern–Strontian Granite. *Summer Programme of the Geological Survey for 1931*, Part II, pp. 105–19.
Marston, R. J. (1971) The Foyers Granitic Complex, Inverness-shire, Scotland. *Quarterly Journal of the Geological Society of London*, **126**, 331–68.
Munro, M. (1965) Some structural features of the Caledonian granitic complex at Strontian, Argyllshire. *Scottish Journal of Geology*, **1,** 152–75.
Munro, M. (1973) Structures in the south-eastern portion of the Strontian Granitic Complex, Argyllshire. *Scottish Journal of Geology*, **9,** 99–108.
Pankhurst, R. J. (1979) Isotope and trace element evidence for the origin and evolution of Caledonian granites in the Scottish Highlands. In *Origin of Granitic Batholiths* (eds M. P. Atherton and J. Tarney), Shiva, Orpington, pp. 18–33.
Paterson, B. A., Rogers, G. and Stephens, W. E. (1992a) Evidence for inherited Sm-Nd isotopes in granitoid zircons. *Contributions to Mineralogy and Petrology*, **111**, 378–90.
Paterson, B. A., Stephens, W. E., Rogers, G., Williams, I. S., Hinton, R. W. and Herd, D. A. (1992b) The nature of zircon inheritance in two granite plutons. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **83**, 459–71. (Also *Geological Society of America Special Paper*, **272**.)
Paterson, B. A., Rogers, G., Stephens, W. E. and Hinton, R. W. (1993) The longevity of acid-basic magmatism associated with a major transcurrent fault (abstract). *Geological Society of America*, *Abstracts with programs*, **25**, (6), p. A42.
Pidgeon, R. T. and Aftalion, M. (1978) Cogenetic and inherited zircon U-Pb systems in granites: Palaeozoic granites of Scotland and England. In *Crustal Evolution in Northwestern Britain and Adjacent Areas* (eds D. R. Bowes and B. E. Leake), *Geological Journal Special Issue*, No. **10**, pp. 183–220.
Read, H. H. (1961) Aspects of the Caledonian magmatism in Britain. *Liverpool and Manchester Geological Journal*, **2,** 653–83.

Rock, N. M. S. (1983) The Permo-Carboniferous camptonite-monchiquite dyke-suite of the Scottish Highlands and Islands. *Report of the Institute of Geological Sciences* No. **82/14**.

Rogers, G. and Dunning, G. R. (1991) Geochronology of appinitic and related granitic magmatism in the W Highlands of Scotland: constraints on the timing of transcurrent fault movement. *Journal of the Geological Society of London*, **148**, 17–27.

Sabine, P. A. (1963) The Strontian granite complex, Argyllshire. *Bulletin of the Geological Survey of Great Britain*, **20**, 6–42.

Stephens, W. E., Holden, P. and Henney, P. J. (1991) Microdioritic enclaves within Scottish Caledonian granitoids and their significance for crustal magmatism. In *Enclaves and Granite Petrology* (eds J. Didier and B. Barbarin), Developments in Petrology, No. **13**, Elsevier, Amsterdam, pp. 125–34.

Torsvik, T. H. (1984) Palaeomagnetism of the Foyers and Strontian granites, Scotland. *Physics of the Earth and Planetary Interiors*, **36**, 163–77.

Tyler, I. M. and Ashworth, J. R. (1982) Sillimanite-potash feldspar assemblages in graphitic pelites, Strontian area, Scotland. *Contributions to Mineralogy and Petrology*, **81**, 18–29.

Tyler, I. M. and Ashworth, J. R. (1983) The metamorphic environment of the Foyers Granitic Complex. *Scottish Journal of Geology*, **19**, 271–85.