Chapter 5 Isle of Mull

Introduction

The igneous rocks of Mull are arguably the most historically significant in the British Tertiary Volcanic Province. They have been examined extensively for the past two centuries, but it was through the classic Mull Memoir of the Geological Survey of Great Britain (Bailey *et al.,* 1924) that they achieved world-wide attention. Not only was the extremely complex geology of central Mull described and illustrated by the beautiful 'One Inch' geological map (Sheet 44), but important concepts such as ring-dykes, cone-sheets, centres of igneous activity, and magma types and magma series were developed, rendering Mull important in the international context.

Mull is a mountainous island with a long, indented coastline. The coastal exposures provide good sections through the relatively early lavas (Figure 5.1); however, the intrusions forming the central complex are largely inland where much of the countryside is mantled by peat. This is especially true of the lower ground, where tantalizing, but incomplete, glimpses of the solid geology are provided by stream sections as, for example, in the Allt Molach (see below). Exposure is, however, often good and continuous on the higher ground. The authoritative account of the field geology contained in the Geological Survey's Memoir and maps has provided the background for much subsequent work over the past thirty years. The emphasis of this more recent work has been on the geochemistry, geophysics and isotope geology of the Tertiary igneous rocks; publications have been summarized by Skelhorn (1969) and Emeleus (1983), and by several authors in Sutherland's review of the *Igneous Rocks of the British Isles* (1982). These investigations covered a range of topics, including the deep geology of the Mull volcano, the likely duration of igneous activity, the origins of the granitic and basaltic rocks and the extent to which they have received contributions from crustal as well as mantle sources, and the magnitude and likely effects of extensive hydro-thermal systems established during the life of the complex.

The sequence of igneous activity on Mull is summarized in (Table 5.1). The general pattern bears similarities with that found on Skye and Ardnamurchan, but it differs in detail. Activity commenced with the eruption of basaltic lavas fed from linear NW-SE fissures now represented by the extensive Mull dyke swarm. A thickness of up to 2 km of lava is preserved and studies of zeolite zones (Walker, 1971) indicate that the original succession may have exceeded 2.2 km in thickness. Eruption of the younger lavas overlapped the establishment of a central complex, as flows, including pillow lavas, were erupted into caldera lakes associated with central subsidence and ring-dyke formation in and around the Early or South-East Caldera (Centre 1; (Table 5.1)).

(Table 5.1) The Mull Central Complex: sequence of events (after Skelhorn, 1969, pp. 2–6)

(youngest)
Dykes were intruded throughout the sequence (Loch Bà–Ben More)
Loch Bà Centre (Centre 3; North-West or Late Caldera)
Loch Bà felsite ring-dyke (Allt Molach-Beinn Chaisgidle, Loch Bà–Ben More)
Hybrid masses of Sron nam Boc and Coille na Sroine (Loch Bà–Ben More)
Beinn a' Ghraig Granophyre (Loch Bà–Ben More)
Knock Granophyre (Loch Bà–Ben More)
Late basic cone-sheets (Loch Bà–Ben More)
Early Beinn a' Ghraig Granophyre and felsite (Loch Bà–Ben More)
Glen Cannel complex and some late basic cone-sheets
(Allt Molach-Beinn Chaisgidle, Loch Bà–Ben More)
Beinn Chaisgidle Centre (Centre 2)
Glen More ring-dyke (Loch Sguabain, Cruach Choireadail)
Late basic cone-sheets (Allt Molach–Beinn Chaisgidle), Loch Scridain sheets (intruded towards middle and end of Centre 2 and start of Centre 3)
Ring-dyke intrusions around Beinn Chaisgidle
?Augite diorite masses of An Cruachan and Gaodhail (Loch Bà–Ben More)

Corra-bheinn layered gabbro (Loch Bà–Ben More)
Second suite of early basic cone-sheets
Second suite of early acid cone-sheets
Explosion vents (numerous at margin of the South-East Caldera) (Loch Bà–Ben More)
Glen More Centre (Centre 1; including the Early or South-East Caldera)
Ben Buie layered gabbro
Loch Uisg granophyre-gabbro
First suite of early basic cone-sheets (Loch Bà–Ben More)
Early acid and intermediate cone-sheets (Loch Bà–Ben More)
Acid explosion vents containing porphyritic rhyolite material (Loch Bà–Ben More)
Glas Bheinn and Derrynaculen granophyres (Loch Spelve–Auchnacraig)
Updoming and folding in south-east Mull as a result of rising diapir (Loch Spelve–Auchnacraig).
Lava eruption on to eroded surface of Mesozoic and older rocks. Latest flows overlap in time with formation of the South-East Caldera where pillow lavas are found. (Lavas: Bearraich, Ardtun, Carsaig Bay, Loch Bà–Ben More. Pillow lavas: Loch Sguabain, Cruach Choireadail)
(oldest)

Three distinct centres of igneous activity have been recognized within the Mull Central Complex (Table 5.1); in each, both acid and basic intrusions are present and granitic rocks may predominate at outcrop, particularly in Centre 3. However, the centres coincide with a major gravity high and it is clear that dense, gabbroic or peridotitic rocks underlie all the centres (Bott and Tuson, 1973); thus, basaltic or picritic magmas have been the driving force in the Mull central complex as in the other centres of the BTVP. The gravity surveys of Mull also show that the areally extensive granitic rocks are relatively thin, probably less than 2 km in thickness (Bott and Tuson, 1973, see also Bott and Tantrigoda, 1987). Other geophysical investigations include detailed studies of the magnetostratigraphy by Mussett *et al.* (1980) and Dagley *et al.* (1987), which suggest that the igneous activity spanned several magnetic reversals. When combined with radiometric age determinations, a sequence of reversed–normal–reversed polarities is apparent, covering about 3.5 Ma in the middle Palaeocene (between about 60 and 57 Ma; Mussett *et al.,* 1988; Table 1.1).

The arcuate, centrally-focused character of the intrusive igneous activity is strikingly demonstrated by the ring-dykes and cone-sheets of the Mull complex, particularly those of Centres 2 and 3. This feature, together with the especially clear examples of cone-sheet swarms and the perfection of individual ring-dykes such as the Loch Bà Felsite, makes Mull a classic area for these forms of intrusion, as it is also for the clear demonstration of a shifting focus of igneous activity as the complex developed.

Granite magmas were available during the activity of all three centres on Mull. Geochemical and isotopic studies (Walsh *et al.,* 1979) provide evidence that the early granites of Centre 1 contain substantial contributions of partial-melt products from Lewisian gneiss, in addition to magma derived from fractional crystallization of basaltic magmas. The granites of the later Centres 2 and 3, however, were principally derived by fractionation of basaltic magma, with only minor contributions from crustal sources. Presumably the initial rise of basaltic magmas into the crust melted out most of the available low-melting-point constituents from the gneisses, contributing to the Centre 1 granites, but leaving little available for the acid rocks in Centres 2 and 3 when subsequent batches of basalt magma rose through the, by then, extremely refractory res-tites. In order to make deductions about the sources of the granitic rocks it is necessary to assume that no major event has affected their compositions since their emplacement. It has been demonstrated that virtually all of the Mull central complex rocks were affected by massive circulation of heated meteoric waters (Taylor and Forester, 1971; Forester and Taylor, 1976), which clearly might have been expected to alter the rock compositions. However, the alteration appears to have been limited and it has been shown that careful sampling can provide material which has not undergone reorganization of either elemental or isotopic compositions (Walsh *et al.,* 1979).

The stratigraphy of the Palaeocene lavas of Mull is not known in the same detail as the Skye lava succession. Little has been published specifically on this topic since the appearance of the Mull Memoir (Bailey *et al.,* 1924). In this, the authors distinguished a major Plateau Group (Table 5.2) of olivine basalts overlain by another thick group of generally non-porphyritic basaltic lavas which comprised the Central Group — flows largely restricted to outcrops within the central complex or immediately adjoining areas (Bailey *et al.,* 1924, plate III and table X). Within the upper part of the Plateau

Group, high on Ben More, the distinctive sequence of pale-coloured olivine basalts, conspicuously feldspar-phyric basalt (Big-Feldspar basalts) and a thick mugearite flow were mapped. A further subgroup, which closely resembled basalts of the Central Group, was found at the base of the Plateau Group around Loch Scridain and on Staffa. This was termed the Staffa Type. The majority of flows in the Plateau Group were silica-poor, olivine-phyric basalts and these voluminous basalts were held to be the products of a Plateau Magma-Type. The finer-grained, generally olivine-poor and more silica-rich Central Group lavas were distinguished as the Non-Porphyritic Central Magma-Type basalts. These and other magma types were thought to form a genetically linked group of basalts and more fractionated rocks and to constitute a Normal Mull Magma Series (Bailey *et al.,* 1924, Chapter 1). The magma types and magma series were defined on chemistry, mineralogy and petrography and therefore included both lava flows and intrusive rocks. The terminology and correlations of the Mull lavas are summarized in (Table 5.2); the Mull Tertiary igneous sites are shown in (Figure 5.2).

Although little regional mapping appears to have been carried out on the Mull lavas since the publication of the Memoir, a large and valuable amount of geochemical and petrological data has built up, particularly in the last fifteen years. Using fresh samples collected outside the zone of intense pneumatolytic alteration around the central complex, Beckinsale *et al.* (1978) were able to subdivide the lavas (mainly of the Plateau Group) into three groups on geochemical criteria. The approximate positions of these groups are indicated in relation to the Memoir stratigraphy in (Table 5.2). The olivine basalts of Group 1 were thought to have come from partial melting of garnet-lherzolite mantle. The Group 2 lavas, equivalent to the Staffa Type, appeared to come from a higher-level mantle source made of plagioclase lherzolite and the Group 3 flows were thought to represent mixtures of Group 1 and Group 2 magmas (or sources).

Essentially the same parts of the succession, and sometimes the same flows and localities, were examined by Morrison (1978), Thompson *et al.* (1982), Morrison *et al.* (1985) and Thompson *et al.* (1986), who came to rather different conclusions about the sources and origins of the flows. Particular attention was paid to the Staffa Type flows (Group 2 of Beckinsale *et al.,* 1978), where it was found that virtually each flow examined had significant chemical and/or isotopic features; that is, each was unique. This variability was attributed to differing degrees of contamination of the basaltic magmas as each followed its own unique course towards the surface. Picritic magmas were thought to have been formed by partial melting of a spinel lherzolite source, the magma ponded at the Moho and evolved to olivine-basalt magma by olivine fractionation. The fractionated batches of basalt magma pursued their own paths upwards, some were caught in density traps within the crust where they produced silicic rheomorphic magmas from the melting of the adjoining crustal rocks. Where this occurred, the basaltic magma assimilated all or some of the partial melts and became distinctively fingerprinted, taking on, in very diluted form, chemical and isotopic characteristics of that particular country rock. A few flows passed through the crust without reaction or mixing and lack the distinctive contaminated features of the majority. The actual amount of contamination undergone by the flows is estimated to have been between 5–10%, insuffi cient to mask features attributable to the mantle sources and equilibration at the base of the crust. However, the possible contaminants — granulite-or amphibolite-facies Lewisian gneisses and Moine rocks — have distinctive lead, neodymium and strontium isotopes and concentrations of elements such as potassium, rubidium, titanium, phosphorus and the rare earths which it is possible to analyse with extreme accuracy using modern techniques (cf. Chapter 1), thus enabling deciphering of these fingerprints, and allowing possible models for Palaeocene subcrustal plumbing to be constructed. Some possibilities are shown diagrammatically in (Figure 5.3). All the lavas except F underwent variable degrees of fractional crystallization at Moho depths; F rose directly to the surface without either appreciable fractionation or contamination. All the remainder, except E, were held at the boundary between Lewisian granulite-facies gneisses and overlying am-phibolite-facies gneisses, where mixing with small amounts of melt from the granulites occurred. Subsequently, A ponded at the Lewisian am-phibolite gneiss/Moine schists boundary and acquired an 'amphibolite' fingerprint from small amounts of crustal melt, whereas B was held within the Moine schists and mixed with small amounts of melt generated from the schists. C was also contaminated by Moine-derived melt but did not receive a contribution from either Lewisian gneiss source.

(Table 5.2) Classification and correlation of the Mull lavas

Mull Memoir (Bailey *et al.,* 1924)	Beckinsale *et al.* (1978)	Morrison (1978) Thompson *et al.* (1982) Morrison *et al.* (1985) Thompson *et al.* (1986)

Central Group (= NPCMT) (Includes pillow lavas in central complex)	Not dealt with in detail	Some samples analysed, all zeolitized or hydrothermally altered.
Plateau Group (majority = PMT)	Group 1 olivine basalts (mainly sampled in north-west Mull) and Group 3 olivine basalts (mainly sampled around Lochaline, Morven)	Mull Plateau Group (MPG)
Pale Group of Ben More (= PMT) (with interlayered mugearite and Big-Feldspar Basalt)		Note that many are transitional between alkali basalt and tholeiite, and compare closely with Skye Main Lava Series. Some lower crust contamination.
(Staffa Type at base = NPCMT)	Group 2 of south-west Mull	Staffa Magma Type (SMT) Variably enriched in lower and upper crustal contaminants.

(NPCMT = Non-Porphyritic Central Magma Type) later = tholeiitic basalt

(PMT = Plateau Magma Type) later = alkali olivine basalt but many flows are in fact transitional between alkali basalt and tholeiite

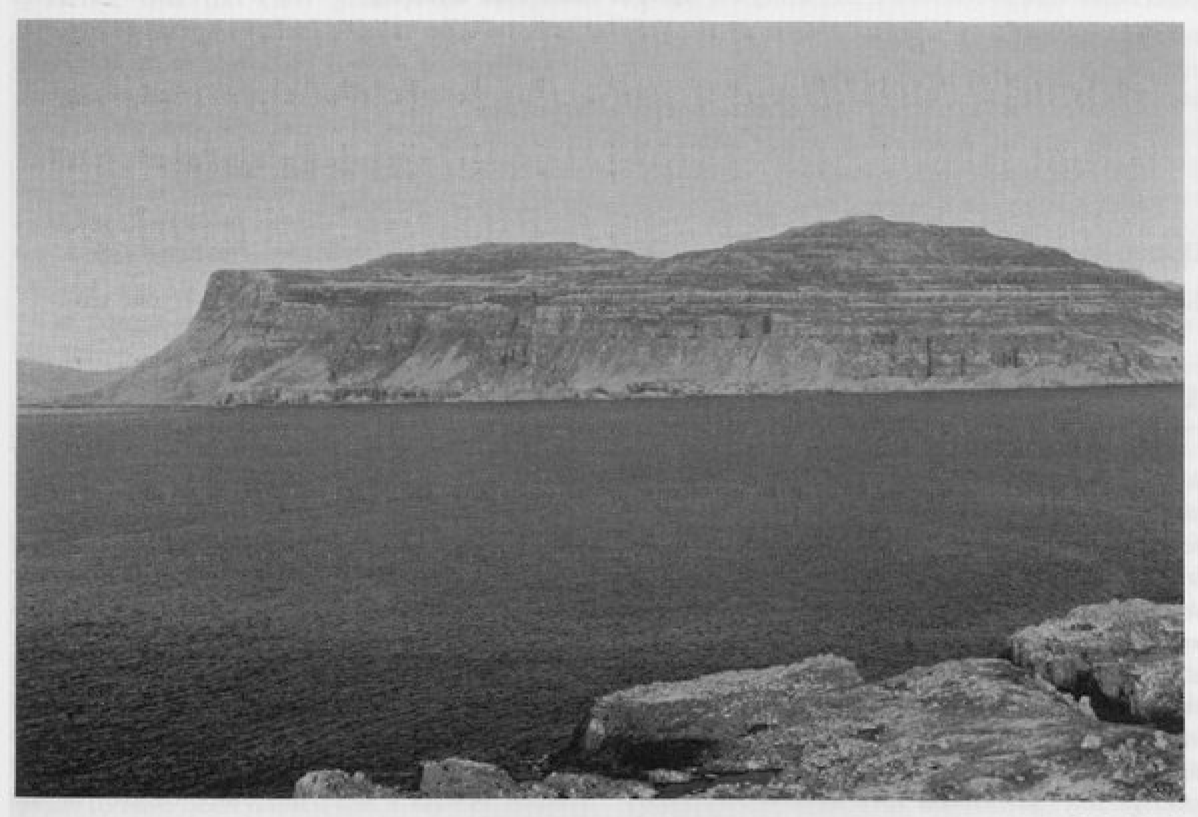
Total thickness of Mull lavas estimated about 2000 m (Bailey *et al.,* 1924)

It is apparent that there are currently two very different views on the origin of the diversity of compositions among the Mull (and other) lavas. In one, the variability is attributed to partial melting occurring at different levels in the mantle, with the possibility of some mixing of the melt products; the mantle is thought to have had long-term vertical heterogeneity prior to the Cenozoic (Beckinsale *et al.,* 1978). A radically different viewpoint is that the magmas originated from a spinel lherzolite mantle source, formed when basaltic magmas on their way to the surface were ponded and their heat triggered localized small amounts of partial melting in the adjoining crustal rocks (Thompson *et al.,* 1982; Morrison *et al.,* 1985; Thompson *et al.,* 1986). If such events were on a sufficiently large-scale, granite-producing anatectic melts could form. The absence of rhyolite flows in the Mull lava succession therefore implies that large volumes of silicic melt were not generated at any given time during this early stage in Tertiary magmatism in Mull. However, conditions obviously changed as the central complex became established and its dense, hot, mafic root grew within the crust below Mull (cf. Bott and Tuson, 1973).

The emplacement of British Tertiary Volcanic Province central complexes was frequently accommodated by folding, faulting and other structural adjustments. On Mull some of the most spectacular examples of these features are provided by the annular folding around the early centre which is particularly well displayed in the Loch Don area (see Loch Spelve below). The significance of early folding has been examined by Walker (1975) who suggested that the deformations may be gravity structures developed in association with central updoming caused by the early diapiric emplacement of the granite magmas.

With a few notable exceptions, the researches into the Tertiary igneous geology of Mull since the publication of the Mull Memoir have been either largely geochemical or geophysical; few studies have involved intensive field-work. This is clearly a tribute to the high quality of the Survey's original field mapping and interpretation. However, the great strides made over the past 65 years in such areas as structural geology and physical volcanology, indicate that there must be considerable scope for further field-based research into many aspects of the Tertiary igneous geology of Mull. The size and complexity of the Mull centres prompts the suggestion that this should be undertaken on the basis of team-work.

References



(Figure 5.1) The flat-lying succession of basalt lavas of the Wilderness area, western Mull, give rise to the trap-type topography. Bearraich site, Mull. (Photo: C.H. Emeleus.)

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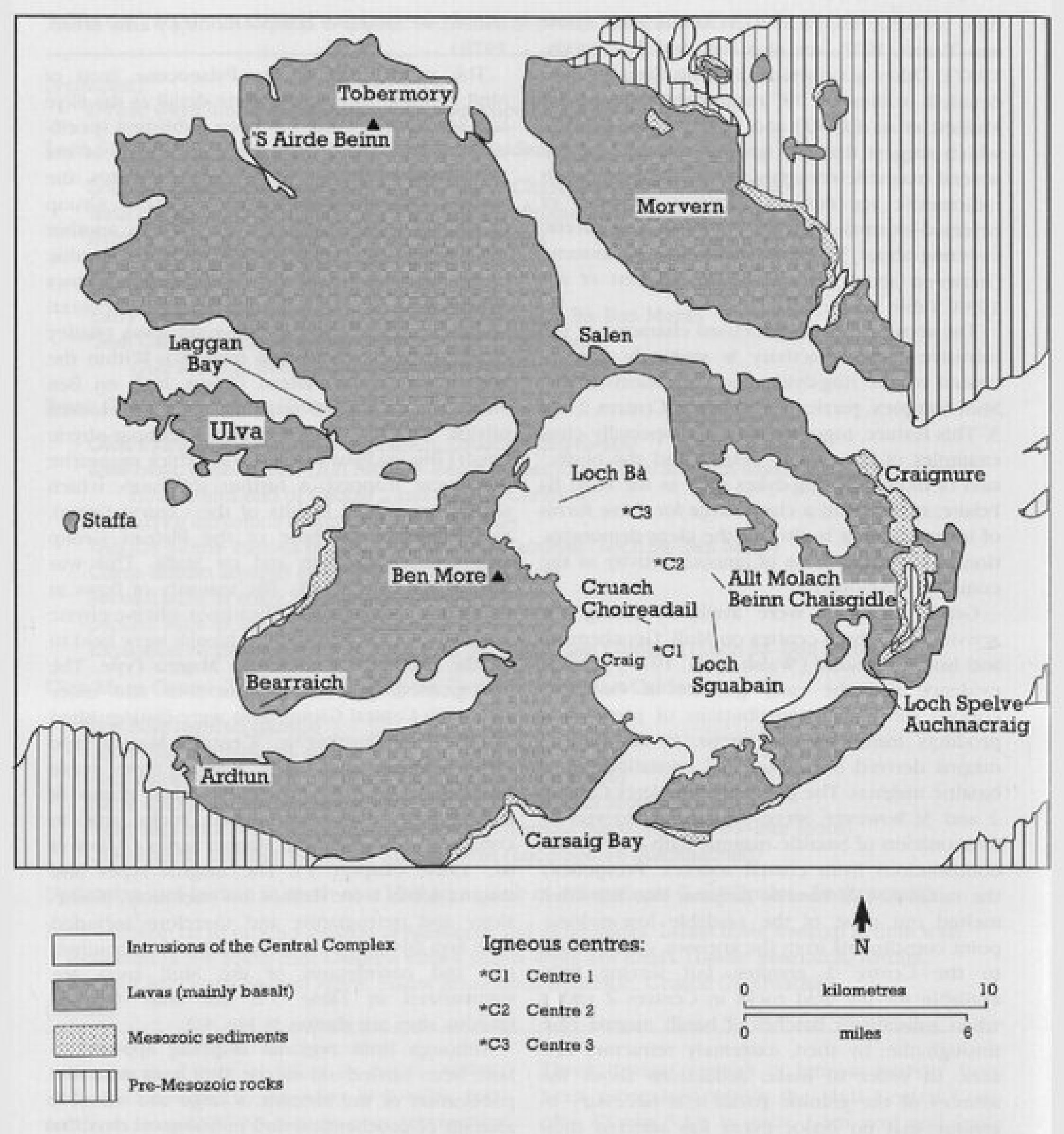
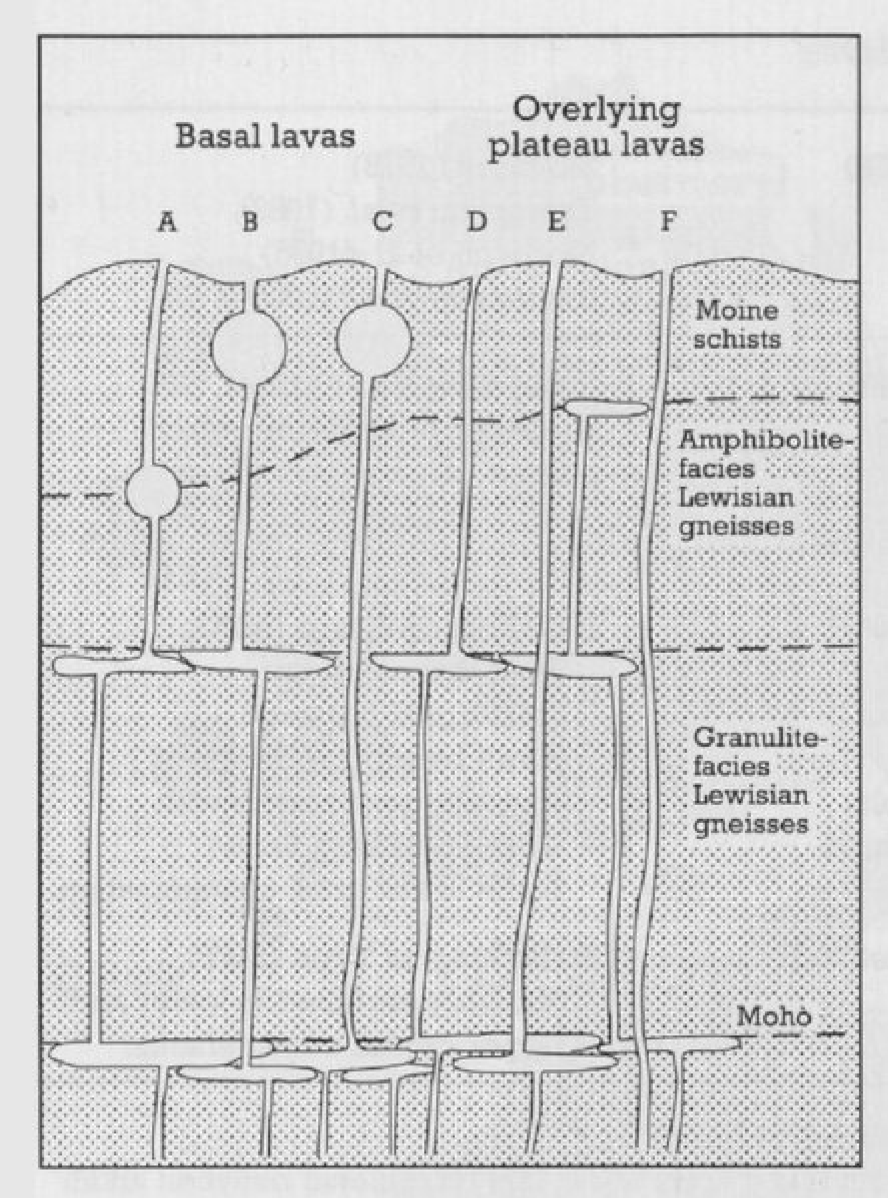


(Figure 5.2) Map of the Isle of Mull, showing localities mentioned in the text.



(Figure 5.3) Sketch of the magmatic plumbing beneath south-west Mull during extrusion of the Palaeocene basaltic lavas (after Morrison et al., 1985, fig. 4). See text for explanation.