Loch Bà–Ben More

Highlights

The Loch Bà Felsite ring-dyke is the international type example of a ring-dyke intruding arcuate faults within which central subsidence has taken place. The ring-dyke and the hybrid intrusions provide evidence that acid and basic magmas coexisted on Mull and the compositional variation shown by porphyritic glassy inclusions in the ring-dyke suggests that the Mull Centre 3 was underlain by a zoned magma chamber. There is. a coastal section across the Mull dyke-swarm axis where 12% crustal dilation has been demonstrated. These features make this a site of international importance.

Introduction

The area between Loch Bà, Ben More and Loch na Keal is a site of multiple interest and of international petrological importance. The Plateau Group lavas attain their maximum thickness here and representative flows belonging to the Central Group lavas are present in various states of metamorphism. Major intrusions belonging to the Glen More and Beinn Chaisgidle centres (Centres 1 and 2 respectively) are demonstrated, together with the full suite of intrusive rocks associated with the Loch Bà Centre (Centre 3). The site has international status as a type locality for ring-dyke structures, the type example being the Loch Bà felsite ring-dyke (Figure 5.18).

As is the case with many of the other sites on Mull, the Memoir remains the most comprehensive account of the geology of the Loch Bà–Glen More area (Bailey *et al.,* 1924). More recent field investigations in the site have been carried out by Skelhorn (1969) who has revised some of the earlier interpretations. The Loch Bà felsite ring-dyke was discovered by the Geological Survey and recognized as a prime example of an arcuate ring-dyke closely associated with ring-faulting. Bott and Tuson (1973) have studied the subsurface extent of the central complex by gravity surveys and showed it to be underlain by a large basic/ultrabasic cylindrical mass. Beckinsale *et al.* (1978) and Morrison (1978) studied the geochemistry of the Mull Plateau and Central Series lavas on a regional scale, the results of which can be broadly applied to this site and are summarized in the 'Introduction' to this chapter. Sparks (1988) has given a detailed account of the petrology and geochemistry of the Loch Bà ring-dyke.

Description

Features of the lavas within the site are described first; these are followed by an account of central complex intrusions.

(a) The lavas

The Plateau Group lavas (Table 5.2) attain their maximum thickness of over 900 m on Ben More [NM 526 331]. They lie within the limit of pneumatolysis around the central complex and the alteration is most severe in the east of the lava outcrop, where the flows adjoin the major intrusions. As a consequence, basalt flows in this area no longer carry fresh olivine and generally contain epidote in amygdales and veins. Trap featuring, reflecting the different weathering properties of the resistant flow centres and the crumbling, amygdaloidal tops, is still discernible and a few recognizable boles are present, attesting to subaerial weathering between successive eruptions.

The lowest division of the Plateau Group, the Survey's Staffa Type basalts, do not crop out in the site as the gentle easterly dip of the lavas has taken the earlier flows below sea-level. The lowest flows preserved are mildly alkaline to transitional basalts which are either aphyric or contain olivine pseudomorphs. These are succeeded by pale-weathering, alkali-olivine basalts belonging to the Survey's Pale Group of Ben More which contains a prominent horizon of mugearite and feldspar-phyric basalt near the base (Table 5.2). The Pale Group forms the upper part of Ben More and isolated outcrops cause the north-western terminations of the ridges of Beinn Fhada and Bheinn a' Ghraig [NM 542 373].

Many of the flows are amygdaloidal and the amygdale minerals are of considerable interest, both in their own right and also in studies concerned with the hydrothermal effects associated with the emplacement of the central complex. A full

description of these minerals is contained in the Memoir and zeolite zones in the lavas have been delineated by Walker (1971). Numerous basaltic dykes and sheets, and some of felsite and craignurite compositions, cut the Plateau Group lavas.

The basaltic lavas of the overlying Central Group are exposed outside the central complex and as isolated masses among the intrusions of the complex. South of Creag Mhic Fhionnlaidh [NM 554 333] these lavas are separated from the Plateau Group to the west by a fault and are terminated to the north and east by intrusions associated with Centre 2. Large, detached masses of Central Group lavas occur on the slopes west of Glen Clachaig, within the North-West or Late Caldera of Centre 3 (Table 5.1). Smaller masses are preserved as screens between the intrusions of Centre 2. The lavas to the south of Creag Mhic Fionnlaidh, outside the caldera, are cut by early acid and basic cone-sheets whereas the flows preserved within the caldera are virtually free from cone-sheets. A few basic dykes also intrude the lavas. The Plateau Group and Central Group lavas to the west of the central complex are pierced by volcanic vents which, in turn, are cut by early basic cone-sheets, the Corra-bheinn gabbro and granophyre veins. The largest vent (at [NM 558 324]) is about 700 m in length. The agglomerate in this and other smaller vents contains fragments of Moine gneiss (Figure 5.19). Gneiss fragments occur in vents outside the calderas, but are not found in the numerous agglomerates within these structures (Bailey *et al.,* 1924, fig. 29) where subsidence has presumably brought the gneisses and schists below the level at which the magmas were liable to rapid vesiculation and explosion.

Towards the later, major intrusions of the central complex, all lavas show progressive effects of thermal metamorphism. These changes are particularly well demonstrated by alteration in the low-temperature amygdale mineral assemblages and successively higher-temperature phases are found as the later intrusions are approached. The lavas also show signs of thermal metamorphism and have been hornfelsed up to pyroxene-granulite facies near to the intrusions.

(b) The Central Complex

Three major intrusions of somewhat uncertain age occupy a 2-km wide, NW-trending tract of ground extending from the south-eastern extremity of the site to the southern slopes of Beinn Fhada and Beinn nan Gobhar [NM 538 317]. These bodies separate the lavas from the intrusions of Centre 3 and form the margin of the Central Complex (Figure 5.18).

The Corra-bheinn Gabbro is one of the intrusions in the extreme south-east of the site, forming the eastern slopes of Sleibhte-coire. Its western and southern contacts are intrusive against Central Group lavas, vent agglomerate and (outside the site) the Derrynaculen Granophyre. To the north-east it is split up by late, basic cone-sheets and probable continuations of the Glen More ring-dyke. The Corra-bheinn Gabbro is probably an early intrusion of Centre 2 (Skelhorn, 1969; but see Bailey *et al.,* 1924). The gabbro exhibits rhythmic layering, igneous lamination and other structures characteristic of cumulate rocks. Layers dip to the north-east between 15° and 75° (but averaging 40°) towards Centre 2. Skelhorn (1969) has identified nine major rhythmic units in the gabbro to the south-west of Coir' an t-Sailein [NM 566 326] and recorded horizons of tabular pyroxene-granulite xenoliths, some of which disrupt the layering which is also banked up against some xenoliths (Skelhorn, 1969).

An interrupted chain of composite quartz-gabbro masses, changing internally to granophyre towards their tops, extends from Coir' a' Mhaim [NM 580 318] to the south of the site, through Coir' an t-Salein and Torr na h-Uamha [NM 560 332] and terminates on Beinn Fhada. These are probably continuations of the Glen More ring-dyke of Centre 2 (Bailey *et al.,* 1924) and cut the Corra-bheinn Gabbro and the lavas north of Creag Mhic Fhionnlaidh.

The Cruachan Augite Diorite intrusion occurs within and outside the Loch Bà felsite. It is cut by numerous late, basic cone-sheets and, although its outcrop is restricted to narrow screens between the sheets, it is mapped as an entity. The composition of the intrusion becomes progressively more acidic upwards and the highest parts are granophyre or felsite rather than diorite. The mass is assigned to Centre 1 and is probably the equivalent of the Gaodhail Augite Diorite (Bailey *et al.,* 1924), although Skelhorn (1969) has suggested that it could be the earliest member of Centre 3.

The main interest of this site derives from the exposure of the western quadrant of Centre 3, the Loch Bà Centre. A complete and unique suite of intrusions and associated rocks is demonstrated and Skelhorn (1969) has revised the sequence of events for the evolution of this centre as follows:

6. The Loch Bà Felsite ring-dyke

5. The hybrid masses of Sron nam Boc and Collie na Sroine

4. The Beinn a' Ghraig Granophyre

3. The Knock Granophyre

2. The early Beinn a' Ghraig Granophyre and Felsite

1. The Glen Cannel Complex: This consists of an early quartz dolerite plug, vents, intrusive rhyolites, and a late felsite and granophyre.

A mass of pyroxene granophyre dominates the Glen Cannel complex and this forms a low dome elongated along a north-west to south-east axis. It thermally alters a felsite mass (also part of the complex) on the south side of Glen Clachaig. The granophyre has yielded a Palaeocene age (58 ± 3 Ma, Beckinsale, 1974). To the west and south of Glen Clachaig, two quartz-dolerite plugs belonging to the complex have been metamorphosed by the granophyre. Other members of the complex occupy ground between Allt Beithe and Coille na Sroine and include agglomerate-filled vents into which a rhyolite dome has been intruded, along with tuffisite dykes containing fragments of Moine schist (which the agglomerates hereabouts do not, see above). These small masses have intruded Central Group lavas.

The early granophyre and felsite of Beinn a' Ghraig is exposed on the ridge immediately east of the summit. It is chilled on both its east and west contacts against Plateau Group lavas at the base of the Pale Group of Ben More, and a screen of lavas occurs between the Beinn a' Graig and Knock Granophyres at its eastern tip.

The Knock Granophyre has a dyke-like outcrop 100–300 m wide, extending north-eastwards for 3 km from the western edge of the Beinn a' Ghraig ridge. The granophyre characteristically develops shearing and cataclastic textures which have been attributed to the emplacement of the Beinn a' Ghraig Granophyre. These two granophyre intrusions are separated by a particularly clear example of a screen: this is composed of highly metamorphosed basaltic lavas and cone-sheets, it extends for about 3 km, has a vertical range of over 500 m and a width of between 3 m and 100 m. The screen rocks have been recrystallized to fine-grained granulites consisting of plagioclase, augite, hornblende and magnetite and the adjoining granophyres have been contaminated with basic material derived from the screen. Screens are abundantly developed in the Mull Central Complex and elsewhere in the BTVP: this example is one of the clearest since the topography of the site, coupled with reasonable exposure, shows the three-dimensional form to best advantage, and the rocks forming the screen have been thoroughly altered by the adjoining igneous intrusions.

A small mass of hybrid rocks consisting of acid-veined quartz gabbros and diorites lies between the Beinn a' Ghraig Granophyre and the Loch Bà Felsite south of Coille na Sroine (at about [NM 553 376]). The hybrids are chilled against the Beinn a' Ghraig Granophyre which has been partially melted and back-veins the chilled, marginal hybrid rocks (Rast, 1968).

The site contains the western quadrant of the Loch Bà Felsite ring-dyke (Figure 5.20), including the historic exposures where its association with a fault and its annular outcrop were first described. The ring-dyke is well exposed and both its outer and inner contacts can be seen to dip outwards at angles of 70°-80°. Between Loch Bà and Beinn nan Gabhar the felsite separates the Beinn a' Ghraig Granophyre from various members of the Glen Cannel Complex and Central Group lavas. On the western slopes of Beinn nan Gabhar, shortly after 'entering' the intrusions of Centre 2 cut by a profusion of late basic cone-sheets, the felsite fails. However, the fault into which it was intruded can be traced southwards until, after a gap of several hundred metres, the felsite reappears and can be traced across the slopes of An Cruachan and the River Clachaig. On the south side of the river its outcrop narrows and disappears once more just beyond the site boundary.

Compositionally, the ring-dyke varies from an apparently flow-banded rhyolite to felsite and typically contains phenocrysts of alkali feldspar and mafic minerals. A particularly striking feature is the common occurrence of dark, fine-grained, elongate wispy xenoliths. The basic character of the xenoliths was first reported by Blake *et al.* (1965); however, Sparks

(1988) has shown that these dark, aphanitic rocks vary continuously in composition from basaltic andesite to andesite, dacite and rhyolite. The phenocrysts in the enclosing rhyolite include plagioclase (An_{32} to An_{24}), sanidine, hedenbergite, fayalite, magnetite, ilmenite, apatite and zircon. The phenocrysts are often aggregated; however, it is unusual to find hedenbergite and fayalite in the same cluster. The dark wispy inclusions are usually aphyric; where phenocrysts occur they include plagioclase (An_{65} to An_{30}), a continuous range of clinopyroxenes from augite to pure hedenbergite, pigeonite, magnetite, ilmenite and rare apatite (Sparks, 1988, p. 446). The significance of this range of phenocrysts, and particularly the compositional spectrum of glassy inclusions, is discussed subsequently.

The site includes an excellent section through the axis of the Mull dyke swarm on the southern shores of Loch na Keal, to the west of Eilean Feoir [NM 531 389]. The majority of the dykes are basaltic and many are multiple, comprising as many as four or five intrusions, which may show cross-cutting relationships. Some 142 dykes have been recorded, with an aggregate thickness of 249 m along a 2-km traverse of the Loch na Keal shore (Bailey *et al.,* 1924). The average dyke thickness is 1.8 m and a total crustal dilation of 12.4% has been calculated. The dykes show the same effects of alteration as the lavas within the zone of pneumatolysis, although often to a lesser extent.

Interpretation

The Loch Bà–Ben More site supports some of the most spectacular geology and scenery on Mull, and is arguably the most important locality as it demonstrates representative rocks from every major Tertiary igneous event on the island. Centre 3 is fully represented and marks a final shift of intrusive activity to the north-west as a possible result of the elongation of the magma chamber in this direction, parallel to the axis of the regional dyke swarm (Skelhorn, 1969). According to Skelhorn, the Centre 2 Glen More ring-dyke, represented in this site by the quartz-gabbro masses, is the earliest intrusion to reflect this elongation. The arcuate, fragmented ring-dykes of Centres 1 to 3 have intricate intrusive relationships from which the history of the complex is determined. They also exhibit a large compositional range from acid to basic rock types. Acidic intrusions, despite their wide aerial extent, represent only a small proportion of the total igneous mass of the Mull central complex, as shown by the gravimetric work of McQuillin and Tuson (1963) and Bott and Tuson (1973). A gravity survey of the Glen Cannel granophyre revealed that it is no more than 1220 m thick and must have a sheet-like form. Walker (1975), however, suggested that the granophyre mass once formed the upper part of a large body of acid magma which had migrated into a curved, flange fracture and thus caused the north-west transfer of the igneous centre to the Loch Bà area, and that further portions of this acid magma migrated to form the younger Knock, Beinn a' Ghraig and Loch Bà intrusions.

The site provides evidence which supports the view that acid and basic magmas probably coexisted in a compositionally zoned magma chamber beneath Mull, and that this mixed magma was injected into fractures associated with ring-faulting and central block subsidence. The Coille na Sroine hybrids provide good evidence for magma mixing, as well as the rheomorphic generation of acid melts. Within the magnificently exposed Loch Bà felsite ring-dyke, there is also excellent evidence for coexisting magmas of contrasted compositions: the dark, glassy inclusions in the felsite (which make up about 15% of the rock) often have lobate, cauliflower-shaped margins and are frequently wisp-like and convoluted. Marshall and Sparks (1984) considered that the inclusions were liquid when they were incorporated into the felsite magma and they explained the heterogeneous, mixed-magma intrusion by envisaging incomplete mechanical mixing between different components in a vertically zoned magma chamber, triggered off by subsidence of the central block. Subsequently, Sparks (1988) made a detailed examination of the rhyolite and inclusion compositions, together with the compositions of phenocrysts in both. The really striking feature to emerge is the compositional range of the glassy inclusions and their phenocrysts (which appear linked by crystal–liquid equilibria). The mafic glasses vary continuously in composition from basaltic andersite through to dacite and rhyolite suggesting that the Loch Bà centre was underlain by a zoned magma chamber, capped by rhyolite magma. Crystals were precipitating from all levels of this chamber, which covers the compositional range of the Middle and Upper zones of the Skaergaard Intrusion in East Greenland (Wager and Deer, 1939; Wager and Brown, 1968; McBir-ney, 1975), when this structurally ordered sequence was catastrophically disrupted to form the heterogeneous Loch Bà ring-dyke. Sparks' (1988) discoveries and interpretation have obvious implications for the subsurface geology of Mull — the gravity high (Bott and Tuson, 1973; Bott and Tantrigoda, 1987) indicates subsurface, dense, gabbroic rocks which may include a Skaergaard-like body. They also shed further light on the possible mode of crystallization of layered basic intrusions: the evidence from Loch Bà suggests

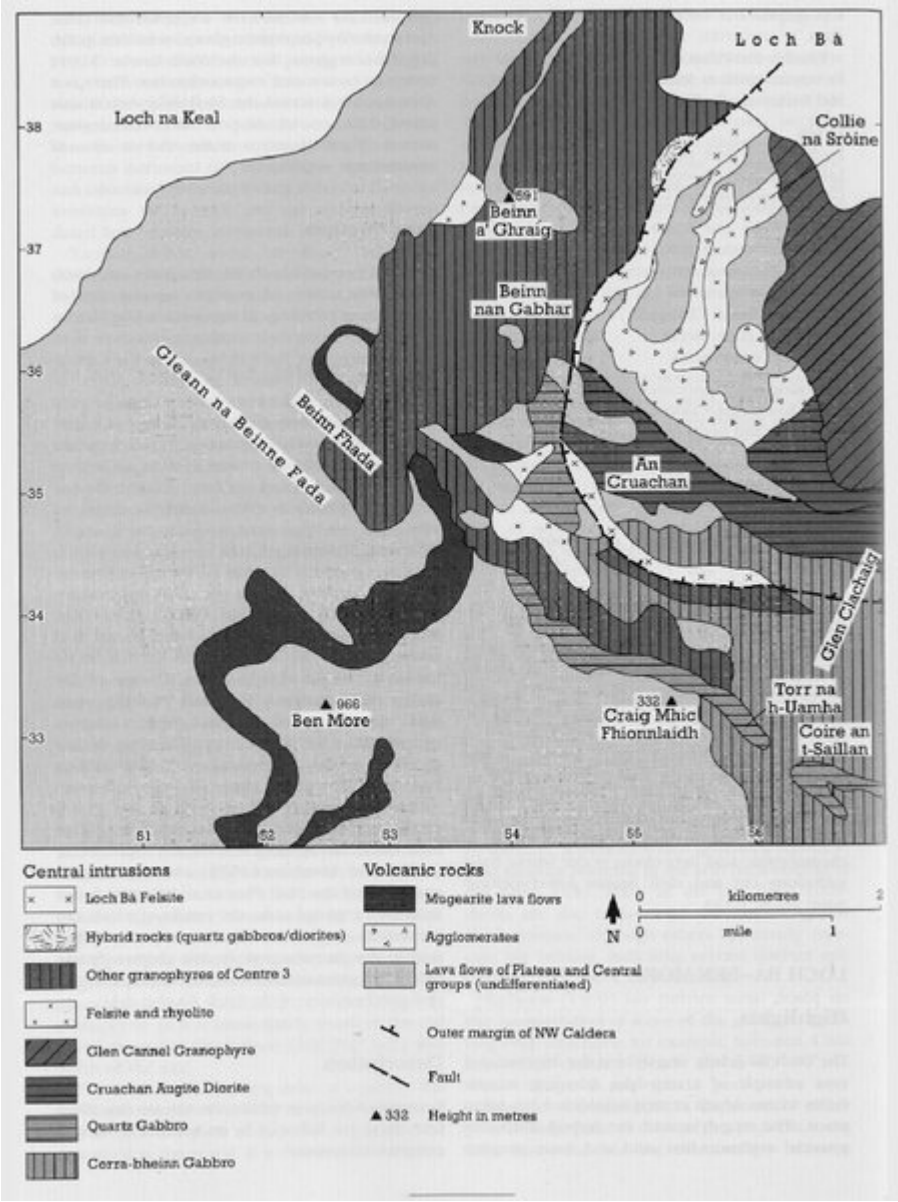
that the compositionally contrasted layers could have built up essentially simultaneously, rather than sequentially as envisaged in the classic models of layering (for example, Wager and Brown, 1968). Sparks (1988) regards the felsite as an intrusive, banded, rhyolitic, welded tuff.

The Loch Bà site provides sound evidence for the frequent suggestion that emplacement of the Mull Central Complex (and others) has involved subsidence of a central block, or blocks, bounded by arcuate ring-faults. Richey (1932) calculated that the downthrow on the block circumscribed by the Loch Bà ring-dyke and associated fault was about 1000 m. Lewis (1968), however, pointed out that much of the displacement could have occurred on two NW-trending faults which transect the block and suggested that the maximum downthrow on the ring-fault, now occupied by felsite, was only about 150 m.

Conclusions

The thick succession of basalt lavas on Ben More and surroundings has been extensively altered by the later intrusions of the central complex, with the result that original minerals (for instance, olivine) were replaced and new ones (for example epidote, chlorite) formed by circulating heated waters and gases. The site lies astride the Mull dyke swarm which locally produced crustal dilation of over 12%; the dykes mostly pre-dated the central complex and thus also are generally altered. A variety of basic, granitic and hybrid intrusions belongs to the youngest centre, Centre 3 of Mull. They provide compelling evidence for the mingling of basic and acid magmas. The Loch Bà felsite ring-dyke is the type example of a ring-dyke. It intruded along a ring-fault bounding a central block which may have subsided by as much as 1 km in aggregate. The ring-dyke intrusion provides spectacular evidence for the explosive disintegration of a crystallizing, zoned magma chamber in which rhyolite liquid passed by continuous compositional variation downwards through intermediate compositions to basaltic liquids. These discoveries are of major scientific importance as they provide a glimpse of the details of the dense rocks known from gravity surveys to underlie Mull; they are of more general importance since they suggest ways in which layered igneous intrusions may crystallize.

References



(Figure 5.18) Geological map of the Loch Ba—Ben More site (adapted from the British Geological Survey 'One Inch' map, Sheet 44, Mull).

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) Pale Group of Ben More (= PMT) (with interlayered mugearite and Big-Feldspar Basalt)	Group 1 olivine basalts (mainly sampled in north-west Mull) and Group 3 olivine basalts (mainly sampled around Lochaline, Morven)	Mull Plateau Group (MPG) 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)

(Table 5.2) Classification and correlation of the Mull lavas

(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 Chàisgidle, Loch Bà–Ben More)

Beinn Chàisgidle Centre (Centre 2)

Glen More ring-dyke (Loch Sguabain, Cruach Choireadail)
Late basic cone-sheets (Allt Molach–Beinn Chàisgidle), Loch Scridain sheets (intruded towards middle and end of Centre 2 and start of Centre 3)
Ring-dyke intrusions around Beinn Chàisgidle
?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)

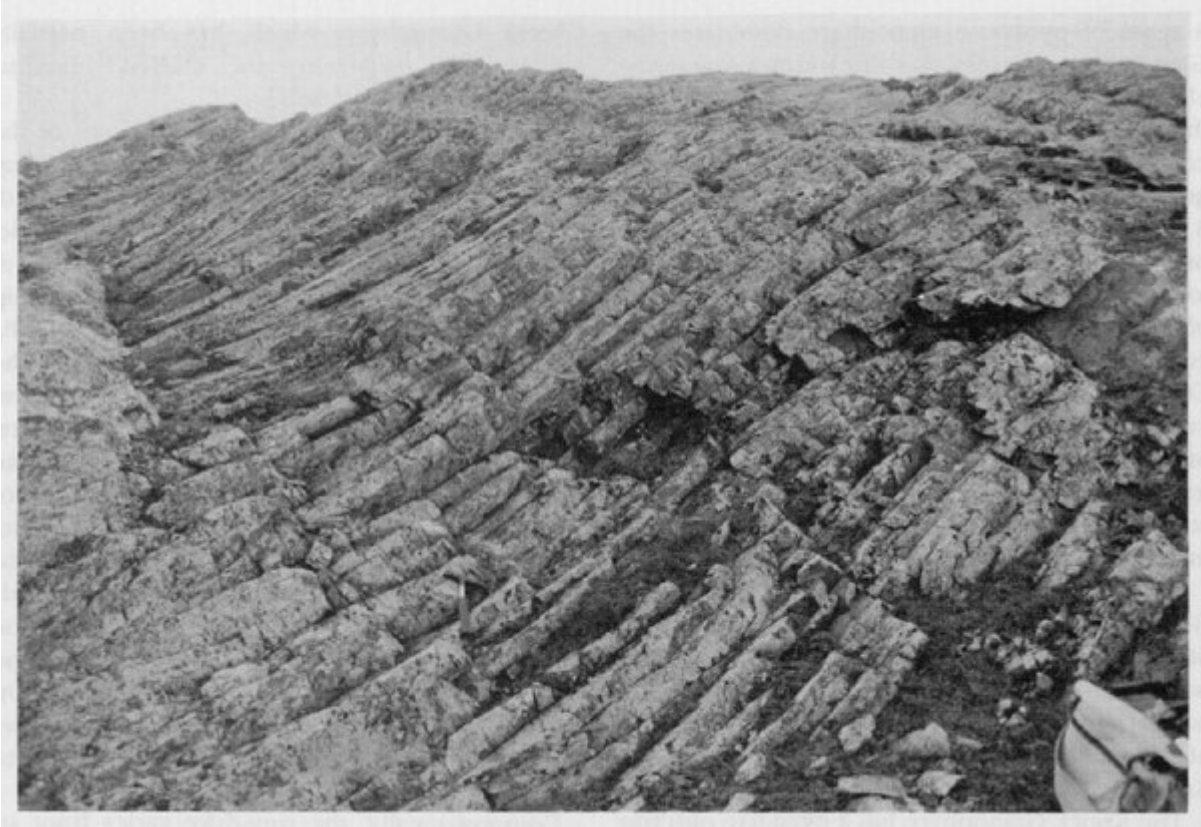
Updoming and folding in south-east Mull as a result of rising diapir (Loch Spelve–Auchnacraig).

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)

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

(Figure 5.19) Vent agglomerate containing fragments of Moine gneiss [NM 558 324]. Loch Ba—Ben More site, Mull. (Photo: CJ. MacFadyen.)



(Figure 5.20) Columnar jointing in the Loch Ba Felsite ring-dyke [NM 552 371]. Loch BA—Ben More site, Mull. (Photo: C.J. MacFadyen.)