LOCH AILSH INTRUSION

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OS Grid Reference: NC330115– 360150– 330160– 310140– 310125

Introduction

The Loch Ailsh intrusion (Figures 7.7, 7.8), lies at the eastern margin of the Assynt culmination, immediately below the Moine Thrust, which brings metasedimentary rocks of the Moine Supergroup over its eastern edge (Figure 7.2). It is largely composed of syenite, an unusual rock type, both in a worldwide and a British context, and the Loch Ailsh syenites have an unusually high ratio of sodium to potassium. Its main rock types are similar to the late syenite suite in the nearby Loch Borralan intrusion but it does not include the very strongly alkaline silica-undersaturated rocks of the latter intrusion, is mineralogically much less diverse and has figured less in the geological literature. Although it is rather better exposed than the Loch Borralan complex, many critical relationships are nevertheless obscured by peat. The Loch Ailsh intrusion is the world type-locality for the nearly mono-mineralic alkali feldspar rock ‘perthosite', and provides evidence for the fractionation, prior to emplacement, of a series of syenitic magmas that become more leucocratic and more peralkaline with time. It is also particularly interesting because of the direct evidence it affords concerning the incorporation of material from Cambro-Ordovician dolomitic limestones, and it provides an instructive range of contact metamorphic rocks from various sedimentary lithologies.

Figure 7.7: Loch Ailsh and the upper valley of the River Oykel from the south. The snow-covered ridge is Ben More Assynt (998 m), with Conival (987 m) at the extreme left. The Loch Ailsh intrusion extends from just north of the loch to the base of the eastern end of this ridge. The dark, rocky hill in the left middle distance is Black Rock, formed of syenite S3 ('perthosite'). The rough ground immediately behind the cottage is Durness Group carbonate rocks, while the low cliff in the foreground is an exposure of Moine metasedimentary rocks. (Photo: I. Parsons.)

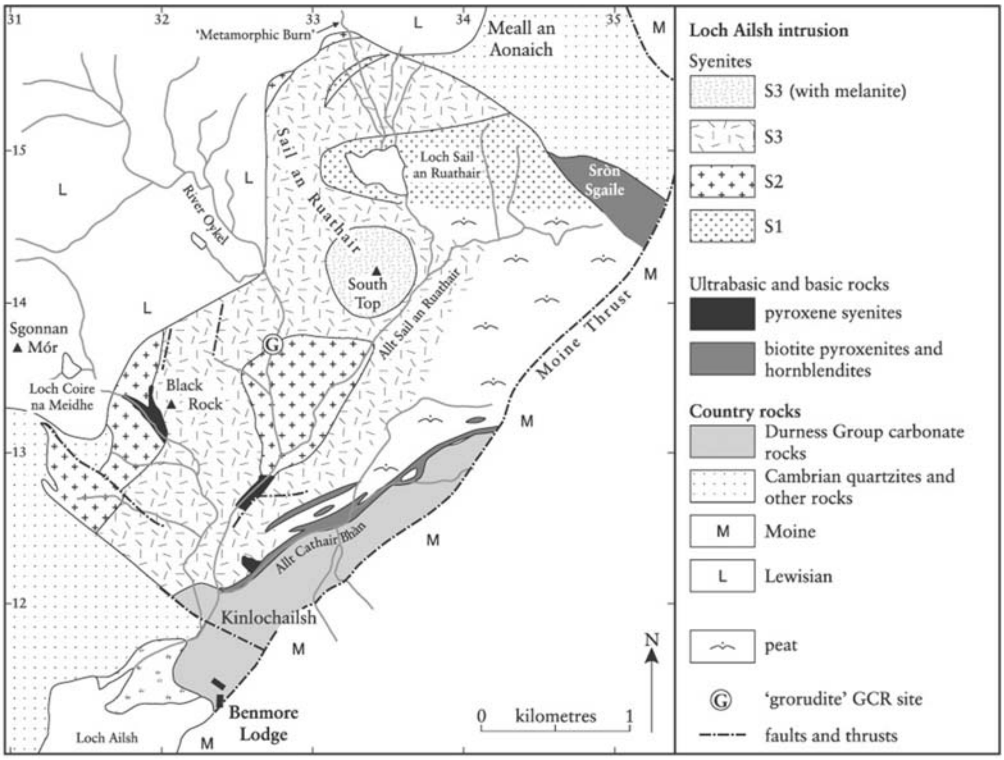

Figure 7.8: Map of the Loch Ailsh intrusion. The extent of the pyroxenites in the Allt Cathair Bhan is based largely on magnetic anomalies. (After Johnson and Parsons, 1979, fig. 15.)

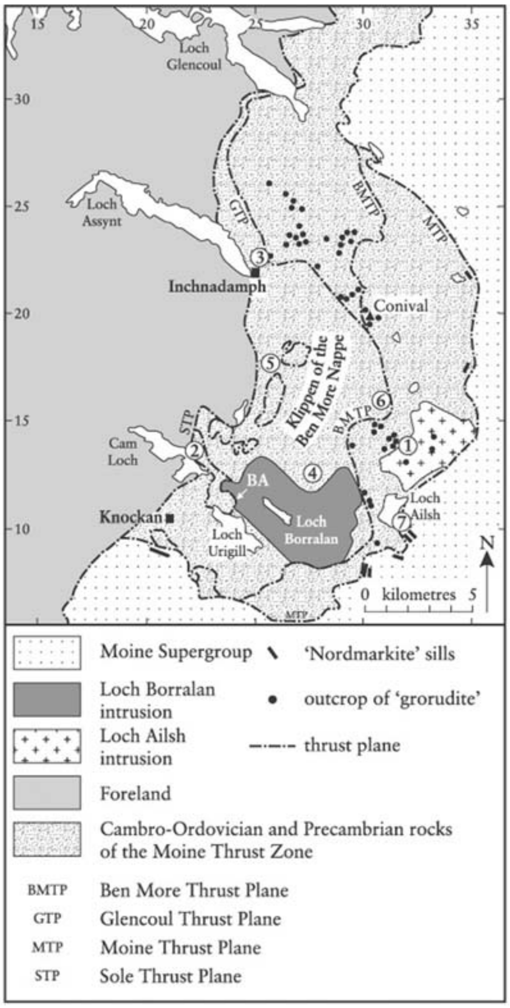

Figure 7.2: Map of the Assynt district showing the major thrusts, the two major alkaline intrusions, and the distribution of two of the six types of minor intrusive rocks. BA is the critical locality, at Bad na h-Achlaise, where nepheline-syenites and pyroxenites of the Loch Borralan intrusion are intruded into one of the klippen (the Cam Loch Klippe) of the Ben More Nappe. GCR sites in the thrust zone related to minor intrusive rocks are shown by circled numbers. 'Grorudite': 1, Glen Oykel South; 2, Creag na h-Innse Ruaidhe. 'Hornblende porphyrite': 3, Cnoc an Droighinn; 4, Luban Croma. 'Vogesite': 5, Allt nan Uamh; 6, Glen Oykel North (diatreme). 'Nordmarkite': 7, Allt na Cailliche. (After Sabine, 1953 and Johnson and Parsons, 1979, fig. 3.)

The intrusion was first described by Peach *et al*. (1907), who considered that it rests on a thrust (which they called the Sgonnan Beag Thrust). The petrology and internal structure were first described, in considerable detail, by Phemister (1926). Following a fashion of the time, he considered the intrusion to be a stratified laccolith, with a floor of dense pyroxenites. This interpretation did not survive later geophysical work (Parsons, 1965a), but the overall shape of the intrusion is still enigmatic. The age relationships of the Loch Ailsh and Loch Borralan intrusions are critical in understanding the relative and absolute timing of thrust movements in Assynt.

The igneous rocks are mainly sodium-rich alkali feldspar-syenites, for the most leucocratic of which Phemister (1926) coined the name 'perthosite'. Phemister subdivided the syenites into numerous named varieties (modern equivalents are given in parentheses): 'perthosite' (leucocratic alkali feldspar-syenite); aegirine-melanite syenite; 'nordmarkite' (quartz-syenite); 'pulaskite' (pyroxene syenite); riebeckite syenite; 'shonkinite' (pyroxene-rich syenite). Phemister's use of 'shonkinite' is not followed by more recent terminology, which requires the presence of nepheline. In contrast with Loch Borralan, feldspathoids are not found in the Loch Ailsh pluton. In addition, he recognized ultramafic biotite pyroxenites and hornblendites, similar (apart from the absence of garnet from the Loch Ailsh examples) to the 'cromaltites' described by Shand (1910) in the Loch Borralan complex, and drew attention to the similarity between them and the rock type 'jacupirangite' discovered in other alkaline complexes.

The pyroxene syenites occur chiefly as xenoliths enclosed in the leucosyenites, and form a discontinuous roof to the earlier syenite units, while the pyroxenites and hornblendites form a substantial, although poorly exposed vertical marginal body. These rocks occur between the more felsic intrusive rocks and Durness Group dolomitic limestones along the eastern margin, in a similar structural setting to the equivalent 'cromaltites' at Loch Borralan.

Halliday *et al*. (1987) obtained a U-Pb age of 439 ± 4 Ma on zircons from two samples of Loch Ailsh syenite, a little older than the age of 430 ± 4 Ma obtained for the Loch Borralan intrusion using the same method. Although the western contact of the Loch Ailsh mass is now only about 1 km east of the contact of the Loch Borralan intrusion (Figure 7.2), at the time of its emplacement the Loch Ailsh intrusion may have been several tens of kilometres farther to what is now the SE, because the Ben More Thrust lies in the ground between. There is good evidence that most units of the Loch Borralan intrusion were emplaced after the main movements on the Ben More thrust plane, because alkaline dykes of the 'grorudite' suite cut the Loch Ailsh intrusion and rocks above the Ben More Thrust only.

There is some disagreement over the age relationships between the Loch Ailsh intrusion and structures within the enclosing Ben More Nappe. Milne (1978) suggested on the basis of careful mapping that the intrusion was emplaced later than the earliest phase of deformation in Assynt, the Sgonnan Mór folding. However, Halliday *et al*. (1987) suggested that greenschist facies recrystallization in some xenolithic pyroxene syenites in the Loch Ailsh intrusion could be correlated with the Sgonnan Mór phase of folding.

The contact relationships of the Loch Ailsh intrusion, and its three-dimensional shape, are not easily defined. On Sgonnan Beag mylonitized syenite is seen against Cambrian quartzite (the Sgonnan Beag Thrust of Peach *et al*., 1907) but the plane of movement at the exposure dips steeply in a southerly direction rather than NE, beneath the intrusion. In the ground north of Loch Sail on Ruathair, in the unnamed stream that Phemister (1926) called the 'Metamorphic Burn' (333 153), the intrusion appears to finger into Cambrian sedimentary rocks dipping to the SE, showing that it is emplaced in the rocks of the Ben More Nappe. The range of contact metamorphosed Cambrian sedimentary lithologies exposed in this stream are an instructive and valuable feature of the intrusion. In the SE of the intrusion, in the Allt Cathair Bhàn (324 122), an interpretation of the very large magnetic anomalies caused by the high magnetite content of the pyroxenites (Parsons, 1965a), showed that the contact of these rocks against Durness Group dolomitic limestones is steep.

In places, rocks of the Loch Ailsh intrusion are considerably deformed by late movements in the Moine thrust zone. Zones of mylonite occur at several localities and are well seen in the River Oykel (325 127) and at the SW corner of Black Rock (318 135). Coward (1985) considered that there was no evidence for late movements on the Moine Thrust itself in eastern Assynt. The geophysical work (Parsons, 1965a) showed that the eastern edge of the Loch Ailsh complex very probably passes under the Moine Thrust, although there are no exposures to confirm this, and it is not possible to say whether the thrust truncated the intrusion or merely acted as a roof. Feldspar in the Loch Ailsh syenites is often very turbid and coarsely exsolved, perhaps because of deuteric alteration beneath an advancing, warm Moine Nappe, and the absence of alkaline hypabyssal rocks from the Moine also suggests late movements on the Moine Thrust itself.

Description

The intrusion is about 10 km² in area (Figure 7.8), extending from within 750 m of the northern shore of Loch Ailsh and on either side of the Oykel valley for some 3 km. It forms several low hills (Figure 7.7), Black Rock on the eastern shoulder of Sgonnan Mór and the ridge of Sail an Ruathair, and extends up to roughly the 350 m contour on the lower slopes of Meall an Aonaich. Most of the intrusion is composed of syenites, very rich in feldspar and poor in ferromagnesian minerals (leucosyenites). Three intrusive phases can be recognized, called S1–S3 by Parsons (1965b). The syenites are all silica-saturated or oversaturated; there are minor amounts of quartz in some rocks, but nepheline has not been found. The earlier syenite units, S1 and S2, contain appreciable amounts (up to 20%) of pyroxene or alkali amphibole, but the last phase, S3, is largely the near-monomineralic alkali feldspar-syenite 'perthosite'.

Contact relationships show that S1 was emplaced first, and chemically it is less evolved than S2 and S3, a feature best shown by the progressive increase in the aegirine content of the pyroxenes (Parsons, 1979). The age relationships between S2 and S3 can be seen in the centre of the complex, where the junction includes an extensive zone of mixing. The central part of S3, forming the 408 m summit of the Sail an Ruathair ridge (333 143), which Phemister (1926) suggested perhaps represented a feeder for the intrusion, is slightly richer in mafic minerals than the bulk of S3 and contains melanite garnet, titanite and thoroughly sodic clinopyroxenes (aegirine-hedenbergite), showing it to be the most evolved part of the complex (Parsons, 1979).

Pyroxene syenites (‘shonkinites' of Phemister, 1926) occur at localities in the River Oykel (326 127), and in the Black Rock Burn (318 133). Phemister believed that these are entirely igneous, forming part of a lower, more mafic zone in a stratified laccolithic body, but Parsons (1968) provided chemical and textural evidence that they are partly formed of mafic material contributed by contact metamorphosed Cambro-Ordovician dolomitic limestone xenoliths. The pyroxene syenites appear to map out on the upper surface of the earlier S2 phase of syenite intrusion, suggesting that they represent a fragmented roof to this earlier phase of injection.

Ultramafic biotite-magnetite pyroxenites and hornblendites, crop out in isolated localities along the eastern margin of the complex, along the Allt Cathair Bhàn (324 122). These rocks were taken by Phemister (1926) to represent the base of a laccolith, much as Shand (1909) had suggested for the ‘cromaltites' at Loch Borralan. However, the profile of the extremely large magnetic anomalies associated with the pyroxenites (Parsons, 1965a) can be explained only by a set of sub-vertical screens of ultramafic rock, also, like Loch Borralan, interposed between syenite and Durness Group limestone. The similar structural setting of the pyroxenites in these two otherwise distinctly different intrusions, and the mineralogy of the pyroxenites, led Parsons (1979) to suggest that the pyroxenite bodies are large metasomatic skarns, formed by reactions between syenite and dolomitic limestone, but at Loch Borralan later excavations clearly showed that pyroxenites were intrusive into quartzites and by analogy with Loch Borralan, the igneous origin of the very similar Loch Ailsh pyroxenites is no longer in doubt. Nevertheless the emplacement of such a rock mass, very rich in the Ca-Mg pyroxene, diopside, as a magma, is an unresolved petrogenetic problem and the reader is referred to the discussion of this in the description of the Loch Borralan GCR site.

The isolated hillock known as Sròn Sgaile in the NE corner of the complex (348 148) is composed of ultramafic hornblendic rocks at the base passing up into a more leucocratic feldspar- hornblende rock at the top. Phemister (1926) thought that this represents a section through the lower zone of his postulated stratified laccolith. The rocks have distinctive textures, particularly the presence of large plates of a green mica with a ‘sieve' texture, enclosing feldspar and hornblende, and are cut by a striking network of syenitic veins with conspicuous ferromagnesian minerals. Although these rocks are undoubtedly part of the Loch Ailsh intrusion, exposure around them is so poor that their structural relationships remain enigmatic. A magnetometer survey did not reveal a connection with the pyroxenites of Cathair Bhàn (Parsons, 1965a).

Syenites

The leucocratic syenites were described in detail by Parsons (1965b). Units S2 and S3 are well exposed throughout the southern part of the complex. S1 is less well exposed and crops out in Coire Sail an Ruathair. The most informative areas are those that show the inter-relationships between the units, and three critical exposures are of particular interest. At the base of the cliffs beneath the northern summit of the Sail an Ruathair ridge the junction between S1 and S3 can be examined (331 152) (Figure 7.9). S1 is coarse grained, red in colour, and has a distinct igneous lamination, shown by alignment of the slightly flattened feldspars. The S1 unit forms a dome-shaped body that does not penetrate S3 on the west side of the Sail an Ruathair ridge. The later S3 veins the earlier syenite, and encloses it as xenoliths. It is possible to demonstrate from rotation of the igneous lamination that the xenoliths have been rotated by the forceful injection of S3. This feature also shows that the lamination is igneous, and not tectonic, in origin. A screen of red syenite resembling S1 is enclosed in S3 in the central portion of the exposed section of the ‘Metamorphic Burn' (see below), an interpretation confirmed by detailed work on the feldspars (Parsons, 1965b). This mass has sharp contacts, but the S3 in this section of the stream contains disseminated red feldspars which are no doubt xenocrysts from S1.

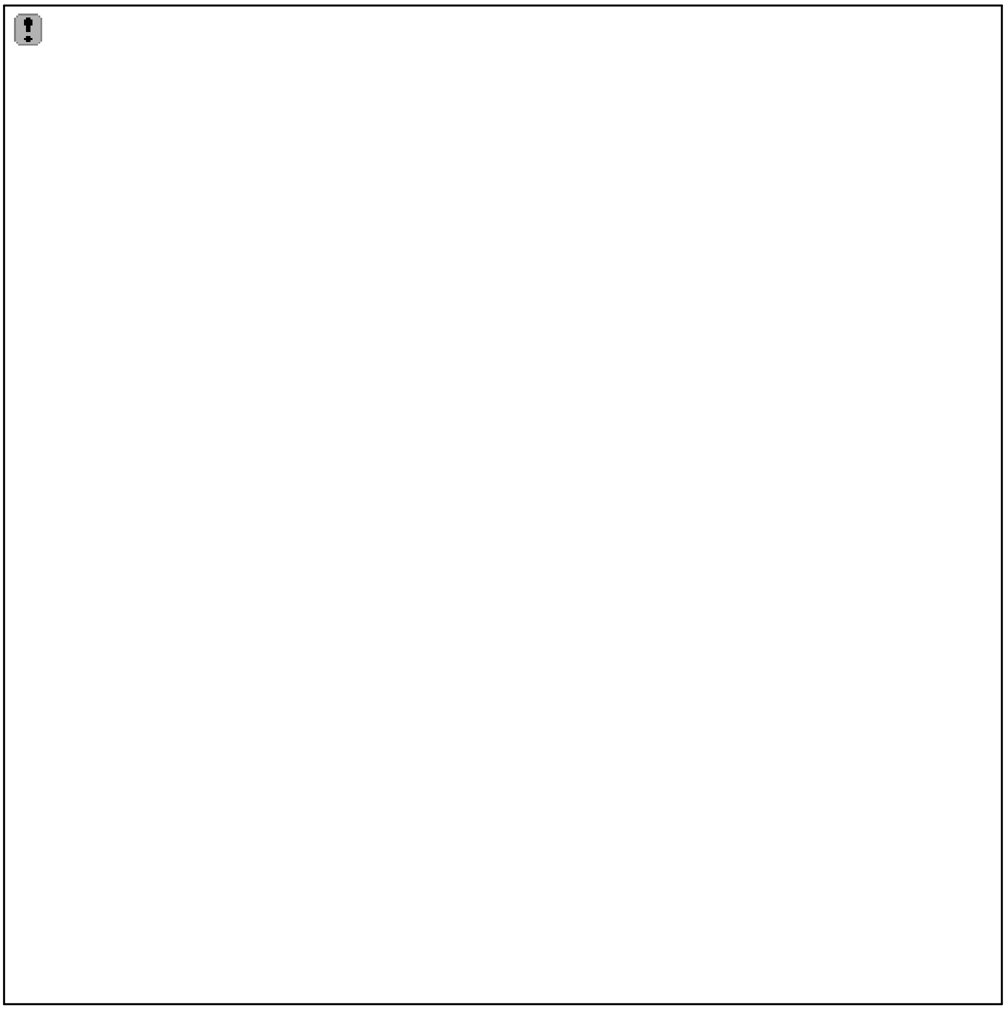

Figure 7.9: Loch Sail an Ruathair and the ridge of Sail an Ruathair in the northern part of the Loch Ailsh intrusion, from the east. The sketch shows the position of the upper contact of a dome of the early syenite, S1, overlain by the perthosite member, S3. (Photo: I. Parsons.)

S2–S3 relationships can be seen in the central part of the intrusion around the confluence of the Allt Sail an Ruathair and the River Oykel (327 130). Here there is an extensive zone of mixing between the two units, and a zone of pink xenocrysts can be mapped in the brown or grey S3 around an inner dome of S2 (Parsons, 1965b). The southern edge of this mixed zone, around the large waterfall in the River Oykel, (326 127) includes pyroxene syenite xenoliths (see next section). Rather similar relationships can be well seen in the upper section of the Black Rock Burn (318 133). Here, red xenoliths of S2 can be seen in S3, again in a zone including pyroxene syenite xenoliths. At the base of the SW cliffs on Black Rock itself (318 134) the suite is involved in a minor thrust plane, and streaking-out of xenoliths can be observed. As elsewhere in the intrusion, S2 underlies S3, but here the upper surface of S2 dips to the SE, and S2 extends on to the flanks of Sgonnan Mór.

Mineralogically, S1, S2 and S3 form an evolutionary series. The mafic mineral in most rocks is a pyroxene, those in S1 being diopsidic (calcium- and magnesium-rich), while those in S3 can have nearly 50 molecular % of the sodium-iron pyroxene component, aegirine; S2 is intermediate (Parsons, 1979). There are slight parallel changes in alkali feldspar composition, those in S1 being exceptionally rich in the albite molecule (*c*. 75 molecular %), those in S3 richer in orthoclase (*c*. 65 molecular % albite). Some facies, particularly of S2, contain a strongly pleochroic riebeckitic alkali amphibole instead of, or in addition to, pyroxene. Melanite garnet, often zoned and intergrown with titanite, appears only in the part of S3 that forms the southern summit on the Sail an Ruathair ridge (Figure 7.8). The boundaries of this variety appear to be gradational, but it contains the most evolved pyroxenes in the complex, suggesting that it was the final part of the intrusion to solidify. This part of the intrusion sometimes contains very small amounts of quartz and also muscovite. The presence of melanite together with quartz is unusual: melanite is usually present together with feldspathoids.

Pyroxene syenites –'shonkinites'

The most important exposure of these rocks is in the River Oykel (326 127). Here, the pyroxene syenites are in the form of blocks, characteristically less than 1 m across, enclosed in leucosyenite, and the whole xenolith complex is cut by a network of leucosyenite veins. These veins are of two types, grey and red, which presumably correlate with the S2 and S3 syenite generations. The pyroxene syenite xenolith zone is enclosed by the gradational contact zone between S2 and S3. The xenoliths are therefore enclosed by mixed syenite forming the upper surface of a dome of S2 (Figure 7.8). The blocks are extremely heterogeneous (Figure 7.10, see Parsons, 1968); there are 'ultramafic clots' on the microscopic scale and up to a few centimetres across, composed almost entirely of pyroxene and/or biotite and amphibole, with either sharp or diffuse margins, enclosed in the pyroxene syenites, which are mostly diopside-biotite-alkali feldspar rocks. The 'ultramafic clots' are texturally very different, particularly in their fine grain-size, to the pyroxenites of Allt Cathair Bhàn and they do not provide direct evidence for the disrupted lower ultramafic zone to the Loch Ailsh pluton postulated by Phemister (1926). On the other hand they have great textural and mineralogical similarities to rocks occurring at syenite–limestone contacts elsewhere in the intrusion.Parsons (1968) illustrated the similarities and proposed that the pyroxene syenites represent the remains of a metasedimentary roof to S2.

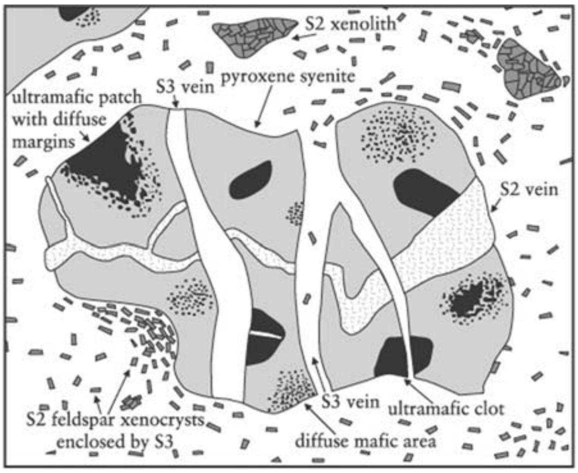

Figure 7.10: Sketch illustrating the relationships between a pyroxene syenite xenolith and feldspathic syenites in the Loch Ailsh intrusion, as seen in the River Oykel and Black Rock Burn areas. A typical xenolith would be about 1 m in length. (After Parsons, 1968, fig. 2.)

Pyroxene syenites also occur as xenoliths in syenite in the Black Rock Burn (319 132 to 316 134). The S2 unit forms an inclined surface extending on to the flank of Sgonnan Mór and the pyroxene syenites are enclosed by both S2 and S3 near their interface. Xenoliths also occur under the conspicuous overhang at the SW corner of Black Rock (318 134) where they and their vein-networks are stretched and in places mylonitized in a minor thrust plane. At three isolated localities in Black Rock Burn (Figure 7.10) altered limestone xenoliths occur among the pyroxene syenites. Parsons (1968) considered this to be strong support for his hypothesis that the 'shonkinites' are not wholly igneous rocks.

A screen, about 10 m thick, of laminated pyroxene syenite, similar to those seen in the southern part of the intrusion, occurs about halfway up the exposed section of the 'Metamorphic Burn'. As at the other localities, the rock occurs on the upper surface of a body of earlier syenite, in this case S1. There are numerous altered limestone xenoliths both above and below this locality. A 5 m-wide screen of dark-green pyroxenite, and some metre-scale smaller xenoliths, occur 100 m higher up the stream. These resemble the ultramafic clots found elsewhere in the pyroxene syenites. The lowermost screen (stratigraphically highest) is attached directly to a mass of metasedimentary rock representing the Fucoid Beds, whereas the uppermost xenolith is resting against a large mass of quartzite.

Ultramafic rocks

A suite of unusual diopside pyroxenites and hornblendites is exposed at isolated localities along the eastern edge of the complex in Allt Cathair Bhàn (Figure 7.8). Although Phemister (1926) suggested that the exposures of ultramafic rocks are the sole representatives of the lowest zone of a stratified laccolith, large magnetic anomalies (Parsons, 1965a) show that under the peat the pyroxenites form a continuous, dyke-shaped body running from Kinlochailsh, at least to a point 2 km to the NE, where the magnetic anomaly dies out, probably because the rocks of the Loch Ailsh intrusion pass under the Moine Thrust. Smaller, discontinuous lenses of ultramafic rocks are implied by the magnetic anomalies to occur in the leucosyenites to the west, and this has been confirmed by excavation.

The ultramafic rocks are deep blue-green biotite pyroxenites. They are often somewhat sheared, when the pyroxene is converted to a green-brown hornblende. The pyroxenes are close to pure diopside in composition (Parsons, 1979). Like the equivalent ‘cromaltites' in the Loch Borralan intrusion, apatite is abundant, as is ilmenomagnetite, and the latter mineral leads to the very large local magnetic anomalies found over the pyroxenite members of both intrusions. The only worthwhile exposures are at 326 123, where pyroxene syenites occur to the west, and 328 123 and 334 127, where veins and screens of syenite can be seen cutting the ultramafic rocks. Parsons (1965a) presented a computer model of the profile of the magnetic anomalies found at the latter locality in which a vertical body of magnetic ultramafic rocks some 75 m thick is divided by screens of non-magnetic syenite; the depth to the base of the body must be at least 90 m. The nearest adjacent rocks to the west are mostly feldspathic syenites except for some pyroxene syenites at the south end of Cathair Bhàn. To the east are exposures of Durness Group dolomitic limestones, in the screes beneath which diopside marbles can be found. Just east of Kinlochailsh (323 120) beautiful green serpentine marbles can be found. It seems that the pyroxenites form a narrow, continuous screen against these dolomitic limestones and it was this relationship, together with the very Ca- and Mg-rich diopsidic pyroxenes, which led Parsons (1968, 1979) to initially favour the hypothesis that the pyroxenite were formed by in-situ syenite–dolomitic limestone reactions. Whether or not the pyroxenites were emplaced as a mobile magma (as was the case in the Loch Borralan complex) cannot be established from the limited exposure available in the Loch Ailsh complex. The cross-cutting veins of syenite at 334 127 suggest that emplacement of the pyroxenites pre-dated at least the S3 phase of syenite emplacement, although the possibility of rheomorphic back-veining must be considered.

Metamorphic xenolithic rocks

An excellent suite of metamorphic xenolithic rocks occur in an unnamed stream (called the ‘Metamorphic Burn' by Phemister, 1926) which flows into Loch Sail an Ruathair (335 151–333 158). The exposures are important because of the evidence they afford of reactions between syenite magma and sedimentary rocks, which bears upon the origin of pyroxene syenites elsewhere in the complex, and they provide a useful instructional suite of contact metamorphic and alkaline metasomatic rocks. The igneous (and igneous-looking) rocks exposed in the stream are mostly brown ‘perthosite' (S3) enclosing screens of earlier syenites, which may be correlated with S1 and S2 on the basis of colour and texture, and inclusions of pyroxene syenite and pyroxenite similar to those seen in the southern part of the intrusion. Interspersed with these are screens and xenoliths of the Cambro-Ordovician succession in correct stratigraphical order, but with Durness Group dolomitic limestones at the base of the slope, and quartzites at the top, implying a set of tongues of metasedimentary rocks more-or-less in place but dipping SE.

A log of the stream bed, starting at the lowest exposures, which occur about 400 m above Loch Sail an Ruathair, was given by Parsons (1968). At the base there are many originally dolomitic xenoliths, now diopsidic and phlogopitic calc-silicate rocks. Mafic patches can be seen in the enclosing syenites, and at certain localities individual pyroxenes can be observed apparently in the process of incorporation into the syenite. At 170 m (measured along the ground from the lowest exposures) an unusual white, melanite garnet-bearing syenite seems to be related to a large limestone xenolith, and just above here is a thick screen of red syenite (S1). At 270 m a 3 m body of fine, flinty dark-green rock with conspicuous pink feldspars and dark minerals, in contact with white or dark-grey quartzite, represents the Salterella Grit of the Cambro-Ordovician succession. Slightly above, 20 m of baked grey shale, with black streaks, represents the Fucoid Beds. Immediately in contact is a 2 m mass of dark-green pyroxenite, with micaceous patches (a 'shonkinite' of Phemister, 1926). There are also two small xenoliths of altered dolomitic limestones; which must have been moved out of their stratigraphical position by the magma. From the 308 m point upwards the syenite (S3) contains massive quartzite xenoliths that include developments of alkali amphibole, an example of the metasomatic process of fenitization. Conspicuous red feldspar xenocrysts sometimes have their long axes aligned, dipping downstream, and there are xenoliths of red syenite (probably S2). The last exposures seen before the stream flows through drift are of a pink, riebeckite-bearing syenite, probably S2.

Interpretation

The overall form of the Loch Ailsh intrusion is difficult to establish because of poor exposure in the vicinity of the contacts. Evidence that it formed a thrust sheet in its own right, as proposed by the early Survey workers (Peach *et al.,* 1907; Phemister, 1926), is not strong and it seems likely that the intrusion was emplaced in the Ben More Nappe either prior to the first folding phase in Assynt (as postulated by Halliday *et al*., 1987) or shortly after (as proposed by Milne, 1978). This relatively early emplacement has been confirmed by the radiometric age of 439 ± 4 Ma obtained by Halliday *et al.* (1987). The ages provided by the alkaline rocks in Assynt are crucial for dating movements in the Moine thrust belt. The Loch Ailsh rocks in places are deformed (mylonitized) by late movements on the Moine Thrust, and there is geophysical evidence that the eastern contact passes under the Moine. The interfingering of syenite with a largely undisturbed sequence of altered Cambro-Ordovician sedimentary rocks, in the 'Metamorphic Burn' is consistent with a relatively gentle style of emplacement into the rocks of the Ben More Nappe. There is no convincing evidence that the intrusion is a stratified laccolith, as proposed by Peach *et al*. (1907) and Phemister (1926), although the late syenite unit S3 appears to overlie one or other of the earlier S1 and S2 units over much of the intrusion suggesting that S3 has a sheet-like form.

The eastern contact, along which a screen of pyroxenites is interposed between syenite and Durness Group dolomitic limestones, is certainly sub-vertical but the magnetic anomalies that lead to this conclusion give little information on the vertical extent of the intrusion. Like the similar pyroxenites along the southern margin of the Loch Borralan intrusion the origin of these rocks is enigmatic. The pyroxenites in the latter intrusion are definitely intrusive into quartzites and therefore certainly existed as a magma, but there are no exposures at Loch Ailsh that demonstrate that the pyroxenites have an intrusive character. It is curious that in both intrusions the pyroxenites occur only where silicate rocks and dolomitic limestone are in contact. There is no easy explanation for the extended sinuous form of the pyroxenite body if it is entirely intrusive. If it is earlier than the syenites as the cross-cutting veins of syenite superficially suggest, then it is possible that it is an incomplete section of an earlier, arcuate intrusion; alternatively if the syenite veins result from rheomorphism then it is a partial ring dyke. Whatever its structural relationships, the high temperature mineralogy requires that the pyroxenites were emplaced as a crystal mush; there is no direct evidence that they are mobilized cumulate rocks formed *in situ* from the syenite magma, as suggested by Matthews and Woolley (1977) for Loch Borralan, although this is a possible mode of origin.

The syenitic rocks were emplaced in three pulses. They were fractionated before arrival in their final resting place, and become chemically more evolved and peralkaline with time. Both the earlier members (S1 and S2) form dome-shaped bodies overlain by a final unit mostly composed of very leucocratic alkali feldspar-syenite ('perthosite', S3). The slightly more mafic, aegirine- and melanite-bearing variant forming the South Top of Sail an Ruathair is the most highly evolved member. More melanocratic, pyroxene syenites occur as xenolithic blocks at various localities; these seem to appear discontinuously on the upper surface of the earlier syenite units and perhaps represent a disrupted roof, a view supported by the sporadic appearance of metasedimentary xenoliths at the same level. The pyroxene syenites have textural and chemical similarities to syenites demonstrably (in the 'Metamorphic Burn') modified by partial assimilation of altered dolomitic limestone. While on the one hand some of the pyroxene syenites have thoroughly igneous textures, there is also strong textural evidence of assimilation of material of metasedimentary origin. Perhaps the pyroxene syenites represent an early phase of igneous activity itself modified by reactions with the sedimentary envelope. Major element chemistry, mineral chemistry and even trace-element chemistry are equivocal on this subject (Parsons, 1979; Young *et al*., 1994).

Conclusions

The Loch Ailsh intrusion includes a suite of sodic syenites unique in the British Isles, which provide evidence for igneous fractionation processes before emplacement, and include the world type locality for 'perthosite'. The pyroxenites of the eastern margins are extremely enigmatic rocks whose extent and subsurface shape have been elucidated by geophysical means. A suite of intermediate, pyroxene syenites include rocks that have a thoroughly igneous appearance as well as types that have certainly formed by reactions between the syenite magma and dolomitic sedimentary rocks from the envelope. There are very instructive exposures illustrating contact metamorphism, alkali metasomatism (fenitization) and assimilation of a large range of Cambro-Ordovician sedimentary rocks. The structural relationships of the Loch Ailsh body, and its known age of 439 Ma, provide an important age-marker for movements in the Moine thrust zone.

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