Centre 3, Ardnamurchan

OS Grid Reference: NM467702

Highlights

The Great Eucrite in this site forms one of the most perfect annular intrusions in the British Tertiary Volcanic Province (BTVP); it gives rise to a nearly complete ring of hills which dominates the Ardnamurchan Peninsula. The intrusive sequence in Centre 3 changed with time, from early eucrites and gabbros to late intrusions of intermediate and acid compositions.

Introduction

This site encompasses Centre 3 which represents the final stage in the intrusive evolution of the Ardnamurchan complex. Centre 3 consists debatably of seventeen concentric intrusions of highly variable petrography, ranging from coarse gabbros and dolerites to minor, late, intermediate tonalites and quartz monzonites. The Centre has been conventionally regarded as an almost perfect set of nested ring-dykes and is of international repute as such. The form of the masses is excellently reflected by the topography of the area. However, their contact relationships where exposed are often obscure. The contacts of the Centre 3 intrusions with the earlier rocks of the complex are also demonstrated.

Centre 3 was first recognized and described by Richey and Thomas (1930), who interpreted its intrusions as ring-dykes. More recent work by Smith (1957), Bradshaw (1961), Wills (1970) and Walsh (1971, 1975 and in Gribble *et al*., 1976) has challenged this interpretation, and new models of the form of the centre and its constituent intrusions have been proposed. The geochemistry and petrogenesis of the intrusions and their relationships has been investigated by Walsh (1975) and Walsh and Henderson (1977).

Description

The rocks assigned to Centre 3 (Figure 4.9) of the Ardnamurchan complex crop out in a natural amphitheatre spanning 7 km from east to west and 6 km from north to south, the topography accurately reflecting the concentric outcrops of the various intrusions (Figure4.10). Richey and Thomas (1930) recognized seventeen intrusions as ring-dykes which generally become progressively younger towards the middle of Centre 3. The following sequence of intrusions was proposed:

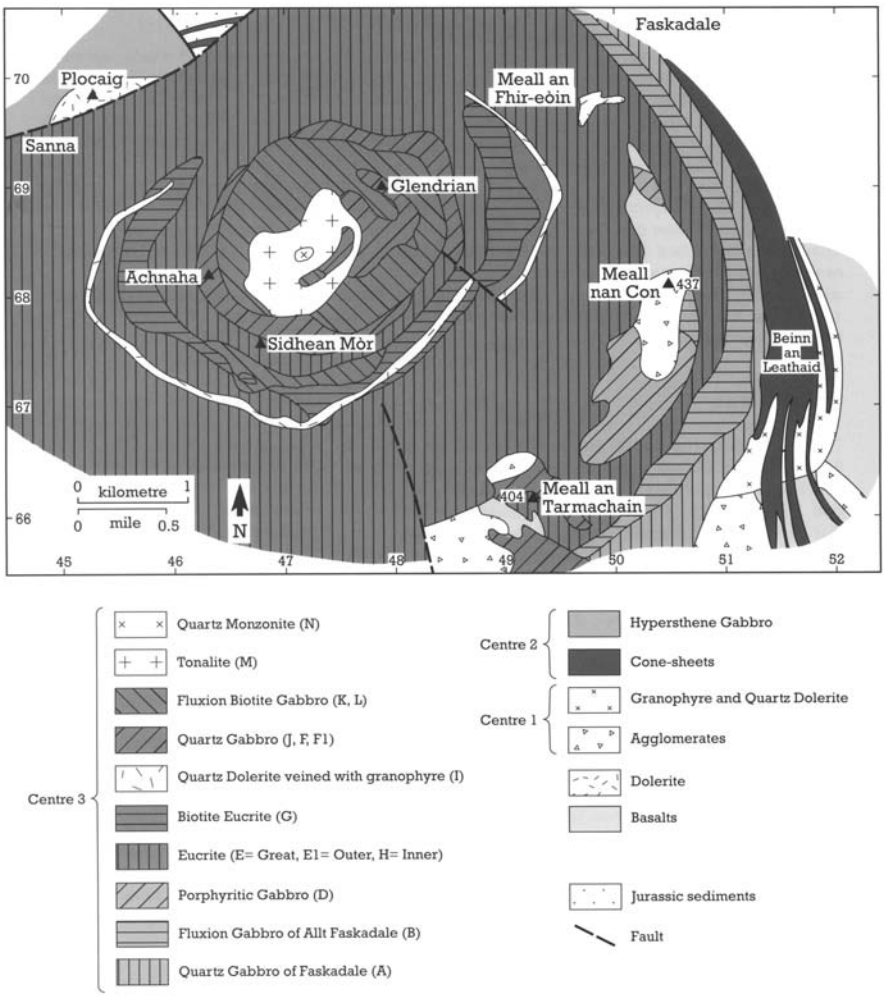

Figure 4.9: Geological map of Centre 3, Ardnamurchan (after Gribble et al., 1976)

Figure 4.10: The natural amphitheatre of Centre 3, Ardnamurchan. The imposing arcuate ridges in the distance are formed by the Great Eucrite. (Photo: A.P. McKirdy.)

oldest

A	Quartz Gabbro of Faskadale
B	Fluxion Gabbro of Faskadale
C	Gabbro of Plocaig (outside site)
C1	Gabbro, south-east of Rudha Groulin (outside site)
D	Porphyritic Gabbro of the Meall nan Con screen
E	Great Eucrite
E1	Outer Eucrite
F	Quartz Gabbro of Meall an Tarmachain summit
F1	Quartz Gabbro, south side of Meall an Tarmachain
G	Biotite–eucrite
G	Inner Eucrite
I	Quartz Dolerite veined with granophyre
J	Quartz Biotite Gabbro
K	Fluxion Biotite Gabbro of Sithean Mor
L	Fluxion Biotite Gabbro of Glendrain
M	Tonalite
N	Quartz Monzonite

youngest

The majority of the rocks are coarse-grained gabbros and dolerites and intermediate rocks comprise only a small fraction of the centre. Few contacts between the individual intrusions are visible and their recognition is based upon minor differences in mineralogy or the presence or absence of structural features rather than clear intrusive relationships.

The intrusions of Centre 3, demonstrated by this site, are described below from the outermost inwards; this order corresponds approximately with the age sequence proposed byRichey and Thomas (1930).

The Quartz Gabbro of Faskadale (A) is the outermost and oldest ring intrusion of Centre 3 and has been described in detail above inBeinn na Seilg–Beinn nan Ord. This mass extends in an unbroken arc from Faskadale Bay, between Beinn an Leathaid and southwards through Meall nan Con and Glas Bheinn to pass beneath the intrusions of Centre 2 on the northern and eastern slopes of Beinn na Seilg. The petrography of the intrusion is very variable and ranges from olivine eucrite to basic granophyre.

On Glas Bheinn (NM 493 648), the truncation of the outer cone-sheets of Centre 2 and Centre 1 country rock by the Faskadale intrusion is very marked, although the actual contact is not visible. Along its contact with the Hypersthene Gabbro of Centre 2 exposures are discontinuous and the relationships of the two rocks are obscured by intervening screens of amygdaloidal basalt and possibly by shattering (Richey and Thomas, 1930). To the south-west of Meall an Tarmachain (NM 493 663), highly metamorphosed remnants of an original volcanic cover form a roof to the Quartz Gabbro, the contact dipping gently to the south-west. On its inner margin, the Quartz Gabbro of Faskadale is in contact with at least three later intrusions of Centre 3 – the Fluxion Gabbro of Faskadale, the Quartz Gabbro of Meall an Tarmachain and the Great Eucrite.

The arcuate Fluxion Gabbro of Faskadale (B) extends from Faskadale along the Allt Faskadale to the south-eastern slopes of Meall an Tarmachain. Its outer margin abuts the Quartz Gabbro of Faskadale and petrographically there is little other than the texture to distinguish the two rocks; at the single exposure of their contact described in the Memoir, the supposedly older Quartz Gabbro shows no thermal metamorphism. The petrological features of the Fluxion Gabbro have been described above.

At Plocaig (NM 453 698), beyond the north-eastern limit of the site near Sanna Bay, a small

and apparently lenticular mass of moderately coarse-grained, occasionally feldspar-phyric olivine gabbro (C) lies between the north-western margin of the Great Eucrite and the Hypersthene Gabbro (Centre 2). This intrusion contains xenoliths of granular, hypersthene-bearing hornfels and of the Hypersthene Gabbro. The contacts are obscure but this gabbro is believed to be intermediate in age between these two major intrusions.

The Meall nan Con ridge and summit are formed of highly metamorphosed agglomerates intruded by a small mass of gabbro (D). The gabbro extends in two short, arm-like projections on either flank of the agglomerate. Thermal alteration of the gabbro ‘arms' ledRichey and Thomas (1930) to conclude that the gabbro is older than the adjoining eucrites;Bradshaw (1961), however, argues that the gabbro might well be part of the Great Eucrite, a view reinforced by the work of Walsh (1971).

The Great Eucrite (E), which here includes the Outer Eucrite (E1), Biotite Eucrite (G) and Inner Eucrite (H) of Richey and Thomas (1930), is the most spectacular unit of the Ardnamurchan complex. It forms an almost continuous, bold, glacially sculptured annular ridge in marked topographic contrast with the subdued landforms developed from the intrusions it encircles (Figure 4.10). The eucrite is thus the only example in Ardnamurchan of a complete ring-intrusion and, at the present level of erosion, makes up over half of the outcrop of Centre 3. The rock is typically coarse and feldspathic, but like many of the Ardnamurchan intrusions, varies greatly in detail; the proportions of feldspar, augite and olivine vary, often abruptly. Flow-banding is restricted to the inner parts of the intrusion and the outermost zones are rich in tangential, near-vertical, augite-rich pegmatite veins. The Great Eucrite is presumed to be younger than the Faskadale Quartz Gabbro, and Fluxion Gabbro, although the evidence for this is inconclusive because of the poor exposure in the critical areas. According to Richey and Thomas, the Biotite Eucrite lies between the Great and Inner Eucrites, distinguished by the widespread, but by no means ubiquitous, occurrence of biotite. However,Bradshaw (1961) has shown that biotite occurs in all the Ardnamurchan eucrites and there appears to be little convincing evidence to show that the three eucrites are separate intrusions.

The Quartz Gabbro forming the summit at Meall of an Tarmachain (F) is a small intrusion which contains localized olivine-rich and eucritic segregations. The clinopyroxenes in this gabbro are markedly different from all other gabbros, with the complex being enriched in iron and deficient in calcium (Walsh, 1975), thus supporting its status as an independent intrusion. It is disputably younger than the adjoining eucrite and the Quartz and Fluxion gabbros of Faskadale. A second mass of quartz gabbro outcrops to the south of the summit (F1); both intrude agglomerates and basalts.

A narrow arcuate intrusion of dolerite veined by granophyre (I) crops out intermittently in small isolated knolls in the low-lying area within the Great Eucrite outcrop. It extends in an extremely narrow, discontinuous horseshoe from Meall an Fhir-eoin (NM 486 698) south, west and northwards to terminate close to the Allt Sanna. It was the first intrusion to be mapped as a ring-dyke on Ardnamurchan by the Survey. The attitude of the contacts with the older Great Eucrite can be closely estimated to dip outwards at about 70°. The dolerite is remarkably homogeneous compared with the coarser gabbros and eucrites, and it contains a relatively higher proportion of biotite and more sodic plagioclase. Localized hornblende and biotite indicate that the mass may be partly a hybrid in origin.

Three masses of quartz biotite gabbro (J) around Glendrain (NM 479 690), Achnaha (NM 463 682) and Druim Liath (NM 475 683) were presumed byRichey and Thomas (1930) to be parts of a single intrusion which once occupied the central parts of the complex, but was disrupted by later intrusions. Exposure is generally poor here and the contact relationships with the adjoining eucrite are difficult to establish. The gabbros are petrographically heterogeneous and show considerable variations in grain size, from dolerites to pegmatites and in modal mineralogy.

Two intrusions of fluxion gabbro have been mapped within Centre 3; these are known as the Glendrain (L) and Sithean Mor (K) gabbros respectively. The Glendrain intrusion is a titaniferous, magnetite-rich, basic rock, and it has an almost complete ring-shaped outcrop about Centre 3 and forms a resistant, prominent ridge above the inner, younger intrusions. It is closely associated with a quartz–biotite gabbro which it almost certainly post-dates, xenoliths

of the quartz–biotite gabbro being reported, but chilling being absent at the exposed contact. The fluxion texture is produced by the lamination of labradorite crystals dipping inwards towards Centre 3 at 30°-40°. Hybridization by an acid magma before emplacement has been suggested (Richey and Thomas, 1930), this resulting in the local concentration of apatite and abundant interstitial feldspar growths of quartz and alkali feldspar. The Fluxion Gabbro of Sithean Mor (K) crops out as a small, crescent-shaped body which forms a prominent steep-sided ridge surrounded by eucrites. Although termed a fluxion gabbro (Richey and Thomas, 1930), only the northern parts show any alignment of feldspars and the rock grades southwards into a uniform quartz gabbro. The rock appears to be younger than the adjoining Inner Eucrite against which it is chilled and it also bears a few xenoliths of the eucrite.

The Tonalite (M) occupies low-lying, poorly exposed ground in the middle of Centre 3 and its outcrop forms one of the most extensive areas of intrusive intermediate rocks within the BTVP. The mass is roughly ovoid, being elongated north-east to south-west, and has a distinctive appearance with large platy biotites in a leucocratic feldspathic groundmass. The margins of the intrusion against the Fluxion and Quartz gabbros are finer grained, more acidic and leucocratic and have been interpreted as the products of chilling, thus establishing that the Tonalite is the younger. Exposures of the contacts are rare and their form confusing; some dip steeply outwards and others dip steeply inwards. A substantial mass of quartz- and biotite-bearing gabbro lies within the eastern part of the Tonalite.

The later Quartz Monzonite (N) forms a small, poorly exposed oval mass within the Tonalite outcrop and can be distinguished in the field by the presence of more abundant, larger, deep-brown biotite crystals in a finer-grained, feldspathic groundmass. At its contacts with the enveloping Tonalite, the Quartz Monzonite is finer-grained and the contacts appear to dip inwards at 65°. Both rocks contain the disequilibrium assemblage of plagioclase, alkali feldspar, quartz, augite, hornblende, biotite, magnetite, ilmenite, apatite and chlorite and have generally been interpreted as hybrids or the results of crustal contamination and assimilation.

The Centre 3 complex is dissected by many crush lines and minor faults generally trending NS or NNW–SSE, as is clearly shown on aerial photographs (for example, seeStewart, 1965 and cover photograph of Gribble *et al.*, 1976). A set of radial joints and crush lines marked by erosion hollows is also prominent. From Meall nan Con to Beinn an Leathaid the intrusions of Centre 3 truncate those assigned to Centre 1. The earlier intrusions (mainly quartz dolerites and granophyres) cut earlier volcanic rocks and are themselves intruded by dense swarms of cone-sheets. The composite sheet-like body of Beinn an Leathaid belongs to Centre 1. In this intrusion, dolerite at the base is succeeded by a granophyre carrying xenoliths of Moine schist and gneiss; a thin transition zone between the dolerite and granophyre occurs east of the summit. Farther to the east, agglomerates of the Northern Vents are exposed. A few NNW-trending dolerite dykes cut the Centre 3 ring-dykes, for example to the east of Achnaha.

Interpretation

Centre 3, Ardnamurchan was first recognized by Richey and Thomas (1930) who, despite an almost total absence of evidence relating to the contacts between intrusions, interpreted it as a series of nested ring-dykes. In more recent years, Richey's axiom that the contacts dip steeply outwards has been challenged and it has been postulated that the contacts dip gently inwards to produce a saucer- or funnel-shaped intrusion (Smith, 1957; Bradshaw, 1961; Wills, 1970; Walsh, 1971, 1975). Therefore, Centre 3 is important both because of its long acceptance as an almost perfect example of a nested ring-dyke complex and because of the doubts raised by subsequent research as to whether it is a ring-dyke complex at all. The problem at present has not been resolved although geophysical investigations (Bott and Tuson, 1973; Binns *et al.*, 1974) have revealed that the maximum positive gravity anomaly for the Ardnamurchan complex is less than half of that found over the Skye, Rum and Mull complexes, indicating that the Ardnamurchan complex occupies a much smaller volume than the others. Moreover, the gravity maximum is located over Centre 2 and not Centre 3. Although these facts are admittedly inconclusive, they can hardly be said to support the hypothesis that Centre 3 consists of a nested complex of ring-dykes some 3 km in radius, each ring-dyke having been formed by the subsidence of a central block of preexisting, relatively dense igneous rock.

More recent workers on Ardnamurchan have tended to reduce the number of components in

the complex by combining two or more of Richey and Thomas's intrusions into single entities. Thus, Smith (1957) and Bradshaw (1961) suggested that the Great Eucrite (E), the Biotite Eucrite (G) and the Inner Eucrite (H) form a single intrusion and Walsh (inGribble *et al*., 1976) suggested that the fluxion gabbros B and L are not independent intrusions but parts of the adjacent quartz gabbros. A. and J. Stewart (1965) listed the ring-dykes but omitted the gabbro south-east of Rudha Groulin (C1) which was described as a sheet, and combined F and F1 into a single intrusion. The Outer Eucrite (E1) is petrographically identical to the Great Eucrite (E) and, although described as a separate mass on the basis of unsatisfactory evidence (Richey and Thomas, 1930), was not shown as an independent entity on the map which accompanied the Memoir. It is listed by Stewart (1965), but has been tacitly combined with the Great Eucrite in the most recent literature and maps of Walsh (1975) and Gribble *et al*. (1976). If this body of work is accepted *in toto*, the number of discrete intrusions (apart from cone-sheets and dykes) forming Centre 3 is reduced from seventeen to ten.

Richey and Thomas (1930) regarded all the Centre 3 intrusions as having derived from a single magmatic parent. More recently, however, Walsh (1975) has shown that this may be true only of the eucrites, gabbros and dolerites. The pyroxenes in the Tonalite (M) and Quartz Monzonite (N) fail to show the significant iron-enrichment to be expected if they had formed from the same magma as the basic intrusions. On these grounds, Walsh (1975) considered the intermediate rocks to be hybrids of basic magma contaminated by assimilation and partial anatexis of country rock and previously emplaced intrusions, a view also supported byWalsh and Henderson (1977) on the basis of rare-earth-element geochemistry.

It is clear that although Centre 3 has long been regarded as containing some of the most perfect examples of ring-dykes in the BTVP, the status of these intrusions is now far from clear and the centre really demands a concerted and co-ordinated field and laboratory investigation to resolve the outstanding problems of the form of its constituents and their spatial and chemical relationships to one another.

Conclusions

Centre 3 has long been accepted as being a classic example of a ring-dyke complex. New evidence, however, contradicts this interpretation and the Centre is probably a saucer- or funnel-shaped intrusion. The controversy surrounding this Centre gives the site special significance. Many of the originally mapped intrusions have been argued to be part of the same intrusion and it is now suggested that the intrusions number no more than ten. The basic intrusions are probably genetically related to the same parent magma, but the intermediate rocks appear to be the result of contamination of a basic magma with crustal rocks.

Reference list

Binns, P.E., McQuillin, R. and Kenolty, N. (1974) *The Geology of the Sea of the Hebrides*. Report of the Institute of Geological Sciences, No. 73/14, 43 pp.

Bott, M.H.P. and Tuson, J. (1973) Deep structure beneath the Tertiary volcanic regions of Skye, Mull and Ardnamurchan, north-west Scotland. *Nature*, *Physical Sciences*, **242**, 114–16.

Bradshaw, N. (1961) The mineralogy and petrology of the eucrites of the Centre 3 igneous complex, Ardnamurchan, Scotland. Unpublished Ph.D. Thesis, University of Manchester.

Gribble, CD., Durrance, E.M. and Walsh, J.N. (1976) *Ardnamurchan*: *a Guide to Geological Excursions*. Edinburgh Geological Society, Edinburgh, 122 pp and map.

Richey, J.E. and Thomas, H.H. (1930) *The Geology of Ardnamurchan, North-west Mull and Coll*. Memoir of the Geological Survey of Great Britain, HMSO, Edinburgh.

Smith, D.I. (1957) The structure and petrology of the third ring-dyke complex, Ardnamurchan. Unpublished Ph.D. Thesis, University of Edinburgh.

Stewart, F.H. (1965) Tertiary igneous activity. In *The Geology of Scotland*. (ed. G.Y. Craig), 1st edn, Oliver and Boyd, Edinburgh, pp. 417–65.

Walsh, J.N. (1971) The geochemistry and mineralogy of the Centre 3 igneous complex, Ardnamurchan. Unpublished Ph.D. Thesis, University of London.

Walsh, J.N. (1975) Clinopyroxenes and biotites from the Centre 3 igneous complex, Ardnamurchan, Argyllshire. *Mineralogical Magazine*, **40**, 335–45.

Walsh, J.N. and Henderson, P. (1977) Rare earth element patterns of rocks from the Centre 3

igneous complex, Ardnamurchan, Argyllshire. *Contributions to Mineralogy and Petrology*, **60**, 31–8.

Wills, KJ.A. (1970) The inner complex of Centre 3, Ardnamurchan. Unpublished B.Sc. Thesis, University of London (Royal School of Mines).