British Tertiary Volcanic Province

C. H. Emeleus
Reader in Geology,
University of Durham

and

M. C. Gyopari
Senior Hydrogeologist,
Groundwater Consulting Services

(with contributions from G. P. Black and I. Williamson)

GCR editors: W. A. Wimbledon and P. H. Banham

JOINT NATURE CONSERVATION COMMITTEE

CHAPMAN & HALL
London · Glasgow · New York · Tokyo · Melbourne · Madras

Chapter 3

The Small Isles – Rum, Eigg, Muck, Canna–Sanday

INTRODUCTION

The Isle of Rum (Fig. 3.2) was the site of a major volcano which was active for a period of one or two million years in the Palaeocene, about 59 million years before the present. The volcano developed on a ridge of Precambrian rocks (Torridonian sandstones unconformably overlying Lewisian gneiss) which was covered by a veneer of Mesozoic sediments and Palaeocene lavas. The ridge was flanked by basin structures in the Minch to the west and the Sound of Rum to the east in which thick sequences of Mesozoic sediments accumulated. At the present time, the deeply eroded roots of the volcano are exposed, together with mainly Torridonian country rocks (Fig. 3.2). The north-westerly dipping Torridonian rocks crop out over most of northern and eastern Rum and form the scarp and dip-slope topography north of Kinloch Glen; the Tertiary igneous rocks form the high, rugged mountains occupying most of the southern part of the island.

Rum abounds in features of geological interest but owes its special significance to the spectacular geology of the eroded remains of the Tertiary volcano. Excellent examples of layered ultrabasic rocks, unrivalled in the British Isles, are an outstanding feature of the complex (Fig. 3.1). The ultrabasic Layered Series is of international importance in the development of theories relating to the origin of layering in igneous rocks (for example, Wager and Brown, 1968; Bédard *et al.*, 1988; Young *et al.*, 1988). The centre is also of significance because of its demonstration of the tectonics associated with its emplacement (for example, Bailey, 1945, 1956; Brown, 1956; Emeleus *et al.*, 1985). Spectacular examples of felsites, explosion breccias, and tuffisites related to the emplacement of the complex are well exposed (for example, Hughes, 1960a; Dunham, 1968). Good examples of contacts between mafic and acid rocks, with evidence for local generation of rheomorphic acid magmas, are also of special interest in the study of the Rum centre (Hughes, 1960a; Dunham and Emeleus, 1967; Greenwood, 1987).

Almost everywhere on Rum there is some significant feature of Tertiary igneous activity exposed. The sites selected cover most aspects, but the island is, in effect, a single site in its own right and it is fortunate that it is a National Nature Reserve. The geology of Rum has been sum-

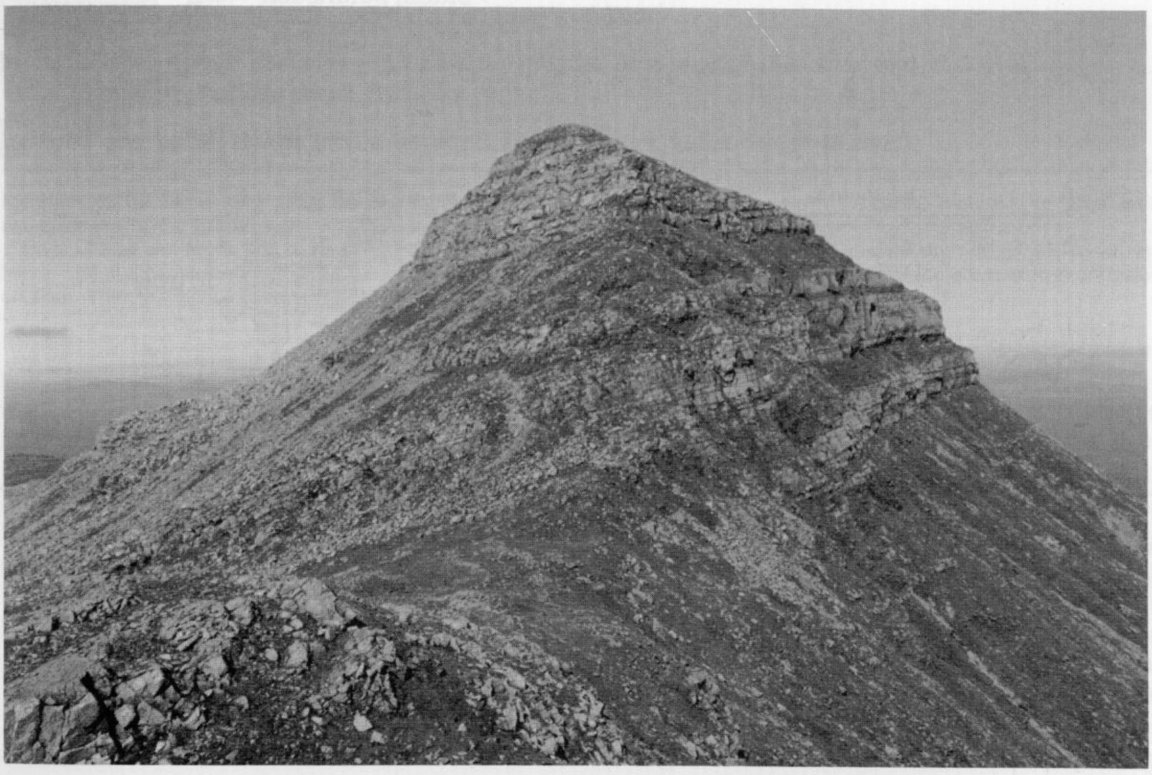
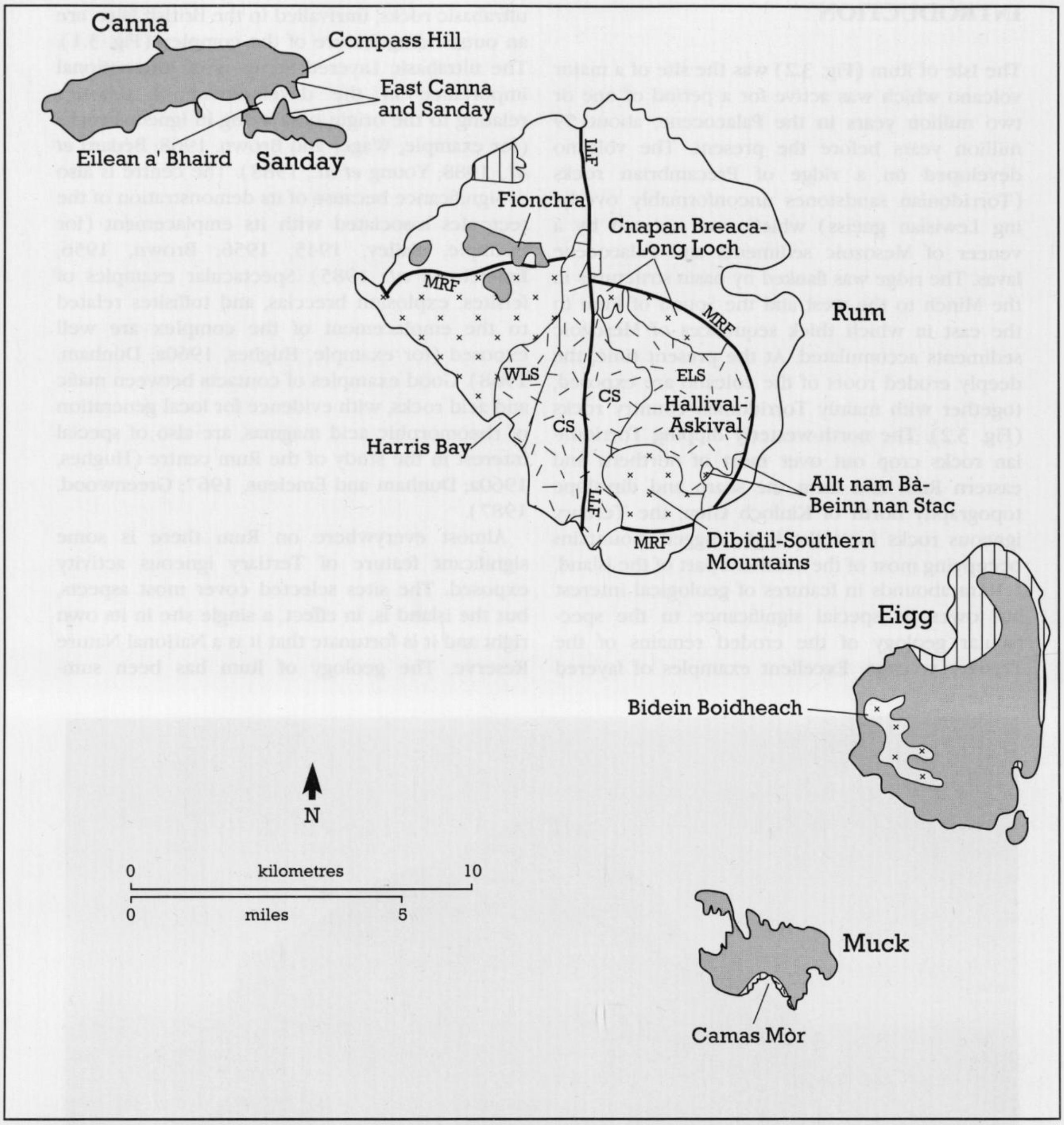


Figure 3.1 Layered allivalite (light) and peridotite (dark) high in the Eastern Layered Series ultrabasic rocks, Hallival. Askival–Hallival site, Rum. (Photo: C.H. Emeleus.)

The Small Isles – Rum, Eigg, Muck, Canna–Sanday



Tertiary

- Lavas, mainly basaltic
- Ultrabasic rocks and gabbro
- Granophyre, felsite, pitchstone, volcanic breccias
- Mesozoic strata
- Pre-Mesozoic rocks

On Rum

MRF Main Ring Fault
LLF Long Loch Fault

CS Central Series
WLS Western Layered Series
ELS Eastern Layered Series
} Ultrabasic rocks and gabbros

Table 3.1 Summary of the Palaeocene igneous geology of Rum and the Small Isles (based on Emeleus and Forster, 1979, table 1, with later amendments)

Valley-filling pitchstone of the Sgurr of Eigg, and associated conglomerates

Dolerite dykes

Lavas and fluviatile sediments of north-west Rum and Canna–Sanday, olivine basalts, hawaiites, mugearite (on Canna), including also tholeiitic basaltic andesite, icelandite (on Rum)

— Period of profound erosion during which the Rum central igneous complex was unroofed and eroded

The Rum Layered Igneous Complex:

  Central Series: feldspathic peridotites, including breccias and some layered allivalites and peridotites

  Western Layered Series (WLS): feldspathic peridotites and gabbroic rocks at Harris

  Eastern Layered Series (ELS): layered feldspathic peridotite and allivalite, also gabbroic and ultrabasic intrusive bodies

  (The WLS and ELS above may be coeval)

Dolerite and basalt dykes (some also post-date the Layered Igneous Complex)

Dolerite and basalt cone-sheets on Rum

Early phase of acid igneous activity:

  Western Granite, also granite at Papadil and Long Loch

  Porphyritic felsite (ignimbrites, in caldera, and intrusions)

  Tuffisites (some may post-date porphyritic felsite)

  Volcaniclastic breccias – probably a mixture of explosion breccias and breccias formed by caldera wall collapse

Dolerite and basalt dykes (some intruded after breccias and prior to felsites)

Initiation of the Main Ring Fault System: movement on this system of arcuate faults probably continued at least until emplacement of the ELS/WLS and was a major tectonic feature during the early acid phase of igneous activity.

Lavas of Eigg and Muck, and those involved in the Main Ring Fault on Rum. Principally olivine basalts, feldspar-phyric olivine basalts and mugearites on Eigg. The dykes cutting these lavas belong to the main post-felsite and granite phase of dyke intrusion on Rum. Thin sedimentary layers occur in the Eigg and Muck successions.

marized in the Reserve handbook (Black, 1974); an outline of the Palaeocene igneous sequence is given in Table 3.1.

The first comprehensive account of the geology of Rum is contained in the Geological Survey's Memoir on the Small Isles of Inverness-shire (Harker, 1908). Many of the views advanced by Harker were subsequently considerably amended in a key paper by Bailey (1945). These contributions, together with the results of investigations between about 1950 and 1966 have been reviewed by Dunham and Emeleus (1967).

The earliest Palaeocene igneous activity on Rum was the accumulation of basalt lavas, probably part of the Eigg and Muck lava fields. Initiation of the central igneous complex was probably preceded by intrusion of numerous gabbroic plugs followed by doming and the formation of an arcuate fault system. This faulting was recognized by Bailey (1945), who showed that gneisses and basal Torridonian sediments contained within it had been uplifted by possibly as much as 2000 m. Acid magmatism led to the

Figure 3.2 Map of the Small Isles showing localities mentioned in the text.

formation of volcanic breccias, tuffisites, bodies of porphyritic felsite and granites. Initially, the breccias were attributed to explosive volcanism associated with the acid magmas which formed the felsites (Bailey, 1945; Hughes, 1960a; Dunham, 1968) and which were considered to be intrusive. Subsequently, Williams (1985) showed that the felsite frequently exhibited typical eutaxitic structures and some, at least, were probably formed as ignimbrites, possibly ponded within a caldera (Emeleus *et al.*, 1985). Recent work on the chaotic breccias of Dibidil and Coire Dubh strongly suggests that much of the fragmented material may be due to catastrophic collapse, from time to time, of the walls of a caldera formed during subsidence on the Main Ring Fault (M. Errington, private communication; observations of the authors and B.R. Bell). The argument for the presence of a caldera was strengthened when it was found that Lower Lias fossiliferous sediments and basalt lavas similar to those on Eigg occurred within the Main Ring Fault system (Smith, 1985), implying that there must have been significant subsidence (1–2 km?) along this fault system after the uplift demonstrated by Bailey. It was also shown that the period of subsidence was followed by further central uplift during which Torridonian strata were brought up over the Mesozoic sediments and later lavas (Smith, 1987; Emeleus *et al.*, 1985). Furthermore, the subsequent emplacement of at least the Eastern Layered Series peridotites and allivalites was clearly guided by these arcuate faults. The complex interplay between acid magmatism, major doming and ring-faulting, intrusion and the extrusion of pyroclastic flows, caldera formation and the development of chaotic breccias, are noteworthy features of the igneous geology of Rum.

The layered ultrabasic rocks and associated gabbros were considered in some detail by Wager and Brown (1968) in their classic work on layered igneous intrusions. Subsequently, these rocks have figured prominently in the development of theories concerning the compositions of the magmas responsible for mafic bodies such as the Rum Layered Series. The frequent close association between the layered ultrabasic rocks and gabbros makes basaltic magmas attractive parent material. However, there is a growing body of opinion which advocates high-temperature picritic basalt or magmas of feldspathic peridotite composition as being parental to the Rum layered ultrabasic rocks and other similar masses. The existence of these high-temperature magmas at high crustal levels was advanced by Drever and Johnston (1958) and Wyllie and Drever (1963) from examination of the minor ultrabasic intrusions about the Cuillin gabbros (Cuillin Hills) and on the Isle of Soay, south of Skye. The close similarities between the minor ultrabasic intrusions and layered ultrabasic rocks on both Skye and Rum suggested to Gibb (1976) that the ultrabasic rocks had been formed from parental magmas consisting of a suspension of olivine crystals in ultrabasic ('eucritic') liquid. Donaldson (1975) subsequently investigated the harrisites and ultrabasic breccias of south-west Rum (Harris Bay) and postulated that the rocks had formed from (possibly hydrous) feldspathic peridotite liquids. Further supporting evidence for the presence of intrusive ultrabasic magmas came from McClurg's (1982) discovery of quenched aphyric ultrabasic dykes intruding the layered rocks, the recognition that at least some of the feldspathic peridotites in the layered succession of ultrabasic rocks were intrusive, sill-like sheets (Renner and Palacz, 1987; Bédard *et al.*, 1988), and the presence of quenched ultrabasic margins to the layered rocks at Beinn nan Stac and Harris Bay (Greenwood, 1987; Greenwood *et al.*, 1990). It thus appears inescapable, from the evidence of the Rum sites (Allt nam Ba-Beinn nan Stac; Askival–Hallival; Harris Bay) and elsewhere (for example, Skye Cuillins), that conditions in the larger central complexes of the BTVP and their immediate surroundings sometimes favoured the rise of hot, dense, picritic liquids to within a short distance (*c.* 1 km?) of the Earth's surface. Although not unique by any means, these examples are unusual and must have involved special conditions involving initial rapid, strongly localized throughput of hot basaltic magmas, thus providing preheated pathways along which the ultrabasic liquids were able to rise to high structural levels before crystallizing and congealing.

Brown (1956) and Wager and Brown (1968) attributed the prominent layering seen in the Rum Eastern Layered Series ultrabasic rocks to accumulation of early high-temperature crystals (mainly olivine, followed by plagioclase) from successive batches of fresh basaltic magma. The model of a frequently replenished magma chamber is generally accepted, but, as outlined earlier, many now consider that ultrabasic magmas, with or without contemporaneous basaltic liquids, were responsible for the large-scale layering.

Young *et al.* (1988) consider that there was a stratified picrite-basalt magma chamber in which both magmas were crystallizing simultaneously. Investigations of layers high in the Eastern Layered Series led Renner and Palacz (1987) to suggest that Unit 14 (Brown, 1956) records replenishments of the Rum magma chamber by fresh batches of both picritic and basaltic magmas, and their field observations show that some of the subsidiary peridotite layers are actually sill-like bodies, intruded into near solid or solid troctolitic (allivalitic) rocks. Bédard *et al.* (1988) also examined layers high in the Eastern Layered Series and concluded that it was highly likely that peridotite layers in this succession formed from thick sills of picrite magma intruded into partly consolidated troctolites, thus coming close to the original explanation of the layering put forward in the Memoir (Harker, 1908). The distinctive textures of the ultrabasic rocks provided type examples of cumulate textures (Wager *et al.*, 1960); early-formed olivine and/or plagioclase were thought to have been cemented by the crystallization of trapped, contemporaneous liquid to give well-formed (early) crystals enclosed by poikilitic (late) crystals. Subsequent studies on Rum and elsewhere (for example, Sparks *et al.*, 1985; Irvine 1987) have shown that there may have been substantial migration of the trapped liquids, which modified the early 'cumulate' minerals; it has also been realized that many of the textures of igneous rocks hitherto considered to have formed when the rocks first consolidated may, in fact, have been considerably modified. The ultrabasic rocks of Rum have been extensively referred to in such studies (for example, Hunter, 1987).

A field guide to the Tertiary igneous rocks of Rum has been published by the Nature Conservancy Council (Emeleus and Forster, 1979) and a compilation map of the solid geology has been published as one of the Nature Conservancy Council's 1:20 000 series on the island (Emeleus, 1980). A special issue of the *Geological Magazine* (Volume **122**, Part 5, 1985) contains a wide variety of papers entirely devoted to the Tertiary

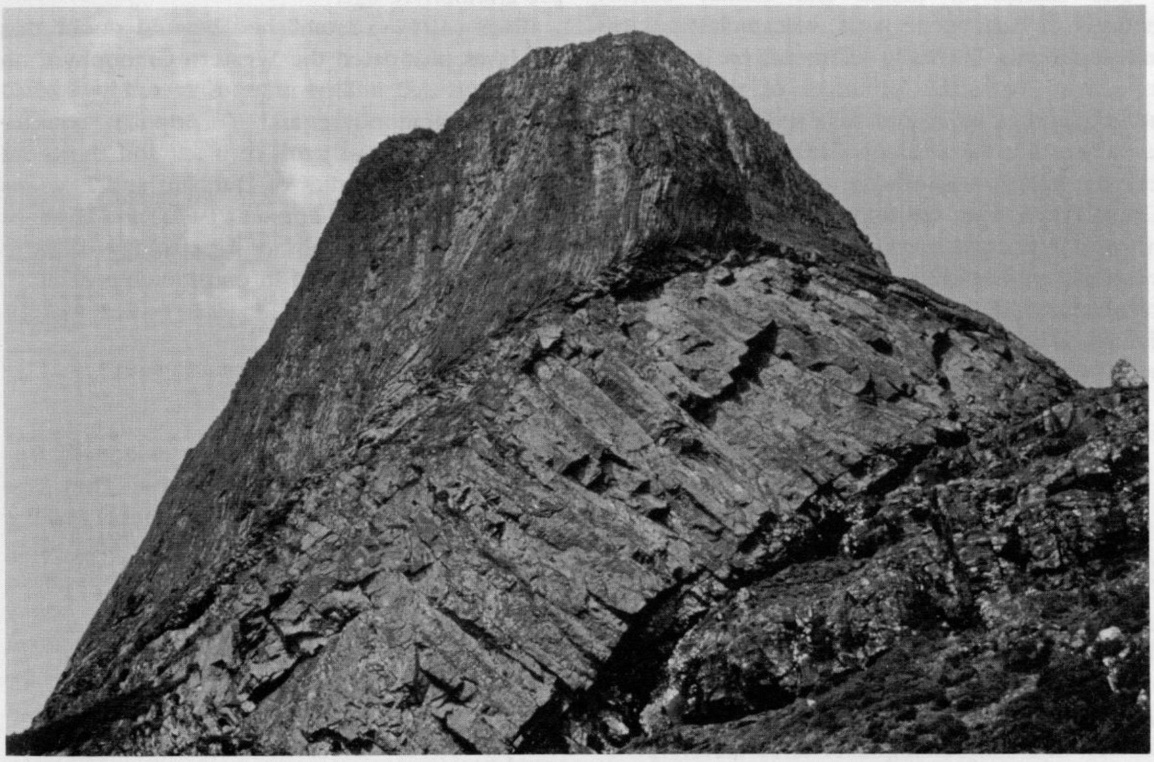


Figure 3.3 The Nose, east end of Sgùrr of Eigg. Massive Eocene pitchstone flow overlies eroded Palaeocene basalt lavas. The pitchstone fills a steep-sided valley, columnar jointing is developed in the pitchstone perpendicular to the valley side (slopes top right to bottom left), but gives way to fine-scale, near-vertical jointing at higher levels. The individual lava flows cut out against base of pitchstone (bottom right side). South-west Eigg site. (Photo: A.P. McKirdy.)

igneous geology of Rum. Much of the recent research has concentrated on the layered ultrabasic rocks; this work has been reviewed and summarized by Emeleus (1987); the pre-layered rocks igneous geology has also been surveyed (Emeleus *et al.*, 1985).

Tertiary igneous rocks also crop out extensively on the islands of Eigg, Muck, Canna and Sanday which have been described by Harker (1908), Ridley (1971, 1973) and Allwright (1980).

On Eigg and Muck, subaerial basaltic lava flows overlie Jurassic sediments and are cut by a dense NW–SE-trending basaltic dyke swarm which continues north-west to Rum where it is cut by layered ultrabasic rocks; the lavas on these two islands thus pre-date the Rum centre. The Sgurr of Eigg forms a conspicuous feature at the south end of Eigg formed by a pitchstone floor filling a valley system eroded into the basalt lavas and the dyke swarm (Fig. 3.3). Radiometric dating of the pitchstone shows it to be one of the youngest igneous events in the British Tertiary Volcanic Province (52 Ma, Dickin and Jones, 1983).

The islands of Canna and Sanday consist entirely of Palaeocene lavas, volcaniclastic rocks and sediments. Fluviatile sediments are intimately associated with the products of the volcanic activity and clasts in inter-lava sediments provide evidence that the lavas on Canna and Sanday are closely linked with those of north-west Rum. Canna and Sanday are important links in a chain of sites that enable a relative dating of the Rum central complex and the later Skye Cuillin central complex in the study of the evolution of the British Tertiary Volcanic Province (Meighan *et al.*, 1981; Mussett, 1984).

FIONCHRA

Highlights

The site is of particular importance since it contains the only example of lavas clearly post-dating a central complex in the British Tertiary Volcanic Province. It also excellently demonstrates the interaction between the accumulation of lavas and the development of a contemporaneous fluviatile system.

Introduction

Four outliers of Tertiary volcanic rocks and associated fluviatile conglomerates and lacustrine sediments form the summits of Fionchra, West Minishal, Orval and Bloodstone Hill in north-west Rum (Figs 3.4 and 3.5). The site is unique within the Tertiary Igneous Province as it contains the only known occurrence of lavas which are demonstrably younger than the nearby central intrusive complex.

The lavas and associated sediments were first described by MacCulloch (1819). Judd (1874) correctly deduced their age relative to the plutonic rocks. However, Geikie (1897) and Harker (1908) both considered them to be relicts of a once extensive plateau embracing all the Small Isles subsequently intruded by the Rum Central Complex. Harker also frequently misinterpreted the massive flow interiors as intrusive sheets or sills (see site descriptions for northern Skye). Tomkeieff (1942) reinterpreted Harker's sills as trachyandesitic lava flows and, together with Bailey (1945), considered them to be of a pre-granophyre age.

Black (1952a) established beyond doubt that the lavas post-dated the Western Granophyre on Orval and had infilled a series of valleys carved into the granophyre and Torridonian country rocks. Through the work of Black and the more recent detailed studies of Dunham and Emeleus (1967), Emeleus and Forster (1979) and Emeleus (1985), the stratigraphy and petrology of these unique lavas are known in considerable detail.

Description

The lavas of the four outliers are essentially flat-lying or dipping gently to the west. They rest unconformably on Torridonian sediments and the Western Granophyre, overlapping the Main Ring Fault. The unconformity is irregular and the lavas appear to have filled an evolving river valley system. The most complete lava succession occurs on Fionchra where Black (1952b) estimated a total maximum thickness of over 500 m; however, not all members are represented here.

Emeleus (1985) remapped the Tertiary lavas of Rum and proposed a fourfold subdivision:

1. Lower Fionchra Formation. This is the oldest lava formation; it fills a river valley cut into

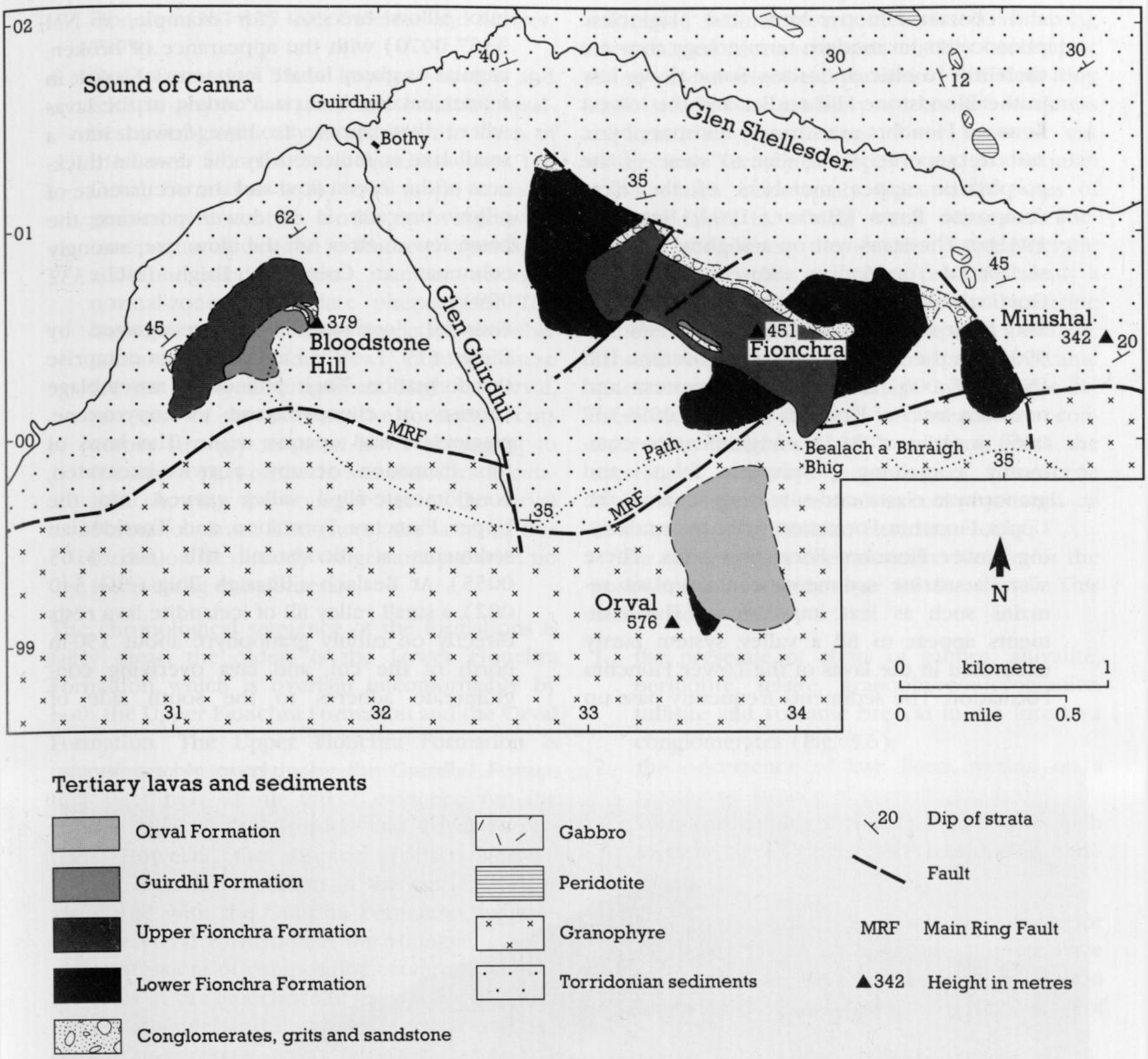


Figure 3.4 Geological map of the Fionchra site, Rum (after Emeleus, 1980).

Torridonian sediments and lined with Tertiary conglomerates. On the south side of West Minishal (NG 348 003), the lavas pass undisturbed across the Main Ring Fault to overlie the granophyre. The lavas are alkali-olivine basalts, typical of many Hebridean lavas, but less alkaline than those of Skye. Most contain phenocrysts of olivine and plagioclase. More fractionated, hawaiitic flows occur in the west of the Orval outlier where Black (1952a) demonstrated that they rest on an eroded surface of weathered granophyre. North of Minishal the lavas rest on thick fluviatile conglomerates which contain clasts derived from rocks now exposed in the Rum central complex (granophyre, porphyritic felsite, gabbro, explosion breccia, allivalite) and the country rocks (gneisses and Torridonian sandstones). There are also clasts of tholeiitic basalt, frequently vesicular, and dolerite. The basalts are compositionally unlike any now exposed on Rum or the adjoining islands.

2. Upper Fionchra Formation. This subdivision contains lavas termed 'mugearites' by earlier workers. Chemically, the lavas are tholeiitic

and contain clinopyroxene and plagioclase phenocrysts; in modern terminology they are tholeiitic basaltic andesites. Some flows low in the Bloodstone Hill outlier and the lowest flows on Fionchra are strongly feldspar-phyric and are superficially similar to some of the porphyritic upper members of the Skye composite flows (Harker, 1904; Kennedy, 1931b). The lavas rest on a slightly irregular surface of Torridonian arkose and Western Granite and are observed to overlap the Main Ring Fault at Bealach a'Bhraigh Bhig (NM 339 999). On the western side of Bloodstone Hill (NG 317 006) and along the western and northern faces of Fionchra (NG 332 009–337 006), a series of fluvial conglomerates, commonly containing porphyritic felsite and granophyre clasts, and silty beds separate the Upper Fionchra Formation from the underlying Lower Fionchra Formation lavas. These silty, lacustrine sediments contain plant remains such as leaf impressions. The sediments appear to fill a valley system partly excavated in the lavas of the Lower Fionchra Formation. The sediments frequently pass up into pillow breccias (for example, at NM 3367 0070) with the appearance of broken, angular or glassy lobate fragments of basalt in a finer basaltic breccia. Ponding of the lavas where they appear to have flowed into a small lake is indicated by the unusual thickness of the lowest flow and the occurrence of pillow breccias in its lower portions; the basal few metres of the flow are strongly columnar at Coire na Loigh (NG 332 009).

3. Guirdhil Formation. Rocks recognized by Ridley (1971, 1973) as icelandites comprise this formation. Their phenocryst assemblage consists of clinopyroxene, orthopyroxene, plagioclase and opaque oxide. The lavas of this formation occupy a twice-excavated, conglomerate-filled valley carved into the Upper Fionchra Formation and Torridonian sediments at Bloodstone Hill (NG 3165 0055). At Bealach a'Bhraigh Bhig (NG 340 002), a small valley fill of icelandite lava rests directly on rubbly granophyre about 150 m north of the col, and lava overlying conglomerate adheres to the south side of

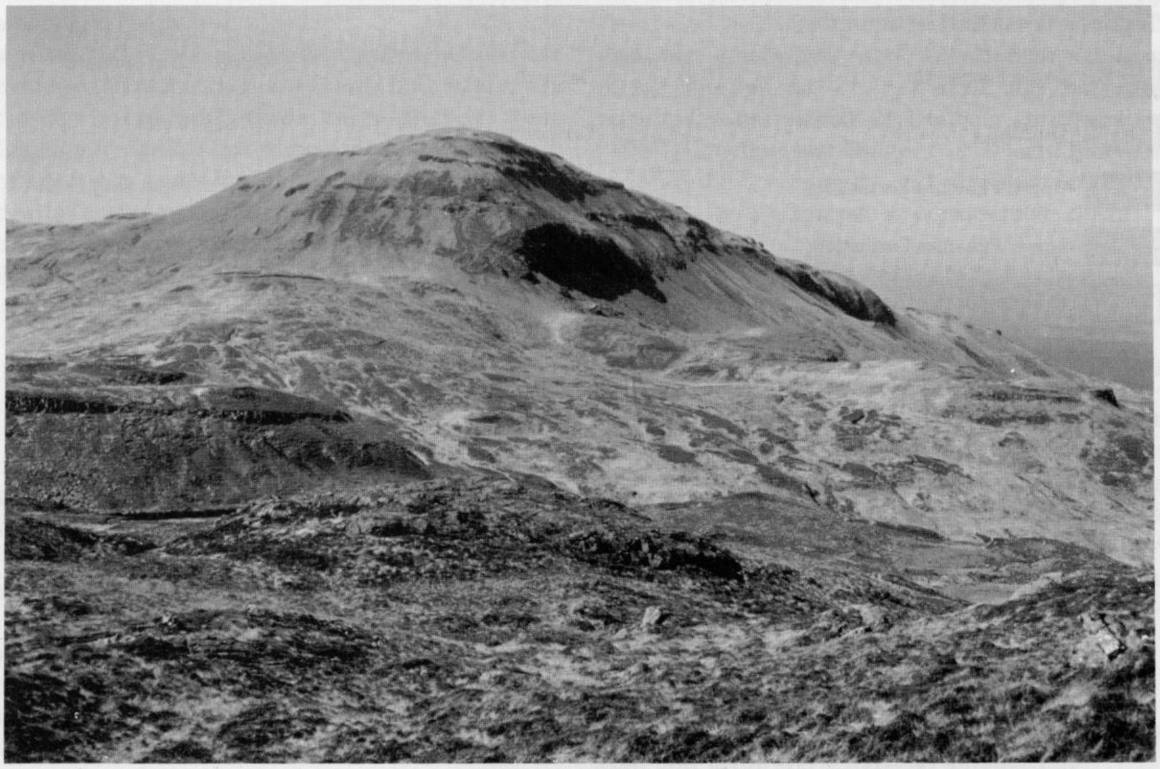


Figure 3.5 Post-Central Complex basic lavas resting on an irregular surface of Torridonian sandstone. Fionchra site, Rum. (Photo: C.H. Emeleus.)

Fionchra (NG 335 005; Emeleus and Forster, 1979).

4. Orval Formation. These lavas are olivine- and feldspar-phyric hawaiites and basaltic hawaiites, petrographically similar to the lavas of the Lower Fionchra Formation. However, the Orval Formation lavas tend to be coarser-grained and contain biotite as overgrowths on opaque oxides and as discrete crystals. In addition, alkali-feldspar mantles strongly normal-zoned plagioclase phenocrysts. The flows are massive and the formation probably contains three or four flows, although these are not easily distinguished. High on Orval, just east of the summit, the formation cuts across strongly terraced flows belonging to the upper part of the Lower Fionchra Formation showing the younger age of the Orval Formation lavas. Elsewhere, the lavas of this formation lie directly on granophyre with no intervening conglomerate.

The chronological sequence of the formations is fairly clear; the oldest is the Lower Fionchra Formation which is overlain unconformably by both the Upper Fionchra Formation and the Orval Formation. The Upper Fionchra Formation is unconformably overlain by the Guirdhil Formation but there is no direct evidence for the relative ages of the Guirdhil and Orval Formations. However, the absence of clasts derived from the Orval Formation in the conglomerates associated with the Guirdhil Formation suggests that the Orval Formation is the younger.

No intrusions of compositions comparable with the lavas in the Fionchra site have been found on Rum, implying that the source(s) must have been outside the present area of the island. A possible source may have been offshore of eastern Canna, since coarse volcaniclastic rocks, probably of very local origin, are interbedded with the lavas of Compass Hill (East Canna and Sanday). However, this problem has not been fully resolved. These lavas are grouped with those of Canna and Sanday in the Canna Lava Formation, the individual 'formations' identified above are now termed 'members' (Emeleus, in preparation).

Interpretation

The Fionchra site contains an incomplete sequence of Palaeocene lavas which record the last major igneous event on Rum. The lavas and associated sediments are interpreted as having accumulated in a succession of hilly landscapes, filling valleys orientated parallel to the Main Ring Fault which was probably a zone of weakness exploited by weathering. River systems cut valleys into Tertiary granophyre and Torridonian rocks which occasionally became the sites of shallow lakes in which were deposited fine-grained sediments; the coarser conglomeratic sediments of the sequence probably had a fluviatile origin. Plant remains in the lacustrine sediments suggest a warm, temperate climate. Erosion occurred during periods of volcanic quiescence when the drainage system was re-established. The Tertiary sediments are considered by Emeleus (1985) to result from the erosion of a terrane consisting of Palaeocene lavas and igneous intrusive rocks as well as Lewisian and Torridonian basement rocks.

The site provides unequivocal evidence for the post-Central Complex age of the lavas. This comes from:

1. the presence of clasts of gabbro, allivalite, peridotite, felsite, granophyre/microgranite, tuffisite and volcanic breccia in the interlava conglomerates (Fig. 3.6);
2. the occurrence of lava flows resting on a weathered surface of granophyre; and
3. lavas overlapping the Main Ring Fault which separates granophyre and Torridonian sediments.

The Central Complex was clearly unroofed prior to accumulation of the lavas and it must have formed high ground which continued to undergo active subaerial erosion throughout the period of lava effusion.

The lavas and some of the sediments are comparable with those on Canna and Sanday (see below) to which they are related. Somewhat similar sediments also occur in south-west Skye (Allt Geodh a'Ghamhna). Taken together with these sites, Fionchra is a major link in a line of evidence which clearly indicates that the Rum central complex predated the central complex on Skye (for example, Meighan *et al.*, 1981; Dagley and Mussett, 1986).

The Rum lavas varied considerably in composition with time. The Lower Fionchra Formation flows are alkali basalts but they were preceded by tholeiitic flows, now only represented by clasts in underlying conglomerates. The succeeding Upper Fionchra and Guirdhil Formations are tholeiitic and show progressively more evolved, or frac-

Figure 3.6 Boulder conglomerate underlying flow-banded icelandite lava flow. The conglomerate contains granophyre, felsite and allivalite clasts derived from the weathering of the Rum Central Complex. South side of Fionchra. Fionchra site, Rum. (Photo: C.H. Emeleus.)

tionated compositions up the sequence; however, the final flows of the Orval Formation, are fractionated alkali basalts and hawaiites. The Rum flows were probably derived from at least two source magmas, one alkali basaltic in character, the other tholeiitic. There are only limited age data available (about 58 Ma; Dagley and Mussett, 1986), but all flows sampled, to date, gave reversed magnetic polarities and it is likely that they were erupted in a short space of time (Mussett *et al.*, 1988, figure 2; see also Chapter 1, Table 1.1).

Conclusions

The final phase of igneous activity on Rum resulted in the accumulation of lavas and associated sediments now exposed only in the Fionchra site. The site provides an excellent opportunity to study the interaction between the emplacement of lava flows and a palaeo-fluvial system.

The Tertiary lavas of Rum were possibly erupted from a centre or centres north-west of Rum and these filled valleys in an incised topography. Four lava members are recognized, each separated by unconformable contacts, conglomerates and some fine-grained lacustrine sediments. Clast populations in the intra-flow conglomerates show that the lavas post-date the emplacement of the Central Complex which was unroofed by the time that the first lavas erupted. Preliminary geochemical investigations show the presence of lavas of both tholeiitic and alkaline affinities.

ALLT NAM BÀ–BEINN NAN STAC

Highlights

The juxtaposition of Lewisian gneisses and basal Torridonian rocks with Jurassic sediments and Palaeocene lavas gives this site particular importance since it demonstrates both subsidence and uplift on the Main Ring Fault which bounds the Rum central complex. The site also contains one of the few examples in the British Tertiary Volcanic Province of a chilled margin to a gabbro–ultrabasic complex.

Introduction

The site (Fig. 3.7 and inset) is characterized by a tectonic collage of fault-bounded slivers of metamorphosed Jurassic limestones, sandstones and shales, Palaeocene lavas, basal Torridonian sediments and Lewisian gneiss. These components occur within a fault zone coincident with the Main Ring Fault and provide a record of tectonic activity during the emplacement of the central complex.

Marble and calc-silicate rocks were discovered close to Allt nam Bà by Hughes (1960b) who proposed them to be of Lewisian age and recognized that their presence, together with Lewisian gneiss, could be attributed to movement along the Main Ring Fault. Subsequently, the discovery of poorly preserved fossil bivalves led to the recognition that the calc-silicate rocks were of Mesozoic age (Dunham and Emeleus, 1967). Smith (1985, 1987), in a detailed study of the fault zone, recorded fairly well-preserved fossils of bivalves, corals and belemnites of Lower Lias age in these rocks. These and other investigations have stimulated fresh interpretations of the Tertiary tectonics of Rum (Emeleus *et al.*, 1985).

Description

A variety of lithologies of strikingly contrasting ages occur as fault-bounded slivers and intrusives in a wide lensoid fault zone coincident with the Main Ring Fault at Allt nam Bà and extending to the south-east slopes of Beinn nan Stac (Fig. 3.7).

In the northern part of the fault zone a wedge of Mesozoic strata crops out. Metamorphosed calc-silicates have long been recognized at Allt nam Bà (Hughes, 1960b) and Smith (1985, 1987) has mapped associated fossiliferous sandstones, sandy limestones and shales of early Jurassic age. The succession of Mesozoic strata is up to 35 m thick and is highly inclined to the west and inverted. Palaeontological evidence suggests that they are probably an extension of the Lower Lias Broadford Beds (Smith, 1985).

Highly metamorphosed calc-silicate rocks within the marginal Layered Series are found in the Allt nam Bà valley (Fig. 3.7 inset; NM 4060 7945). They consist of various assemblages of calcite, grossularite, diopside, vesuvianite, leucoxene and tilleyite. Where they are cut by a narrow syenite vein they additionally contain wollastonite and pyrite (Hughes, 1960b). A further narrow strip of limestone, about 100 m to the south, is separated from the northern outcrop by gabbro and a minor intrusion of hybrid acid rocks. Two hundred metres to the south along the line of the same fault zone, a homogeneous, dull, coarse-grained marble is composed almost entirely of calcite (NM 404 942) and contains poorly preserved belemnite and bivalve remains (Emeleus and Forster, 1979). These calc-silicates and related sediments, together with limestones recently rediscovered by Smith on the south-western slopes of Beinn nan Stac (Smith, 1987) are the only Jurassic outcrops known on Rum. They are of early Jurassic age, comparable with the Broadford Beds on Skye (Smith, 1985). Younger Jurassic rocks are, however, well exposed on Eigg less than 10 km to the south-east.

The Main Ring Fault zone crosses to the eastern side of Beinn nan Stac about 1 km south-east of the summit where it is over 100 m wide. On the inner side it is bounded by Torridonian Basal Grit and Bagh na h-Uamha Shale (see Black and Welsh, 1961, for divisions of the Torridonian strata). On the outer, south-eastern side a thin strip of Rudha na Roinne Grit overlying Bagh na h-Uamha Shale occurs and dips steeply towards the fault zone. Within the fault zone, a variety of rocks are found including an elongate lens of Lewisian gneiss, a small area of Basal Grit and a strip of flinty, sheared amygdaloidal basalt. Smith (1985) has shown the basalts to be far more extensive than previously established; they are fault-bounded to the east and south-east with an unconformable contact between basalt and Mesozoic strata to the north. These lavas predate those at Fionchra in northern Rum and may be a faulted wedge of more extensive Tertiary lava fields which now cover much of Eigg and Muck and with which they have geochemical similarities (Smith, 1987).

Undeformed porphyritic felsite and an explosion breccia are also found within the fault zone and have probably exploited the lines of weakness along the faults.

The prominent cliff feature which extends from near the summit of Beinn nan Stac SSE along the crest of the ridge towards Allt nam Bà is formed by baked, resistant Torridonian sediments (Bagh na h-Uamha Shales) and probably owes its origin to the contact effects of the Marginal Gabbro of the ultrabasic/basic complex. At a locality about 450 m ESE of the summit (NM 4007 9403), the marginal olivine gabbro becomes fine grained and contains skeletal olivine

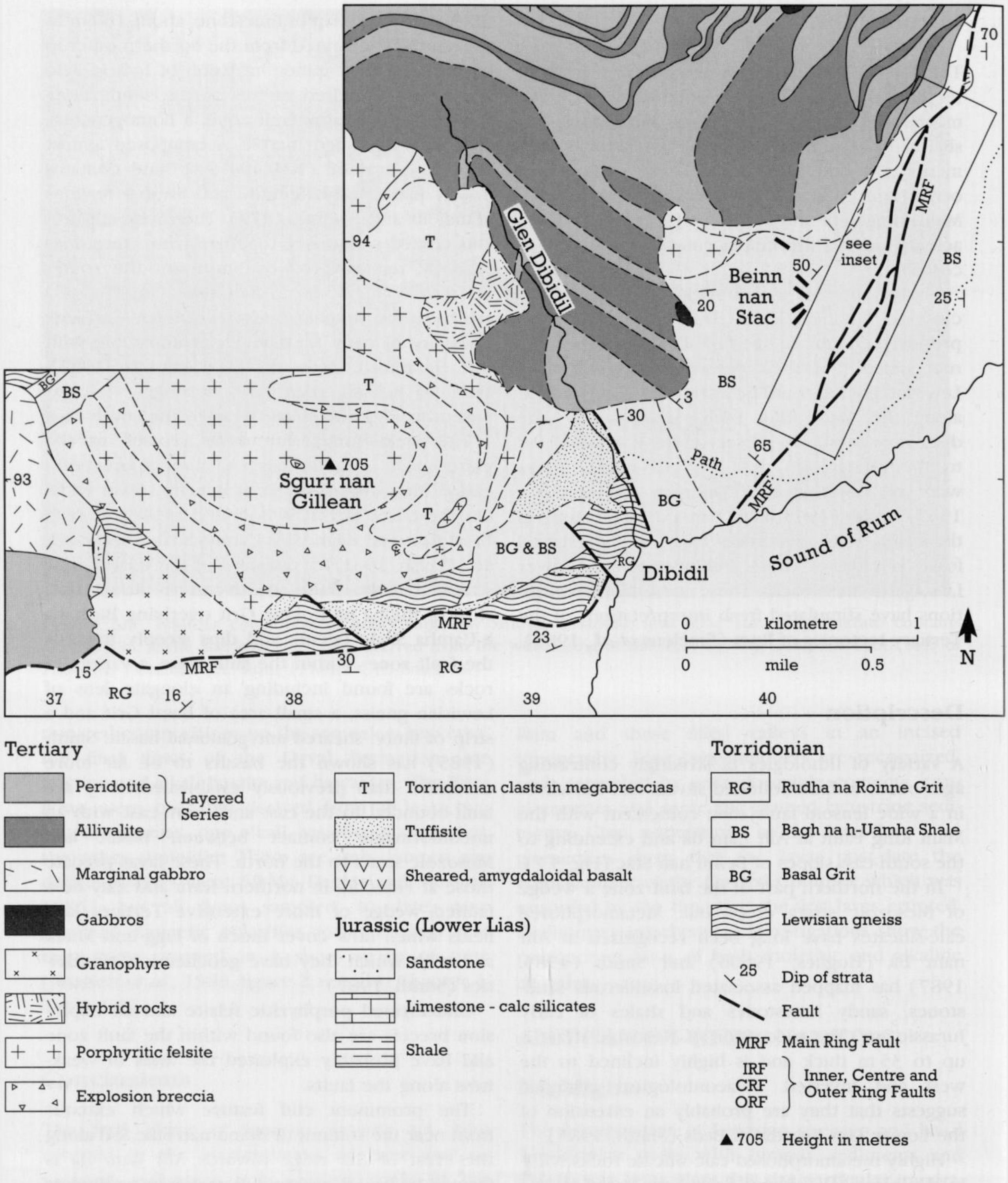
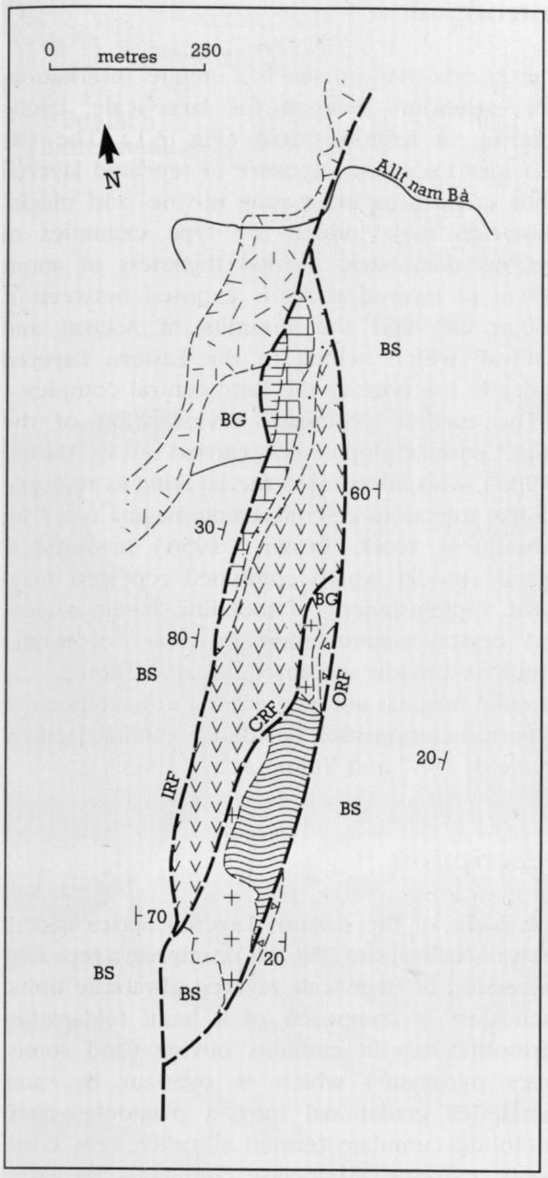


Figure 3.7 Geological map of the Dibidil–Southern Mountains and Allt nam Bà–Beinn nan Stac sites, Rum. Inset (on opposite page) shows detail to the south of Allt nam Bà. Main figure after Emeleus (1980) with subsequent modifications (Greenwood, 1987). Inset after Smith (1985, fig. 1).



phenocrysts in a variolitic matrix. This is one of the few places on Rum where there is a clear indication of a chilled facies to the rocks rimming the ultrabasic–gabbro complex (Greenwood, 1987; Greenwood *et al.*, 1990). At this locality it is overlain by up to 7 m of hybrid rock which is in turn overlain by baked shale. The field relationships here suggest that the baked shales, explosion breccias and felsite of Beinn nan Stac form a SE-dipping roof to the later gabbros and ultrabasic rocks, similar to the roof seen at the east end of Cnapan Breaca (see below).

Interpretation

Smith (1985, 1987) has shown that the Jurassic sediments on Rum are closely comparable with the middle Broadford Beds of Skye and do not correlate with the nearby Great Estuarine sediments of Eigg. Eigg and Rum are separated by the southern extension of the Camasunary Fault (Binns *et al.*, 1974) which on Skye shows a considerable pre-Palaeocene downthrow to the east (Peach *et al.*, 1910). On Skye, only the lowermost Jurassic beds occur west of the Camasunary Fault and it is likely that this situation pertained on Rum at the start of Tertiary volcanism.

The wide fault zone in south-east Rum contains several individual, distinct, fault planes related to different stages of movement along the Main Ring Fault. Smith (1985) mapped the following faults which are shown on Fig. 3.7 inset.

Outer Ring Fault (ORF) – easternmost boundary fault.

Centre Ring Fault (CRF) – separating sheared Palaeocene basalts from felsites and gneisses.

Inner Ring Fault (IRF) – westernmost fault; responsible for the juxtaposition of stratigraphically low-level Jurassic sediments and Palaeocene basalts against Torridonian sediments.

The proposed model for the movement of the Main Ring Fault is discussed for the Cnapan Breaca and Dibidil sites. According to Smith (1985, 1987) the initial diapiric uplift and ring fracturing is thought to have occurred along the ORF, bringing Lewisian and basal Torridonian to higher stratigraphic levels. The ensuing caldera subsidence occurred along the CRF, evidence for which is the presence of Mesozoic sediments downfaulted against Torridonian and Lewisian rocks. Renewed uplift of about 2 km along the IRF is required to bring stratigraphically low Torridonian to the structural level that it now occupies within the Main Ring Fault. A more detailed discussion of the proposed movements within the fault zone is presented in Smith (1985). The occurrence of chilled picritic rocks at the edge of the layered ultrabasic rocks provides evidence for the existence of ultrabasic, or strongly picritic basaltic, liquids in the complex (Greenwood *et al.*, 1990).

Conclusions

The juxtaposition of basement Lewisian and Torridonian rocks and stratigraphically high Jurassic sedimentary rocks and Palaeocene basalts within the fault zone can be explained by movement along the different fault planes; the presence of Mesozoic strata provides crucial evidence for early subsidence during which the felsite and explosion breccia probably formed.

The exposed Main Ring Fault complex in south-east Rum is therefore of considerable importance in the study of the tectonic evolution of the Rum Complex in providing a comprehensive record of different stages of movement during its emplacement. Recent studies within this site have made an important contribution to the understanding of the Tertiary geology of Rum, in the overall context of the British Tertiary Volcanic Province. It is now evident that marginal complexes, such as that present here, merit further careful scrutiny both on Rum and elsewhere.

A chilled contact facies of the Layered Ultrabasic rocks provides evidence supporting the view that ultrabasic liquids played a role in the formation of the Central Complex.

ASKIVAL–HALLIVAL

Highlights

The site contains the thickest, unbroken succession of layered ultrabasic rocks in Great Britain. The large- and small-scale layered structures, the petrography and geochemistry of the layered rocks and their emplacement mechanisms have been studied in great detail and have contributed significantly to theories relating to the origins of igneous layering. The site is of international importance for these reasons.

Introduction

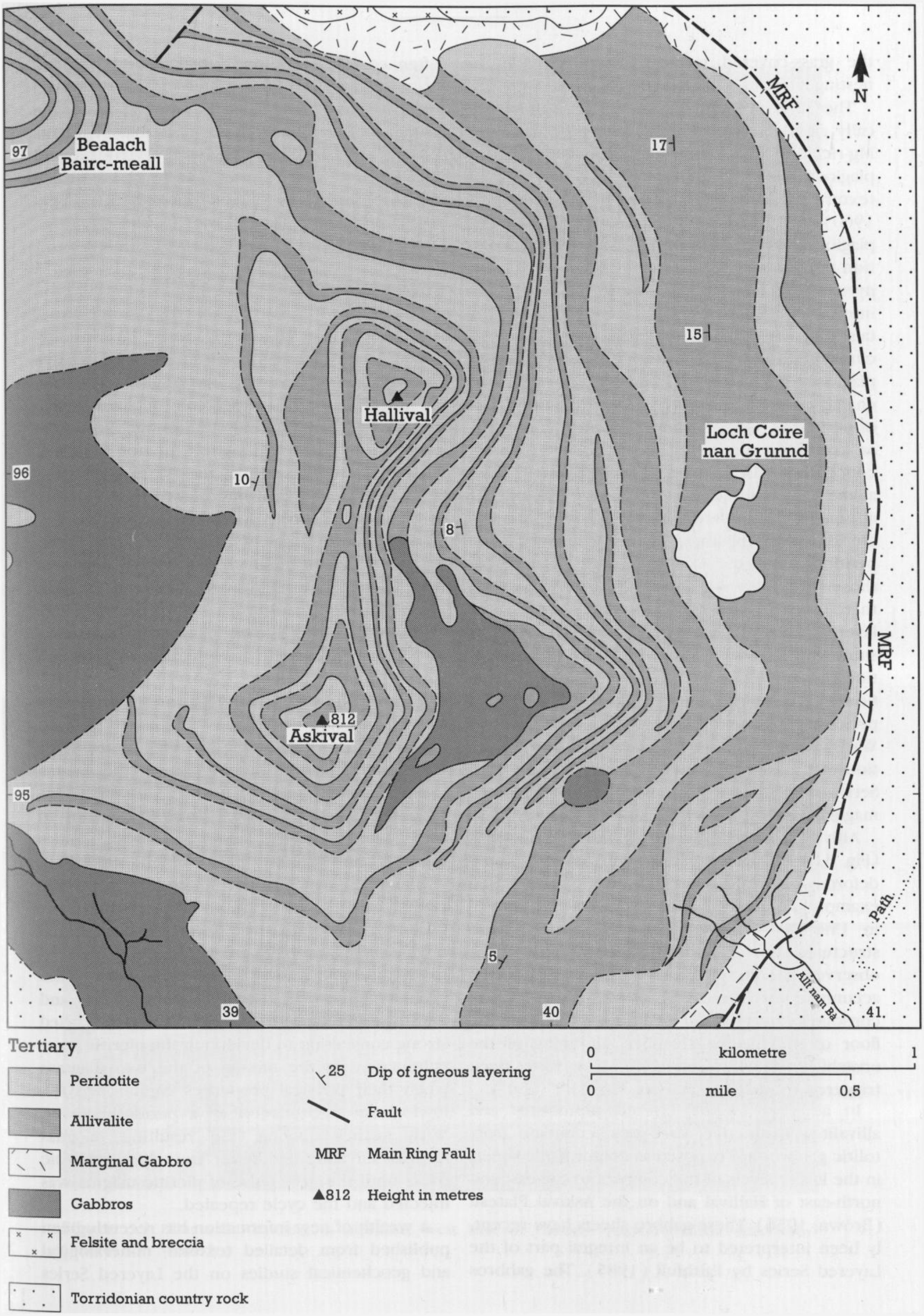
The Askival–Hallival site is a unique, internationally significant location for large-scale, cyclic layering in igneous rocks (Fig. 3.1). The site provides excellent exposure of repeated layered units comprising alternating olivine- and plagioclase-rich rocks which are type examples of igneous cumulates. A total thickness of about 700 m of layered rocks is exposed between *c.* 160 m OD and the summits of Askival and Hallival, which belong to the Eastern Layered Series in the core to the Rum central complex.

The earliest systematic investigation of the Rum Central Complex was carried out by Harker (1908), who interpreted the layering as multiple sill-like injections of contrasting magma types. In subsequent work, Brown (1956) favoured a genetic model which combined repeated magmatic replenishment of tholeiitic basalt magma and crystal accumulation processes, a model which is broadly accepted today, although the parental magmas are now argued to have been of a picritic composition (evidence summarized by Emeleus, 1987 and Young *et al.*, 1988).

Description

The rocks of the Eastern Layered Series in the Askival–Hallival site (Fig. 3.8) comprise a repeated succession of large-scale layered ultrabasic units. Each unit is composed of a basal feldspathic peridotite rich in cumulus olivine (and sometimes pyroxene) which is overlain by, and sometimes gradational into, a plagioclase-rich, troctolitic cumulate termed allivalite. Less commonly, extreme plagioclase cumulates, or anorthosites, may occur at the very top of a unit. Brown (1956) distinguished fifteen such units in the Askival–Hallival area ranging in thickness from under 10 m to over 80 m. The units are generally considered to be an upward-younging stratigraphic sequence with a primary easterly dip of about 20°. The terraced topography which characterizes the slopes of Askival and Hallival (Fig. 3.1) results from the contrasting weathering properties of peridotite and allivalite; the allivalites form prominent, resistant escarpments, while the peridotites erode more easily forming

Figure 3.8 Geological map of the Askival–Hallival site, Rum (after Emeleus, 1980).



N
MRF
Bealach
Bairc-meall
97
17
15
96
95
10
8
5
Hallival
Askival
▲812
Loch Coire
nan Grunnd
Path
Allt nam Bà
39
40
41
Tertiary
Peridotite
Allivalite
Marginal Gabbro
Gabbros
Felsite and breccia
Torridonian country rock
25 Dip of igneous layering
Fault
MRF Main Ring Fault
▲812 Height in metres
0 kilometre 1
0 mile 0.5

the grass-covered terraces which provide the nesting sites for Rum's manx shearwater colony.

The allivalites and peridotites are mineralogically simple, containing variable proportions of Mg-rich olivine, diopsidic pyroxene, calcic plagioclase and chrome-spinel. The petrographic textures reflect cumulate processes (Wager *et al*., 1960) and all minerals occur as cumulus phases; plagioclase in particular defines a strong lamination parallel to layering in allivalites. Plagioclase, pyroxene and, very occasionally, olivine are also intercumulus phases forming large poikilitic crystals up to 20 mm in diameter enclosing the cumulus phases. The resistance to weathering of plagioclase poikilocrysts is responsible for the characteristic honeycombed weathering surface of peridotite. Cumulus chrome-spinel, commonly an accessory mineral in peridotite, is frequently concentrated in seams several millimetres thick at the very base of peridotite layers marking the abrupt unit boundaries. Weak harrisitic textures are sometimes exhibited by olivine crystals in the peridotites, but they are not as well developed as those in the Harris Bay site (see below). While there is little overall cryptic variation through the layered units in eastern Rum, individual units show slight variability, becoming more fractionated upwards, with a return to less fractionated compositions in the basal feldspathic peridotite of the overlying unit (Dunham and Wadsworth, 1978). This corroborates the suggestion that each major unit in the Eastern Layered Series represents a fresh unit of unfractionated magma (Brown, 1956).

Allivalites commonly are rhythmically layered (Fig. 3.9) and frequently contain zones of slump deformational structures; a particularly good example is exposed on the eastern face of Askival in Unit 14 (Brown, 1956; Fig. 3.10). Such structures are of a similar nature to those observed in unlithified sediments and suggest the accumulation of considerable thicknesses of poorly consolidated crystal cumulates on, or near to, the floor of the magma chamber. Slumping of the unstable magmatic sediments may have been triggered by tectonic activity.

In addition to the layered peridotites and allivalites, distinctive, dark-grey, cumulate troctolitic gabbros are exposed as conformable sheets in the lower levels of the complex to the east and north-east of Hallival and on the Askival Plateau (Brown, 1956). These gabbro sheets have recently been interpreted to be an integral part of the Layered Series by Faithfull (1985). The gabbros often contain numerous subangular to rounded clasts of granular basic hornfels, probably derived from Tertiary basalts in the roof zone to the complex. Their presence suggests that fragments off the roof and upper wall country rocks were incorporated into the chamber and were sealed off as the intrusion solidified inwards and downwards from the walls and roof.

Interpretation

The spectacular large-scale cyclic layering exposed in this site has been subject to intensive investigation concerning its origins. Recently, interest has been focused on detailed petrographic and geochemical studies and the refinement of theories relating to the formation of such rocks. Consequently, the site has achieved significant petrological importance in the theory of layering in igneous rocks world-wide.

The layered rocks of eastern Rum are interpreted to be the result of successive pulses of magma injected into a shallow-level magma chamber (Wager and Brown, 1951; Brown, 1956; Wadsworth, 1961). This magma is currently argued to have been of a picritic composition (for example, Volker, 1983; Emeleus, 1987; Greenwood *et al*., 1990). Each pulse, or replenishment of new magma, is envisaged to have produced a single unit by high-temperature crystal accumulation on the floor of the magma chamber (Wager and Brown, 1951). Successive pulses of new magma crystallized in this way to build up the Layered Series. Recent studies (Huppert and Sparks, 1980; Faithfull, 1985; Tait, 1985) have proposed that pulses of new picritic magma ponded at the base of the chamber beneath cooler, less-dense residual magma. Initial olivine crystallization in the picritic liquid lowered its density, and it was cooled against the older magma above. The resulting temperature and density differences are thought to have caused strong convection to develop in the picritic layer culminating in the mixing of the two magmas when their physical properties equilibrated following the fractionation of a peridotite layer. With further cooling, the resulting magmas formed allivalitic and other troctolitic gabbroic rocks until the next pulse of picritic magma was injected and the cycle repeated.

A wealth of new information has recently been published from detailed textural, mineralogical and geochemical studies on the Layered Series

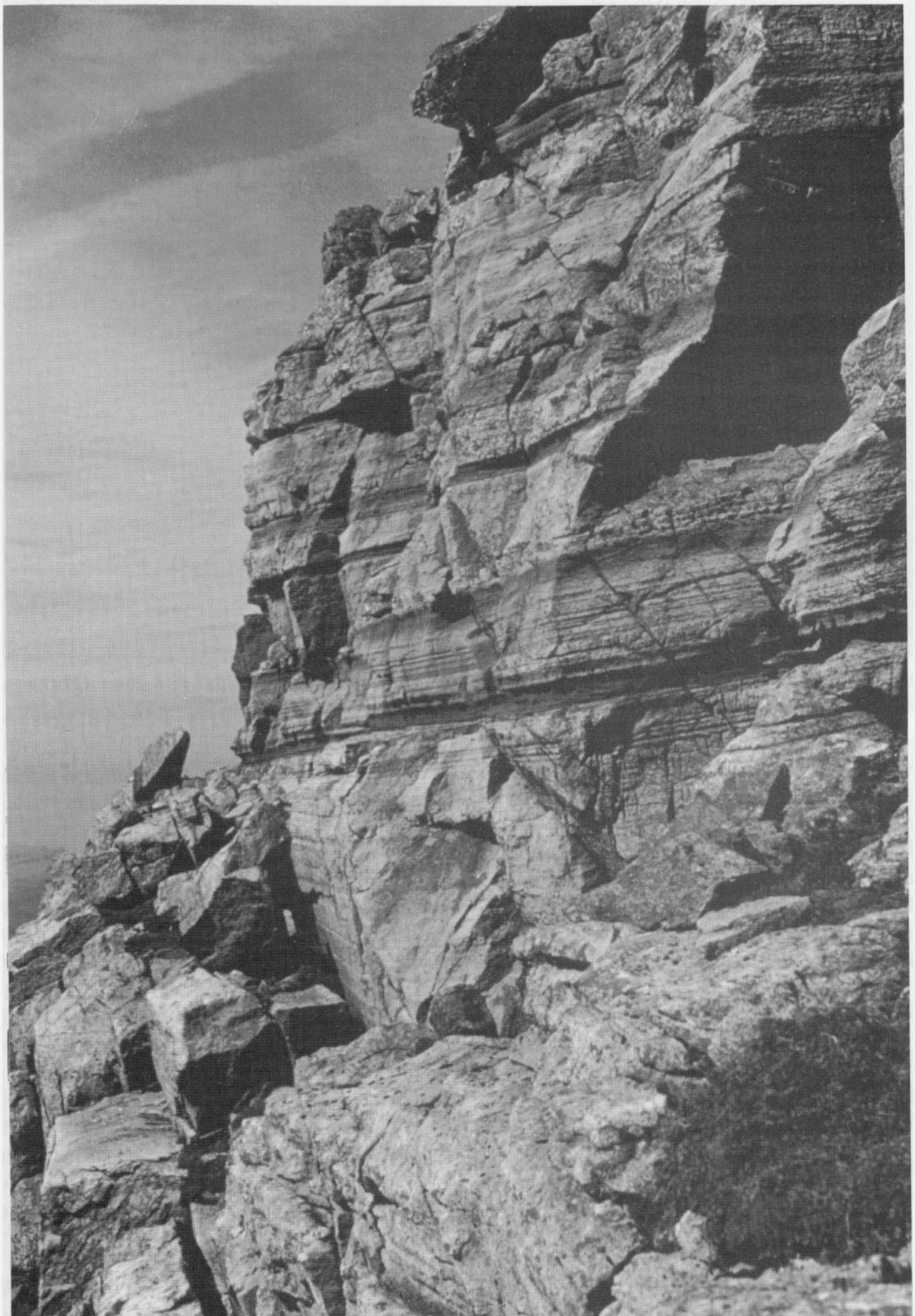


Figure 3.9 Fine-scale layering in allivalite, west side of Hallival. Askival–Hallival site, Rum. (Photo: A.P. McKirdy.)

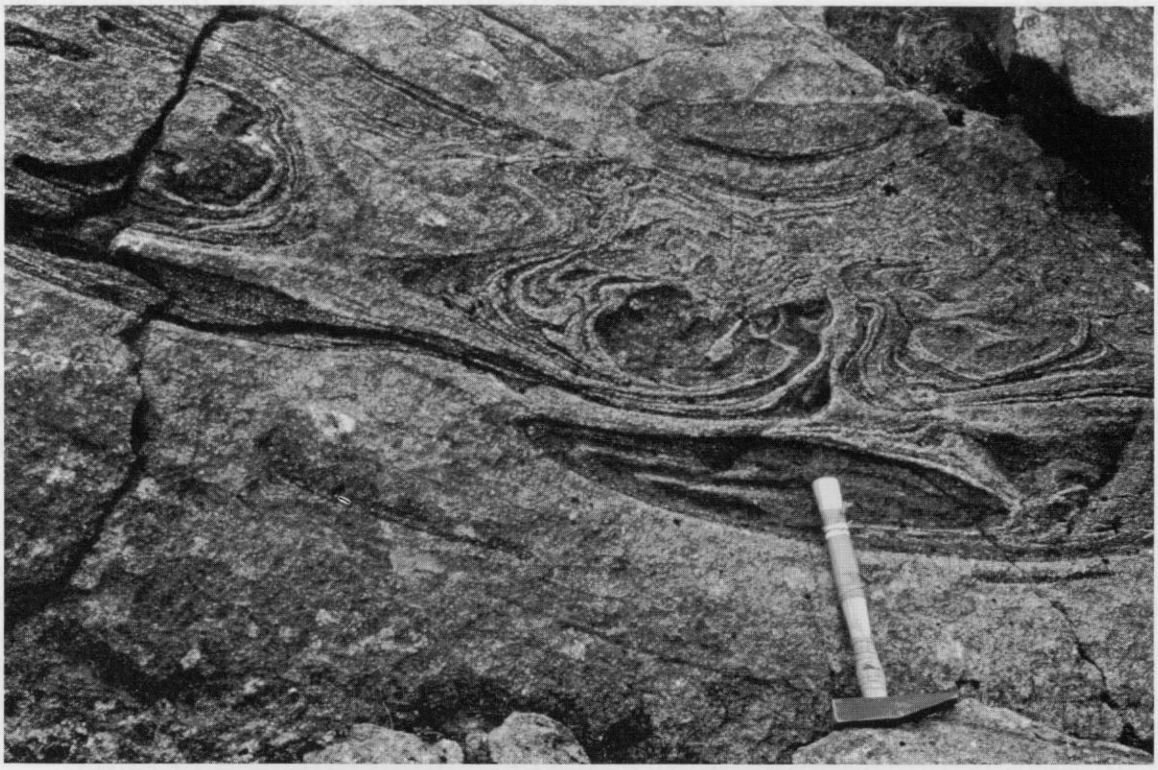


Figure 3.10 Slumped folding in allivalite, near Askival summit, Rum. Askival–Hallival site, Rum. (Photo: A.P. McKirdy.)

heralding a new era of current interest in the site. This work includes that of Faithfull (1985) who related cryptic variation in the lower Eastern Layered Series to post-cumulus effects; Tait (1985) produced detailed crystallization models from geochemical and isotope studies; Palacz and Tait (1985) investigated contamination of the magmas using isotope evidence; Butcher *et al.* (1985) described upwards-growing peridotite 'finger' structures and interpreted them as modal metasomatic replacement of allivalite by peridotite; Butcher (1985) discussed channelled metasomatism by intercumulus liquids within late-stage veins; and the cumulate rocks have been cited as examples exhibiting textural equilibrium (Hunter, 1987).

The Rum complex differs from other classic layered intrusions such as the Skaergaard (Wager and Brown, 1968) in that there is little or nothing of a marginal border group. Instead, the layered ultrabasic rocks are often bounded by rather variable gabbroic rocks which usually, but not always, separate them from the earlier Tertiary intrusions and Torridonian sediments. Marginal gabbros are exposed in the stream sections of Allt na h-Uamha (NM 409 968) and Allt Mor na h-Uamha (NM 405 973) in the east of the site. The gabbros have intruded along the line of the older Main Ring Fault near these streams and south to Allt nam Bà. Elsewhere, as on Beinn nan Stac and Cnapan Breaca, the relationships strongly suggest that the Marginal Gabbro and the layered ultrabasic rocks underlie earlier felsites and associated rocks which form an outward-dipping roof to the mafic rocks. In an investigation of the margin of the ultrabasic–gabbroic complex, Greenwood (1987) suggested, on the basis of detailed mineralogical and geochemical studies as well as a consideration of the field relations, that the Marginal Gabbro was probably not a distinct, separate body from the main succession of ultrabasic rocks but that it represented various degrees of modification of the more feldspathic ultrabasic rocks through reaction with country rocks. Extensive intrusion breccias are commonly developed at the contacts with earlier, more acid rocks (for example, Torridonian near Allt na Uamha); rheomorphic acid magmas generated at these contacts may well have reacted with partially crystallized mafic magmas to give the very variable gabbroic rocks that characterize the Marginal Gabbro zone of earlier workers.

Both Brown (1956) and Wadsworth (1961) postulated that the ultrabasic complex was emplaced as a solid mass along the Main Ring Fault lubricated by basaltic magma which subsequently formed the Marginal Gabbro. However, the lack of disturbance of layering right up to the edges of the intrusion and the roof-like contacts, give grounds for questioning this mode of emplacement. Recent publications argue that the layered rocks formed *in situ* from picritic magmas, with the possibility that some of the peridotites are in fact sill-like bodies intruded conformably into the layered allivalite rock (Emeleus, 1987; Renner and Palacz, 1987; Bédard *et al.*, 1988; Young *et al.*, 1988).

Conclusions

The excellent vertically and laterally extensive exposures of large-scale rhythmic layering in ultrabasic and gabbroic rocks on Hallival and Askival are unique within the British Isles. Unlike the other Tertiary centres of Mull and Skye, the Rum layered rocks formed as the last major event in the central complex and are thus virtually free from the overprinting effects of any subsequent igneous or tectonic events. Owing to this, they are particularly suited to the development of models concerning the origins of the layering, the accompanying rock textures and the variations found in their mineralogy and chemistry. The large- and small-scale structures and textures in the layered rocks are in many respects very similar to those developed in clastic sediments and invite interpretation in terms of the sedimentation from mafic magmas of successive crops of crystals of different densities. These features are common in peridotitic, gabbroic and other igneous rocks world-wide and, because of the exceptional clarity of the Rum examples, the theories developed here have strongly influenced petrogenetic thought regarding the crystallization of high-level magma chambers (for example, Wager and Brown, 1968; various articles in Parsons, 1987; Renner and Palacz, 1987; Bédard *et al.*, 1988).

HARRIS BAY

Highlights

The site is the type area for harrisite, a rock containing spectacular growths of olivine crystals. It contains arguably the best-exposed contact of layered gabbroic rocks against (granitic) country rocks in the BTVP, which shows, firstly, the intrusive nature of the gabbros and, secondly, evidence for extensive partial melting of the earlier granite.

Introduction

The Harris Bay site (Fig. 3.11) contains exposures of ultrabasic rocks belonging to the Western Layered Series and the Central Series of the Rum Central Complex. Unusual cumulate features are well-developed in the rocks of this site including 'harrisitic', or crescumulate, olivine textures and poikilo-macrospherulitic plagioclase textures. In addition, the site is also of special significance because it contains excellent exposures of the contact between the ultrabasic rocks and the earlier granitic rocks of western Rum; evidence for partial melting of the granite by the mafic rocks is particularly convincing (Greenwood, 1987).

Wadsworth (1961) identified at least four petrographically distinct stratigraphic units in the layered ultrabasic rocks within the site. At Harris Bay these are underlain by unusual eucritic cumulates which were termed the Harris Bay Series. Later investigations within the site by McClurg (1982) and Volker (1983) assigned part of Wadsworth's Western Layered Series to the later intrusive Central Series. The view that harrisitic olivines represent local coral-like growth from the floor of the magma chamber (Wadsworth, 1961) has been modified by Donaldson (1982).

Description

The Western Layered Series, which occupies most of the site, comprises the Harris Bay, Transitional and Ard Mheall series (Wadsworth, 1961). Eucritic gabbros of the Harris Bay Series form the lower part of the succession, above which a 50 m thick gradational unit, the Transitional Series, passes up into feldspathic peridotites of the Ard Mheall Series (*c.* 380 m thick). Unlike the Eastern Layered Series, layering is on a scale of a few metres to centimetres, dipping gently to a centre just east of An Dornabac, but nearly flat lying in Harris Bay. The layering is frequently defined by texture rather than modal layering. The later intrusive Central Series, recognized by McClurg (1982) and verified by Volker (1983), occupies a north–south strip up to 2 km wide from the south coast to the Long Loch and Minishal. Central Series rocks crop out on the eastern edge of the site and include rocks previously designated by Wadsworth (1961) as the Dornabac and Ruinsival series. The Central Series is characterized by predominant feldspathic peridotite and peridotite breccia, together with minor dunite, allivalite and gabbro.

The characteristics and subdivisions of the ultrabasic and basic layered rocks within the Harris Bay site are summarized in Table 3.2 (after Wadsworth, 1961).

The majority of ultrabasic rocks within the Western Layered Series are feldspathic peridotites containing varying proportions of olivine, plagioclase, chrome-spinel and diopsidic augite. There is a great variety of cumulate igneous textures in these rocks, signifying the interest of the site. Harrisitic textures (Wager and Brown, 1951), or crescumulate textures (Wager and Brown, 1968), were first described from Harris Bay by Harker (1908). Unusual poikilo-macrospherulitic textures are also found here which take the form of massive radial, braid-like growths of plagioclase (Donaldson *et al.*, 1973).

The harrisitic (olivine crescumulate) textures characterize the rock that was termed harrisite by Harker (1908). They were formed by large skeletal growth of forsteritic olivine. The individual crystals, or bundles of crystals, may be up to 2 m in length and often form coral-like growths from the planar surface provided by an underlying normal olivine cumulate (cf. Wadsworth, 1961, plate 4). Good examples of this type of harrisitic texture can be seen in the Transitional Series close to the road near Harris (NM 340 964) and at many places on Ard Mheall in the overlying Ard Mheall Series. Radiating, and sometimes apparently isolated pods of harrisitic-textured rock also occur, particularly within the eucritic Harris Bay Series in coastal exposures near Harris Lodge (NM 337 957).

Massive radial and braid-like growths of poikilitic plagioclase crystals enclosing numerous olivines occur within igneous breccias a short way north-east of Loch an Dornabac, just north of the site at NM 357 977. These individual radial growth structures range in size from 0.15 m to almost a metre in diameter and up to fifteen radiating crystals have been found growing out from a single nucleus. The term poikilo-macrospherulitic has been applied to these structures (Donaldson *et al.*, 1973). In some growths there is a radial symmetry. The feldspar textures resemble the 'lace' or 'honeycomb' textures described by Brown (1956) from the Eastern Layered Series. The feldspars involved in these structures have grown *in situ* and support current views that 'diagenetic' processes are of considerable importance in the crystallization of igneous cumulates (for example, Irvine, 1987).

Extensive zones of peridotite breccia occur within the Central Series ultrabasic rocks of the site. The breccias contain rounded, irregular and angular blocks of feldspathic peridotite lying randomly in a more feldspathic ultrabasic matrix, often approximating the mineralogy of allivalite. In places the breccias contain blocks which themselves display layering or even slumping. Clearly, the source for the blocks was a well-lithified cumulate. Wadsworth (1961) mapped an extensive zone of breccia, the Lag Sleitir Breccia, transgressing the Harris Bay, Transitional and Ard Mheall series. These breccias are well exposed in the stream sections where the Allt Lag Sleitir and the Abhainn Rangail join (NM 346 956). Wadsworth demonstrated that many of the blocks were derived from the Ard Mheall Series and considered that the breccias formed along a fault scarp within the magma chamber. An extensive zone of breccias cutting the Ruinsival Central Series was also thought to have such an origin.

Numerous other occurrences of breccia have been recorded from the same general area (Donaldson, 1975; Volker, 1983) and to the north around the Long Loch and Barkeval (McClurg, 1982). Structures within these breccias suggest formation by either intraformational slides, brittle deformation or plastic deformation. The transgressive nature of the Lag Sleitir Breccia towards the Western Layered Series is one of the stronger pieces of evidence which justifies the establishment of the Central Series of ultrabasic rocks and gabbros (McClurg, 1982; Volker, 1983).

The ultrabasic rocks are cut by numerous intrusions of gabbro. These are clearly later than the host rock which they vein but, as their margins show no signs of chilling, they would appear to have been intruded before the surrounding rocks had cooled. Wadsworth (1961) suggested that they formed from a magma closely related to that from which the ultrabasic rocks formed. The most unusual of these intrusions is the Glen Duian Gabbro, an assemblage of numerous thin gabbroic sheets which intrude the layered eucrites of the Harris Bay Series with

Figure 3.11 Geological map of the Harris Bay site, Rum (after Wadsworth, 1961, figure 2; Volker, 1983).

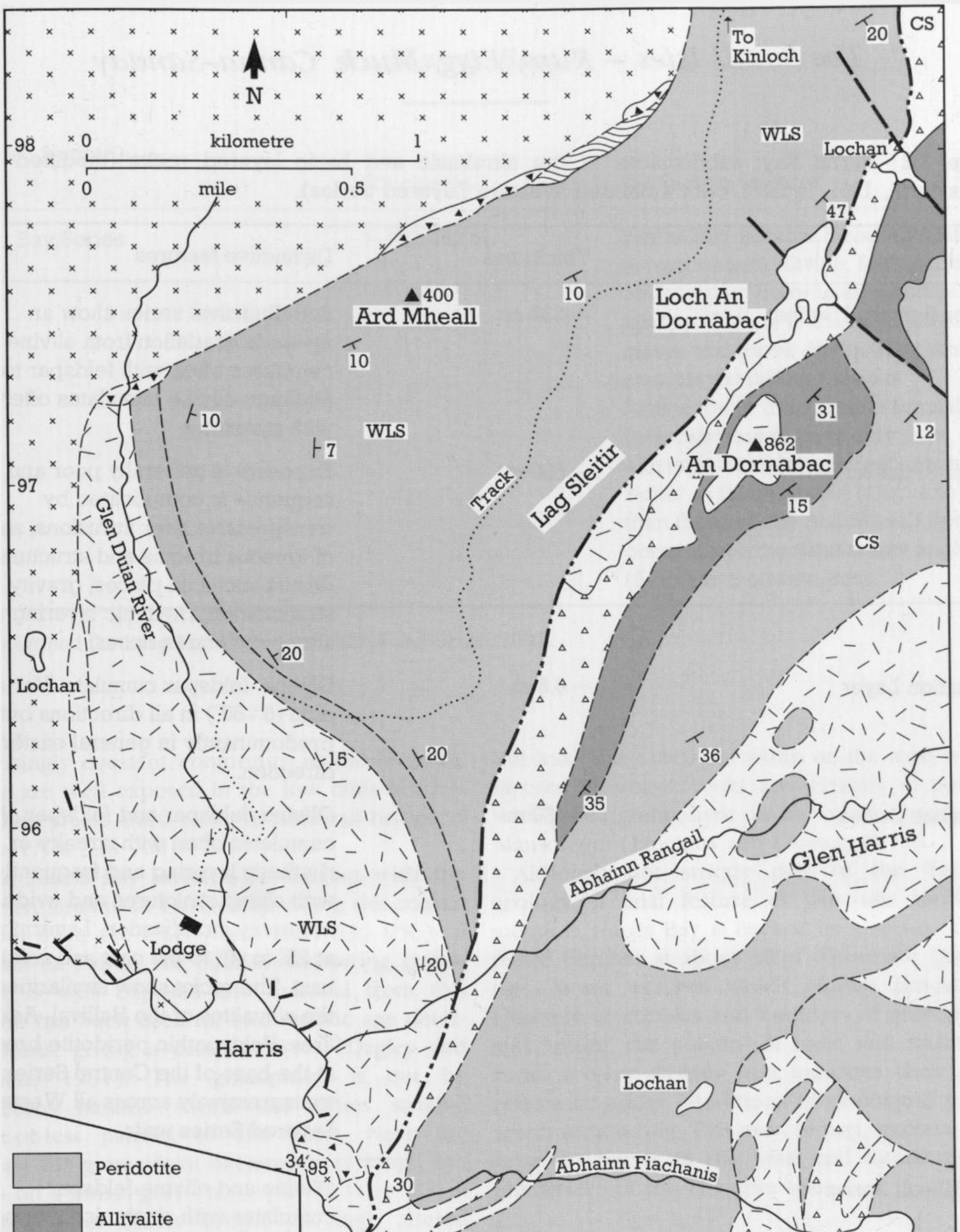

N
0
kilometre
1
0
0.5
mile
To Kinloch
CS
20
WLS
Lochan
47
Loch An Dornabac
400
Ard Mheall
10
10
10
7
WLS
862
An Dornabac
31
12
15
CS
Track
Lag Sleitir
Glen Duian River
Lochan
20
15
20
36
35
Abhainn Rangail
Glen Harris
WLS
Lodge
20
Harris
Lochan
Abhainn Fiachanis
34
95
30
Loch Fiachanis
CS
Lochans
40
CS
529
Ruinsival
30
35
98
97
96
94
93
Peridotite
Allivalite
Peridotite breccia
Gabbro and eucrite
Intrusion breccias
Granophyre
Lewisian gneiss
Intrusive boundary between CS and WLS
Dykes
Fault
Dip of igneous layering
WLS Western Layered Series
CS Central Series
400 Height in metres

Table 3.2 Harris Bay: subdivisions of the ultrabasic and basic layered rocks (modified from Wadsworth, 1961, table 1, with amended Western Layered Series).

		Thickness	Distinctive features
PART OF CENTRAL SERIES	Upper Ruinsival Series	~ 330 m	Both Ruinsival series show an upwards gradation from olivine cumulates often with feldspar to feldspar–olivine cumulates often with pyroxene.
	Lower Ruinsival Series*	~ 500 m	Exposure is generally poor and the sequence is complicated by transgressive later intrusions, zones of igneous breccia and structural disturbances. In places, gravity stratification, rhythmic layering and slump structures occur.
	Transition Layer	~ 0.5 m	Olivine–feldspar cumulate. Variable dips (5°–50°) in all directions but predominantly in general easterly direction.
	Dornabac Series	~ 130 m	Olivine–feldspar and feldspar olivine cumulates often with streaky or rhythmic layering and frequently with slump structures and evidence of gravity stratification. Layering dips at 35° to 40° to the east and south-east. The rocks show similarities to the allivalites of the Hallival–Askival area. Feldspathic peridotite breccia at the base of the Central Series cuts transgressively across all Western Layered Series units.
AMENDED (1982) WESTERN LAYERED SERIES	Ard Mheall Series	~ 400 m	Olivine and olivine-feldspar cumulates with rhythmic layering throughout. Harrisitic cumulates are intimately associated with normal cumulates and are very prominent within the lower half to two-thirds of the sequence and they are also locally important higher in the series. The layering has a general dip of 5° to 10° (exceptionally 15°) to the south-east or east.
	Transition Series	~ 50–60 m	Olivine-feldspar cumulates, often with pyroxene, of both harrisitic and normal types. Olivine is more abundant than in the Harris Bay Series, while the content of feldspar is higher than in the Ard Mheall Series.

(Table 3.2 contd)

	Thickness	Distinctive features
Harris Bay Series	~130–140 m	Essentially eucritic mesocumulates in texture with olivine, feldspar and ubiquitous pyroxene as cumulus phases. Olivine is the most abundant phase and forms distinctive tabular crystals exhibiting igneous lamination in the normal cumulates. Intercalations of generally thin harrisitic cumulates (crescumulates) richer in feldspar and pyroxene than those of the Ard Mheall Series occur. Layering dips at low angles (5–10°) to the north-east.

* Now termed the Long Loch Group (of Volker and Upton, 1990).

surprisingly constant conformity to the layering. These are well exposed in the low cliffs bordering Glen Duian Burn close to the road bridge at Harris (NM 338 960).

The Harris Bay Series is in contact with the Western Granite at Harris Bay. Along the coastal section from the Mausoleum (NM 336 956) to Gualain na Pairce, the pinkish-weathering granophyre is well exposed and material from this section has been used for radiometric age determinations, giving a date of 59 Ma (Dagley and Mussett, 1981). The granophyre is cut by numerous basaltic sheets and dykes striking more-or-less parallel to the coast. Near the contact the granophyre becomes very tough and takes on a bluish-grey colour. In the cove 200 m south-west of Harris Lodge, the dull, altered granophyre is separated from the Harris Bay Series by a zone, of variable width (2–10 m), of acid hybrid rock containing acicular amphibole and plagioclase crystals. The Harris Bay Series eucritic rocks are layered to within a metre of the contact with hybridized rocks and there is little or no disturbance of the layering at the contact. The contact exposures at the south-east end of Harris Bay provide outstanding examples of intrusion breccias where the basic/ultrabasic rocks have come into contact with acidic rocks; this is a common phenomenon on Rum and it provides a particularly clear example of melting, or partial melting of acid rock by a later mafic intrusion (Fig. 3.12). The intrusion breccia zone is several metres wide on the east of Harris Bay but less than a metre in width on the west where layered ultrabasic rocks are virtually in contact with baked granophyre on the coast close to the Mausoleum (Emeleus and Forster, 1979).

Although not strictly part of the Tertiary geology, a final feature of this site merits a mention. Harris Bay is backed by a series of fine raised beaches at about 30 m. These are Quaternary storm beaches which consist almost exclusively of cobbles and boulders of granophyre and arkose; the paucity of basic and ultrabasic rocks is very striking and indicates their poor resistance under conditions of prolonged mechanical weathering. This may, in part, explain their relative scarcity in the basal and intralava conglomerates of the Fionchra site.

Interpretation

The formation of the Western Layered Series, partly exposed in the Harris Bay site, was probably contemporaneous with the Eastern Layered Series (Emeleus, 1987), the intrusion of the picritic magmas being partly controlled by the Main Ring Fault. However, in the Harris Bay site, the Western Layered Series has intruded and cut the western granophyre mass causing a zone of hybridization and brecciation. The granophyre–Layered Series contact in Western Rum has all the characteristics of an original igneous feature and not a fault as previously suggested (Wadsworth, 1961). This feature, together with

Figure 3.12 Intrusion breccia at the contact of ultrabasic rocks with earlier granite. Eastern end of Harris Bay. Harris Bay site, Rum. (Photo: C.H. Emeleus.)

the roof contacts to the ultrabasic intrusion which are exposed in the Cnapan Breaca and Dibidil sites and on Ard Nev north of this site, and the continuation of the undisturbed layering up to the margins of the complex, suggest that the layered ultrabasic rocks crystallized essentially *in situ* in relation to these contacts.

Unlike the Eastern Layered Series of the Askival–Hallival site, the Western Layered Series and the Central Series contain predominantly feldspathic peridotites and layering involving allivalite is only sporadically developed. It has been suggested that feeders for the successive batches of new magma may have been sited in the western part of the complex, spreading magmas across the chamber floor to the east (Emeleus, 1987), causing peridotite rocks to develop near the feeder(s) and allivalites at the furthest extremities.

The gabbroic cumulates of the Harris Bay Series were formed from a magma considerably less basic than the overlying feldspathic peridotite cumulates. Wadsworth (1961) considered that this could reflect primary differences in magma composition, contamination of more basic magma with granophyre, or the result of strong crystal fractionation in a very thick unit of which the Harris Bay Series is the top. The overlying Transitional Series may represent, according to Wadsworth, gradual replacement of the basaltic magma of the Harris Bay Series with the more mafic magma of the Ard Mheall Series.

The contrasted thicknesses of intrusion breccia along the intrusion contact either side of Harris Bay may be explained by the movement of rheomorphic acid magma, together with inclusions, along the contact. Partially brecciated dykes in granophyre at the eastern exposure indicate that little movement occurred apart from shattering of the edge of the mafic pluton by the acid magma. On the western exposures, acid magma is seen intruding back into the mafic complex in cliffs near the Mausoleum; this probably represents an injection of low-density rheomorphic magma formed at the contact zone and which subsequently moved up and away from its source (cf. Greenwood, 1987).

The layered peridotites and breccias of the Central Series were intruded after the Western Layered Series. They cut across the Transitional and Ard Mheall members and also transgress the Main Ring Fault on its northern and southern margins. The long axis of the Central Series parallels the Long Loch Fault which probably had a strong influence on the emplacement of the Central Series (McClurg, 1982) and possibly controlled the feeder conduits to the whole Layered Series.

The formation of harrisites has been conventionally explained by the upward growth of olivines from the crystal mush on the floor of the magma chamber during periods of quiescence. Wager *et al.* (1960) regarded this texture as a special kind of crescumulate. Donaldson (1982) agreed that most harrisites have such an origin, but argued that some unusual occurrences must have crystallized within the crystal mush. This concept was supported by occurrences of discontinuous, lensoid layers of harrisite; cumulate layers terminating against harrisite; isolated lensoid masses of crescumulate; tongues/lobes of harrisite protruding up into overlying cumulate layers; coarse, randomly orientated hopper and branching olivines growing upwards and downwards in the centres of harrisite lenses. Donaldson postulated that a process of filter-pressing concentrated a differentiate of upwards-migrating intercumulus melt which collected beneath layers of low permeability in the crystal mush. These accumulations of melt were thought to be capable of propagating laterally as sill-like injections and crystallizing as harrisites. The poikilomacrospherulitic plagioclase growths (Donaldson *et al.*, 1973) also probably have a similar, post-depositional 'diagenetic' origin.

Donaldson (1977b) examined the morphology of the olivines in the harrisitic rocks and found that their features could be reproduced in the laboratory. These experiments indicated that crystallization of the branching olivines in harrisites involved crystallization with 30–50° undercooling of the magma. The skeletal and dendritic olivine crystals in the harrisites were found to show notable similarities to the spinifex-textured olivines of Archaean ultramafic rocks (Donaldson, 1974).

Conclusions

The ultrabasic/gabbroic layered rocks of Harris Bay belong to the Western Layered Series and they comprise a lower gabbroic unit which grades into overlying feldspathic peridotite. The intrusion of the later Central Series, which contains spectacular ultrabasic breccias, is also demonstrated by this site. The ultrabasic rocks can be shown to have intruded against the Western Granophyre, the contact being an igneous feature and not a fault as previously proposed. This contact is one of the best exposed in the British Tertiary Volcanic Province between low-melting-point country rocks and later high-temperature mafic intrusives. The site is, however, of special interest as the ultrabasic and gabbroic rocks show many textural characteristics which are as yet unknown in, or not as well-developed in, other layered intrusions. The site is the type locality for harrisite, displaying spectacular crescumulate olivines of both cumulate and post-cumulate origin. Pioneering work on the origin of these rocks has been carried out at this site.

CNAPAN BREACA–LONG LOCH AND DIBIDIL–SOUTHERN MOUNTAINS

Highlights

These sites contain clear evidence for substantial uplift along the Main Ring Fault of Rum. The well-developed felsite/explosion breccia/tuffisite association is now known to be a combination of subaerial ignimbrites, tuffs and caldera breccias. At the roof-like contacts with the gabbros and ultrabasic rocks, there is excellent evidence for hybridization between the gabbroic rocks and remelted felsite.

Introduction

The Cnapan Breaca–Long Loch and Dibidil–Southern Mountains sites (Figs 3.7 and 3.13) demonstrate the earlier Tertiary igneous rocks in the northern and southern margins of the Rum Central Complex, respectively. Both sites contain closely related felsite, granophyre, explosion breccia, tuffisite and bedded tuff in association with the Main Ring Fault. They record an early acidic phase in the evolution of the Rum complex. The Dibidil–Southern Mountains site (Figs 3.7) is of special significance in this respect because of the size and excellent exposure of the acid igneous bodies. The relationships between these early intrusives and Lewisian/Torridonian basement and the later Cenozoic ultrabasic and basic intrusives are well exposed in both sites. Together, the sites provide crucial information in the study of the magmatic and tectonic evolution of the Rum complex.

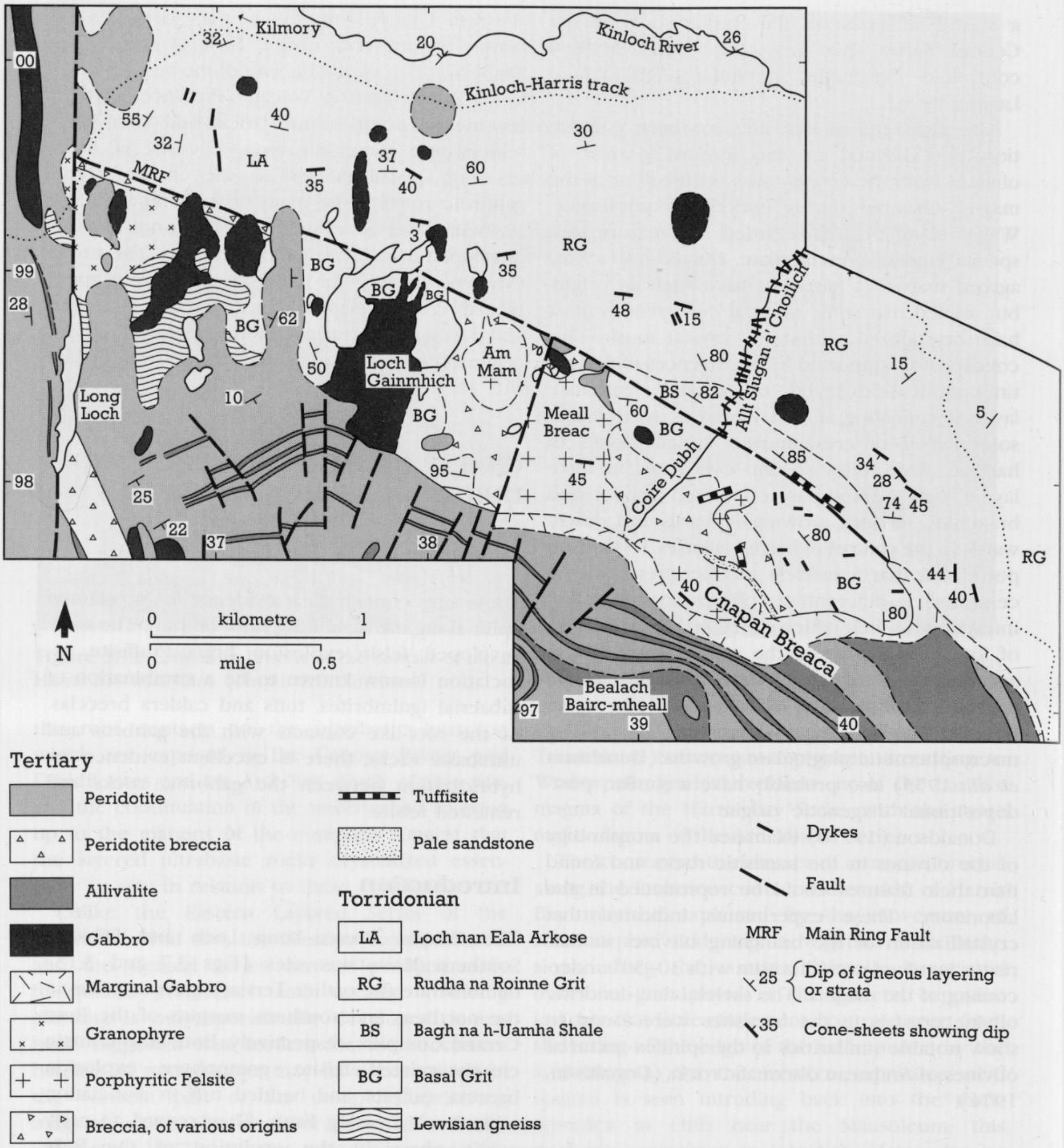


Figure 3.13 Geological map of the Cnapan Breaca–Long Loch site, Rum (after Emeleus, 1980).

Dunham (1962, 1964, 1965a, 1968) carried out the first comprehensive investigation of the felsites and associated rocks in the Cnapan Breaca–Long Loch site. The felsites and granophyres were related to a common parent magma generated by the fusion of Lewisian country rock. The degassing of this magma was considered to be responsible for the occurrence of explosion breccia and tuffisite. However, Williams (1985) reinterpreted some of the felsites to be of sub-aerial, pyroclastic origin. The Dibidil–Southern Mountains area was first mapped in detail by Hughes (1960a), who termed it the Southern Mountains Igneous Complex. Hughes regarded the complex as being bounded by a minor ring fracture, within and partly coincident with the Main Ring Fault. Current ideas, however, suggest a rather different structural setting; the Main Ring Fault clearly bounds the acidic Tertiary igneous rocks, but elsewhere they terminate against intrusions belonging to the later phase of emplacement of the ultrabasic and associated basic rocks.

Description

Cnapan Breaca–Long Loch

The northern part of the site (Fig. 3.13) is underlain by Torridonian arkoses and shales to the north of the Main Ring Fault of eastern Rum which bounds the plutonic complex. Away from the complex, the Torridonian strata have a fairly uniform dip of 10°–20° to the north-west but become progressively disturbed towards the Ring Fault near which they strike east–west and dip north at angle up to 70° and more. The lowermost Torridonian sediments, the Basal Grit and Bagh na h-Uamha Shale groups (Black and Welsh, 1961), occur within the Ring Fault and are well exposed in the area between Cnapan Breaca and the northern end of Meall Breac. They have been highly disturbed by movement along the fault and are intricately folded.

Patches of granodioritic, dioritic, amphibolitic and feldspathic Lewisian gneisses are exposed in a wide area around the Priomh Lochs (NM 368 986), either side of the Long Loch Fault and adjacent to the Main Ring Fault north of Meall Breac (NM 386 988). The presence of these rocks within the Main Ring Fault was used by Bailey (1945) as key evidence for an uplift of at least a thousand metres of the central, fault-bounded block.

Contacts of Lewisian and Torridonian rocks are exposed to the east and north of the Priomh Lochs (NM 372 988). Originally virtually planar, they have been affected by later movements and now dip north-eastwards at between 30° and 85°. The junction is generally faulted, although movement on the fault may not be large. An apparently unconformable relationship is seen north of the lochs (at *c.* NM 369 990), where gneiss is overlain by a coarse sedimentary breccia which passes up into bedded, gritty, coarse sandstone.

In the Cnapan Breaca–Long Loch and Dibidil–Southern Mountains sites, large masses of porphyritic felsite are closely associated with highly brecciated country rock. A felsite sheet caps Cnapan Breaca, dipping 35° to the south-west; a pipe-like mass with steep contacts is found in the east of Coire Dubh; a partly sheet-like, steep-walled mass occurs in western Coire Dubh and on Meall Breac; and on Am Mam, a felsite body with steep northern margins becomes sheet-like in the south. Small lenses of felsite also occur in an east–west-trending mass of explosion breccia along the Main Ring Fault to the north of Long Loch; unlike the other felsites, these are demonstrably older than the breccia which also contains fragments of the felsite as well as gabbro and arkosic sandstone.

The grey, weathered felsites contain conspicuous glomeroporphyritic aggregates of plagioclase, augite and opaque oxides, together with separate phenocrysts of quartz set in a holocrystalline groundmass of quartz and alkali feldspar. In addition, Williams (1985) has recognized some of the felsites at the base of the Cnapan Breaca sheet to be of pyroclastic origin. Typical features of eutaxitic welded tuffs are described by Williams from areas within the felsite, these are: a strong planar fabric, formed by collapsed, attenuated pumice fragments (*fiamme*) and Y-shaped flattened glass shards; rounded Torridonian clasts also occur. A subaerial origin, as opposed to a shallow intrusive origin as suggested by Dunham (1968), for at least some of the felsites is therefore invoked from such evidence. Similar features occur south-west of Meall Breac (NM 384 981). Some of the felsites are ignimbritic.

The felsites are closely associated with coarse breccias and tuffisites which occur almost wholly within the Main Ring Fault. Largely unbedded breccias have a wide outcrop north of Cnapan Breaca, in Coire Dubh around Meall Breac and around Three Lochs Hill (NM 373 987) and form an E–W-trending strip along the line of the Ring Fault to the north of Long Loch. The breccias contain predominantly angular Torridonian sedimentary rock clasts which range from a few centimetres up to several metres in size. Basic igneous and Lewisian gneiss fragments are also occasionally present. Dunham (1968) distinguished two main types of breccia, one made up almost entirely of subangular, rounded blocks derived from the basal Torridonian set in a matrix composed of finely comminuted Torridonian, and the other containing Lewisian and basic igneous fragments set in a very fine-grained matrix of Lewisian. The first type occurs in Coire Dubh and west of Meall Breac, while the second type is found to the north of both Meall Breac and Three Lochs Hill (Am Mam). The east–west strip of breccia to the north of Long Loch differs from the other outcrops in that it contains fragments of rounded basal Torridonian, gabbro, angular felsite and gneiss set in a dark, almost glassy, comminuted matrix derived from all rock types present as clasts except felsite; it is spatially closely associated with the Main Ring Fault and may have resulted from explosive activity localized along the fault.

The occurrence of blocks of coarse gabbro in the second type of breccia recognized by Dunham (1968) is important since it indicates that there were plutonic gabbroic intrusions in existence before emplacement of the felsites and other acidic bodies. This view is reinforced by the discovery of rare blocks of feldspathic peridotite in these breccias on the north end of Meall Breac (Emeleus, in preparation). Some of the coarse gabbros show the effects of crushing, possibly produced during movement of the Main Ring Fault; quite extensive areas of uncrushed gabbro crop out east of Loch Bealach Mhic Neill (NM 376 990) and plugs of petrographically similar gabbro occur on both sides of the Main Ring Fault, for example, north of Loch Gainmich (NM 380 988) and between Kinloch and Coire Dubh (see Emeleus, 1980).

Thin, intrusive tuffisite sheets crop out in the eastern part of the site in close association with felsite and explosion breccia. The petrography of this unusual rock type is described below in the Dibidil–Southern Mountains description; there extensive sheets of tuffisite occur. On Cnapan Breaca, the tuffisites can be generally shown to be younger than the explosion breccia; however, they are also sometimes demonstrably older than the felsites. Dunham (1968) records several tuffisite bodies cutting the Torridonian, both within and outside the Ring Fault, which show no apparent association with either felsite or explosion breccia.

From the southern side of Meall Breac, an olivine gabbro lying between the explosion breccia/felsite and the layered ultrabasic rock extends south-eastwards with widening outcrop. The mass, which is generally poorly exposed, is dyke-like in form and identical to the gabbro which crosses Cnapan Breaca and extends to the Main Ring Fault further to the east. This gabbro is the Marginal Gabbro (Brown, 1956) which has been postulated to have provided a 'lubricant' during the solid emplacement of the layered ultrabasic rocks, although recent evidence questions this interpretation (Greenwood, 1987).

The emplacement of the later gabbro against the felsites to the south of Meall Breac and Cnapan Breaca caused partial fusion of the felsite, resulting in extensive back-veining of the basic rocks by acidic material. Dunham (1964) reported that the remelted felsite back-veined the solid chilled margin of the gabbro, caused some acidification of partially solidified gabbro and then mixed with the still-liquid gabbroic magma in the interior of the intrusion to produce hybrid rocks.

In the west of the site, three tongues of ultrabasic rock extend northward from the main ultrabasic body, cutting through Lewisian and Torridonian country rock, explosion breccias, granophyre and the Main Ring Fault. McClurg (1982) recorded several similarities in these peridotites with the Layered Series peridotites and the peridotite matrices of the ultrabasic breccias. Consequently, McClurg considered the emplacement of the tongues to be contemporaneous with the tectonic disturbances responsible for the formation of the intra-magmatic ultrabasic breccias found elsewhere in this site.

Small-scale (1–3 cm thick) banded structures occur in the tongue peridotites, and in small ultrabasic and gabbroic intrusions elsewhere in the Province (for example, Rubha Hunish, Skye and Camas Mòr, Muck). On Rum, these structures reflect variation in the modal proportions of interstitial clinopyroxene and plagioclase, with the proportion of modal olivine varying very little; this has been termed 'matrix banding' by Dunham (1965b).

Superb examples of layered peridotites of the Central Series occur on the low ridge immediately west of Long Loch and south of the Kinloch–Harris road (NM 363 991; see Fig. 3.14). This is one of the most accessible localities for examination of the varied layered structures in allivalite and feldspathic peridotite: for example, small-scale phase layering, density-stratified layering, layers with size grading, erosional surfaces and a variety of structures due to slumping. Excellent examples of distorted allivalite layering adjacent to slumped peridotite blocks occur just north of the Harris track (NM 363 994), and spectacular peridotite breccias, with subsided blocks up to 3 m in diameter and highly distorted layering, are beautifully displayed 300 m SSE of the south end of Long Loch (McClurg, 1982;

Figure 3.14 Gravity stratified rhythmic layering in allivalite, west of Long Loch, Rum. (Photo: C.H. Emeleus.)

Emeleus, 1987, Fig. 11). Numerous basaltic cone-sheets are exposed in the Allt Slugain a'Choilich which dip either towards a centre in upper Glen Harris or to one somewhat further west. These tholeiitic sheets, which both cut and are cut by basaltic and doleritic dykes, have been studied by Forster (1980).

The major north–south Long Loch Fault, one of the principal features of the geology of Rum, occurs at the western edge of the site. This fault has a considerable zone of crushing, up to 50 m wide in places, involving ultrabasic and earlier rocks. The other spectacular fault on Rum, the Main Ring Fault, is well exposed within the site in Coire Dubh near to the intake of the hydroelectric pipeline (NM 393 983) and close to the deer fence gate. To the east of Cnapan Breaca, the marginal gabbro joins but is unaffected by the Ring Fault and the two are coincident for some distance to the south. West of this point, recent mapping of the margin of this gabbro suggests an upper surface dipping north at a low to moderate angle. Thus, the pre-Marginal Gabbro rocks of this site, the felsites, breccias and associated Torridonian rocks of the northern marginal complex, probably form a roof to these later mafic rocks which may continue beneath this roof as far north as the Main Ring Fault.

Dibidil–Southern Mountains

Lewisian gneisses crop out in a series of elongated, partly fault-bounded blocks for about 2 km west from Dibidil Bay (Fig. 3.7). Here, as on the south-east flanks of Beinn nan Stac, the distribution of gneiss is obviously closely linked with the Main Ring Fault. Torridonian rocks are also present as isolated masses within the igneous rocks and as a more substantial mass in the lower east side of Dibidil within the ring fault. Torridonian country rock outside the ring fault shows signs of disturbance near to this structure on the southern edge of the site.

Extensive sheets of porphyritic felsite are closely associated with coarse breccias and Torridonian sediments at several levels on Sgurr nan Gillean. The felsites in this site have the same general characteristics as those described from Cnapan Breaca–Long Loch. The largest sheet covers the summit area of Sgurr nan Gillean and forms the high ridge extending north out of the site to Ainshval (NM 377 944). At a lower level, on the east side of the hill and about 600 m north-west of the bothy (NM 393 929), a steep-sided felsite intrusion appears to connect the uppermost and lower sheets extending down towards the Dibidil River. This felsite was regarded as a feeder for the felsite sheets (Hughes, 1960a).

The close relationship between the felsite and breccia is clearly demonstrated on Sgurr nan Gillean, where the felsite sheets are generally bordered by breccias. The breccia has the form of flat-lying sheets, sometimes sandwiched between undisturbed Torridonian sediments. This relationship suggests that the breccia formed well below the land surface, however, like some of the Cnapan Breaca felsites in the north, the felsites show evidence in places for a subaerial, ignimbritic origin.

This site is of particular note in that it contains the most extensive developments of tuffisite in any of the Hebridean Tertiary central complexes. Hughes (1960a) first described the rocks as intrusive tuffs, and they were later recognized to be tuffisites by Dunham (1968), following the terminology of Reynolds (1954). Several tuffisite masses have been mapped along the southern edge of the site, closely connected with the Main Ring Fault. Excellent exposures of tuffisite occur near the ford in lower Dibidil (NM 393 931), where slabs in the Dibidil River expose a network of veins and stringers of dark-coloured, fine-grained rock charged with crystals of feldspar and quartz and numerous fragments of Lewisian country rock. Inclusions of porphyritic felsite also occur within the tuffisites of lower Dibidil and, since there is evidence that felsite cuts tuffisite on the southern slopes of Sgurr nan Gillean, there must be a time overlap in felsite and tuffisite formation.

Coarse, acidified, hybrid gabbros are found in several places in the Rum central complex, usually around the periphery of the ultrabasic/gabbroic complex. Hybrid rocks containing conspicuous elongate plagioclase and amphibole (after orthopyroxene) crystals up to 30 mm in length are found in sharp contact with later gabbro to the west of the Dibidil River (NM 3398 9373); further extensive exposures of finer-grained hybrid rocks occur on slabs and rock surfaces for some distance west of this locality. These hybrid rocks appear to be of late formation as they are not cut by the numerous dykes and inclined sheets which are so abundant in the felsite immediately to the west (for example, NM 385 935). The gabbros in Glen Dibidil have recently been recognized to belong to the layered ultrabasic series and are not later intrusive bodies as previously thought (Greenwood, 1987).

The small area of granophyre to the east of Papadil (NM 374 924) is not well exposed. It probably cuts felsite and Lewisian gneiss to the east and north, being fault bounded to the south where it is crushed near to the Main Ring Fault. It is cut by the gabbro which margins Central Series ultrabasic rocks against which it has been recrystallized.

Interpretation

The exposures, within both sites, of porphyritic felsite, explosion breccia, tuffisite and granophyre along the margins of the central complex record an early phase of acidic magmatism and associated tectonism along the Main Ring Fault. Walker (1975) has proposed that acidic magmatism is a characteristic feature of all British Tertiary igneous centres and the record of this early event is particularly well seen on Rum.

The acidic magmatism on Rum was closely associated with the development of the Main Ring Fault (Bailey, 1945). Emeleus *et al.* (1985) have recently proposed that rising acidic magma caused initial doming of Lewisian and Torridonian country rock which ultimately led to ring fracturing. Basal Torridonian and Lewisian rocks were uplifted within the ring fault system. Subsequent relaxation of magmatic pressures caused the central uplifted block to subside along the ring fracture. This is attested by the presence of Mesozoic sediments and Cenozoic lavas (see Allt nam Bà) juxtaposed against faulted slivers of basal Torridonian and Lewisian gneiss which had been elevated by the initial uplift and left stranded at high structural levels along the Main Ring Fault (Emeleus *et al.*, 1985). Large masses of basal Torridonian and Lewisian gneiss on the southern lower slopes of Sgurr nan Gillean and in the Cnapan Breaca–Long Loch site, represent relict roof rocks to the Central Complex.

The caldera-like subsidence within the Main Ring Fault appears to have been clearly associated with a reduction of magmatic pressures caused by escaping magma and volatiles along fault systems. The explosion breccia provides evidence for violent release of volatiles from the acid magma which shattered the country rock along lines of weakness such as faults and bedding planes (Hughes, 1960a). However, Williams (1985) has argued that they may represent vent breccias in a deeply eroded edifice through which felsic magma rose resulting in either shallow, sill-like and steep-sided intrusions or subaerial pyroclastic extrusion; evidence for the latter occurs on Cnapan Breaca. Williams also postulated that the close association of breccias with felsites on the inner margin of the Main Ring Fault could indicate an origin for the breccias by caldera-wall collapse; evidence for this interpretation is good in Dibidil (M. Errington, pers. comm.).

Using petrographic and geochemical evidence, Hughes (1960a) demonstrated that the felsite and granophyre crystallized from the same magma derived from the fusion of Lewisian basement. The granophyre probably represents a thick ring-dyke intruded along the line of the ring fault at deeper levels than the felsite and it thus did not suffer degassing and associated explosive activity. Contemporaneous emplacement of tuffisite along the ring fracture system also occurred, representing fluidized, high-pressure injections of shattered country rock (Hughes, 1960a) mixed with fragment porphyritic felsite magma.

The northern and southern sites provide valuable information as to the nature of the margin to the later ultrabasic/basic complex. The contact between the latter and the felsites and associated rocks has been shown generally to dip outwards at both sites at angles as low as 40°, representing a roof-like contact (Emeleus, 1987). The ultrabasic layering is undisturbed right up to these contacts and extends beneath the overlying rocks where hybridization of basic/ultrabasic intrusives with felsite is observed. It is probable that large parts of the northern marginal complex and Southern Mountains marginal complex are immediately underlain by the layered ultrabasic rocks and that the contact represents the original roof to the mafic complex. If the roof contacts are projected upwards to the centre of the complex, the vertical extent of the Eastern Layered Series is limited to a few hundred metres above the present-day peaks. The layered ultrabasic rocks are, therefore, not considered to have been emplaced as a solid, upfaulted block, as previously suggested. The ultrabasic magma may have intruded upwards, causing further uplift along the Main Ring Fault involving the felsites and associated rocks (see Emeleus, 1987 for discussion), the layered series crystallizing essentially *in situ* beneath them. The emplacement of the Layered Series, however, still presents many difficulties and work is currently in progress which will hopefully resolve these problems.

Conclusions

The Dibidil–Southern Mountains and Cnapan Breaca–Long Loch sites are important localities exposing the margin of the igneous complex and allow investigation of the early magmatic and tectonic evolution of the Rum centre. The felsite–granophyre explosion breccia–tuffisite association can be related to major caldera-like subsidence along the line of the Main Ring Fault, with contemporaneous acidic magmatism. The roof contacts between these rocks and the underlying layered series are of particular importance in these sites since they provide evidence that the ultrabasic/basic complex crystallized *in situ* in relation to these rocks, although further uplift along the Main Ring Fault may have occurred during the emplacement of the ultrabasic magmas/rocks.

The precise nature of the origin of the felsites and associated rocks, and the structural complexities of the sites, have received little attention since the work of Dunham (1968). The areas merit reassessment in view of the reinterpretation of the Cnapan Breaca felsite–explosion breccia association (Emeleus *et al.*, 1985; Williams, 1985) and work is currently in progress. Early acidic magmatism and the presence of welded tuffaceous felsitic rocks, such as those observed on the northern margin of the Rum complex, are common to many Tertiary igneous centres. The opportunity for a comprehensive understanding of well exposed acidic rocks in these sites on Rum will provide valuable information on the early magmatic and tectonic evolution of the British Tertiary Igneous Volcanic Province as a whole (cf. Bell and Emeleus, 1988).

SOUTH-WEST EIGG

Highlights

The Sgùrr of Eigg pitchstone lava flow dominates the site. The flow fills a valley system, floored with fluviatile sediments, which was carved into Tertiary basaltic lavas. The pitchstone is one of

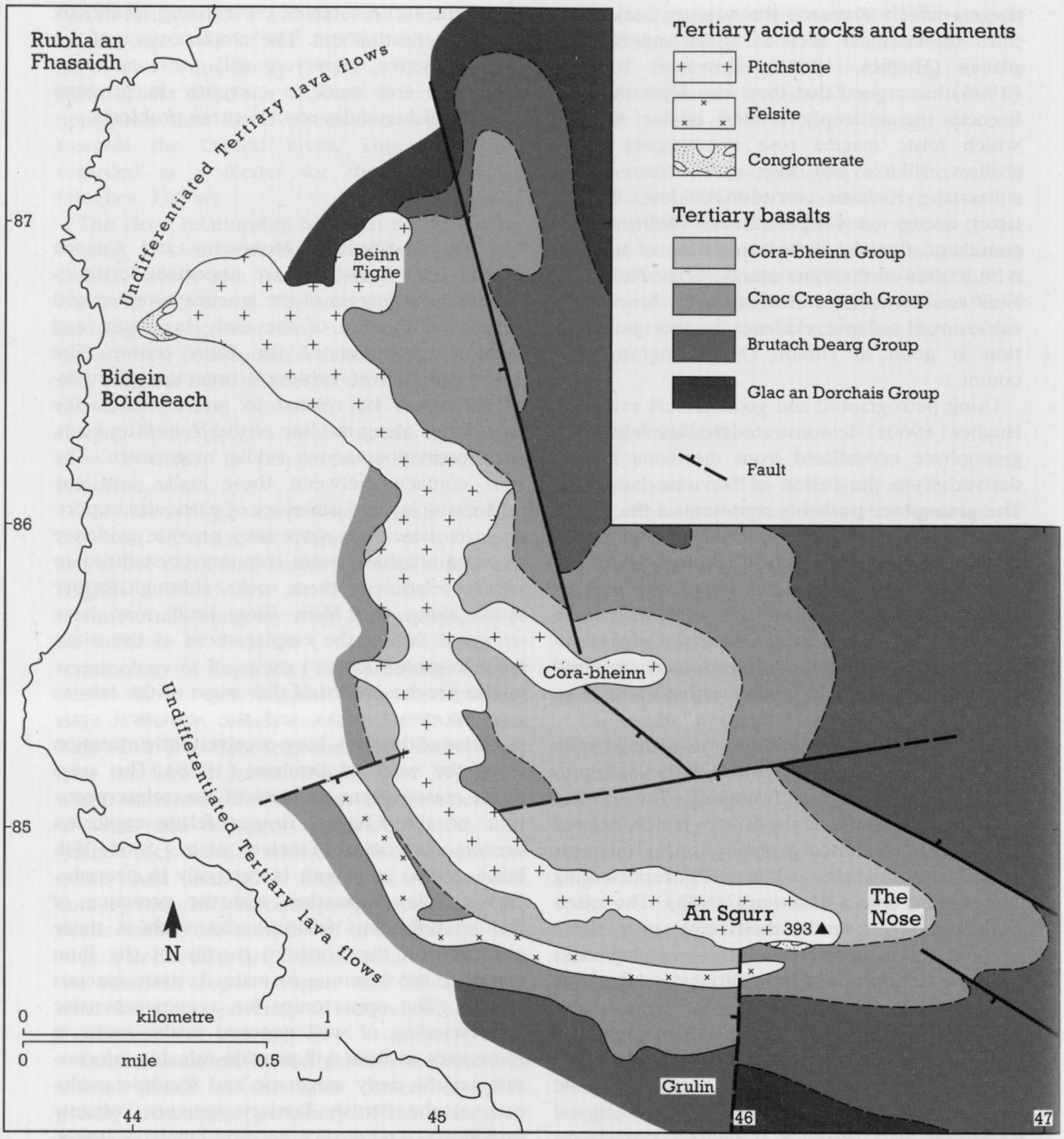


Figure 3.15 Geological map of south-west Eigg (after Allwright, 1980, fig. 2.3.2).

the youngest igneous rocks in the British Tertiary Volcanic Province.

Introduction

The south-western part of Eigg lying between Rubha an Fhasaidh and An Sgùrr provides good exposure through a Tertiary lava succession (Fig. 3.15). The site is dominated by the unique columnar pitchstone outcrop forming the Sgùrr (Fig. 3.16) and also demonstrates intercalated sediments in the lava pile, together with both acid and basic minor intrusions.

On Eigg, the basaltic lavas show slight differences from those on Skye, but vary little in detail from those on Mull. The most striking and

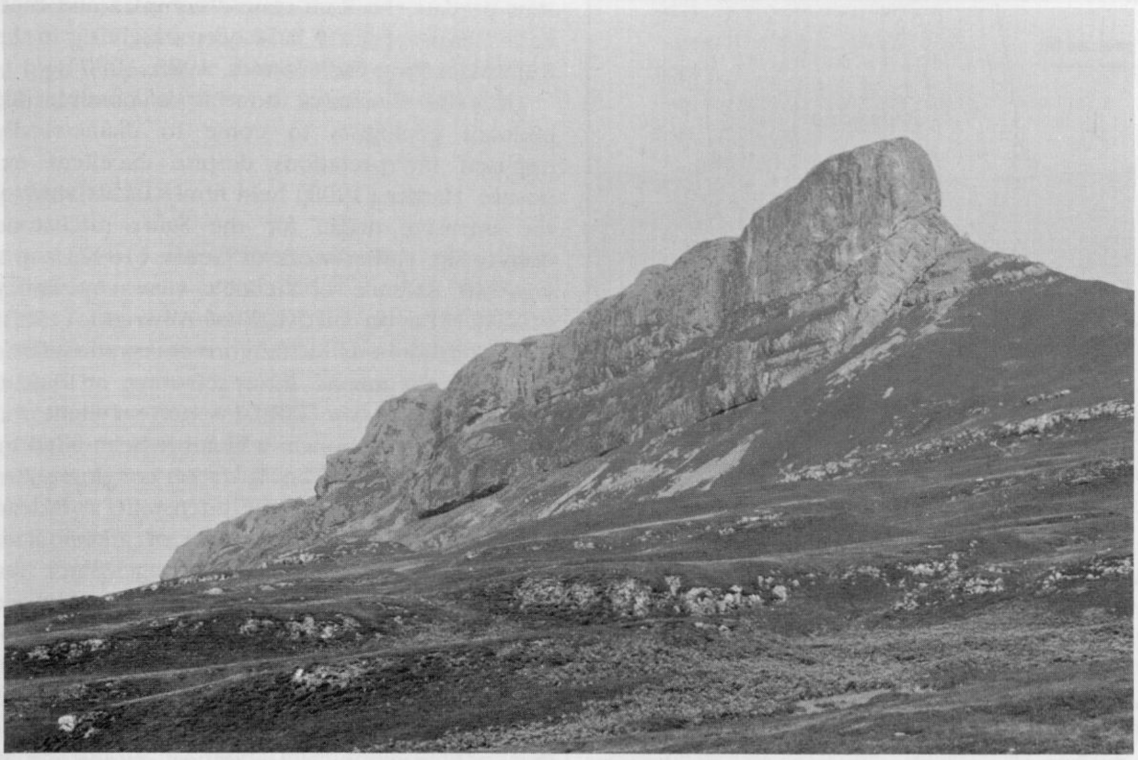


Figure 3.16 Ridge of the Sgùrr of Eigg, formed by an Eocene pitchstone flow filling a valley eroded from Palaeocene basalt lavas. South-west Eigg site. (Photo: C.H. Emeleus.)

controversial geological feature is the relatively young pitchstone forming An Sgùrr and adjoining hills. Geikie (1897) regarded the pitchstone as a subaerial lava flow which had occupied a system of small river valleys eroded into the underlying lavas, but Harker (1908) reinterpreted it as an intrusion. Bailey (1914) subsequently supported Geikie's view but invoked auto-intrusion to explain some features. Ridley (1973) supplied new mineralogical and geochemical data from both An Sgùrr and the earlier lavas but remained uncommitted as to the nature of the pitchstone. Recent research, however, favours an extrusive origin for the Sgùrr pitchstone (Allwright and Hudson, 1982).

Description

From Laig cliffs (NM 463 880) to the outcrops of pitchstone at Beannan Breca (NM 448 865) or Cora-bheinn (NM 457 856), the exposure in the crags displays a full sequence, at least 200 m in thickness, through the lavas of western Eigg. The flows are predominantly alkali to transitional olivine-phyric or olivine-rich basalts. The only exceptions are several flows of feldspar-phyric basalts near to the top of the sequence.

The lavas are typical Palaeocene basalts containing olivine phenocrysts in a groundmass of labradorite, clinopyroxene and titanomagnetite. In hand specimen, they commonly weather with rusty crusts. In contrast, the pitchstone is black and lustrous and carries alkali-feldspar phenocrysts and glomeroporphyritic aggregates of clino- and orthopyroxene, titanomagnetite and alkali feldspar in a pale-brown, glassy matrix (Ridley, 1973; Allwright, 1980).

A thick pitchstone sheet forms the ridge from An Sgùrr westwards to Beinn Tighe and rests, often with spectacular unconformity, upon the basaltic lavas. At several localities along its base, the pitchstone is seen to be brecciated, flow banded, and to contain possible flattened shards (*fiamme*). It lies upon a conglomerate possibly produced by fluvial reworking of agglomerate. Fragments of wood and other plant remains have been found hereabouts. A thick lens of fluviatile conglomerate underlies the pitchstone at Bidein Boidheach (Fig. 3.17; NM 441 867).

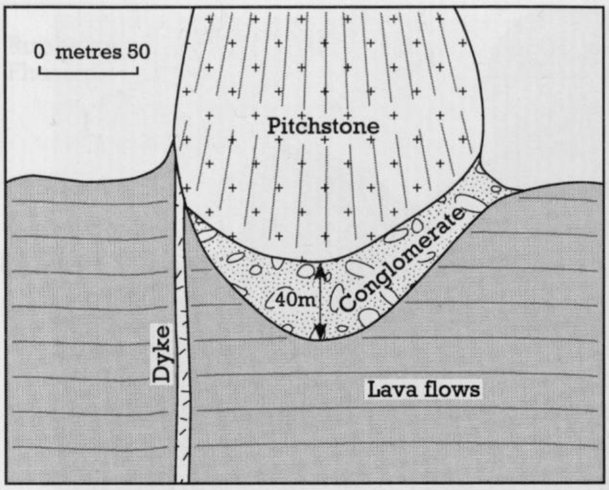


Figure 3.17. Section through pitchstone and lava flows, near Bidein Boidheach, south-west Eigg (after Allwright, 1980, figure 6.4b).

Along the south face of An Sgùrr (NM 460 846) several felsite sheets intrude the pitchstone. These are interpreted as being due to the back-injection of residual acid magma since they are mineralogically identical to the pitchstone, differing only in their well-crystallized matrices (Ridley, 1973; Allwright, 1980). Below the ridge of An Sgùrr another major felsite–the Grulin Felsite – intrudes the basaltic lavas and is demonstrably later than some of the basic dykes. The Grulin Felsite has been regarded as the feeder for the Sgùrr pitchstone, although this view is now discounted (for example, Dickin and Jones, 1983). Petrographically, this rock is a quartz microsyenite.

The pitchstone post-dates the NW-trending basic dykes of Eigg as can be seen at the east end of An Sgùrr (NM 464 847) and in the cliff section near Bidean Boidheach. Radiometric age determinations on the pitchstone indicate an age of *c.* 52 Ma; it is thus one of the youngest igneous rocks in the British Tertiary Volcanic Province (Dickin and Jones, 1983).

Interpretation

The basaltic lavas of this site are cut by an extensive swarm of NW-trending basaltic dykes (Speight *et al.*, 1982; Allwright, 1980). The probable continuation of the dyke swarm appears in south-east Rum where it is cut by the layered complex. The Eigg (and Muck, see below) lavas thus predate the Rum central complex and their equivalents appear to have been caught up in the Rum Main Ring Fault (Smith, 1985, 1987).

The site illustrates how it is possible for eminent geologists to come to diametrically opposed interpretations despite excellent exposure. Harker (1908) held firmly to his view of the intrusive origin for the Sgùrr pitchstone despite the earlier work of Geikie (1897) and a vigorous defence of Geikie's views by Bailey (1914). The careful work of Allwright (1980) leaves no doubt as to the correctness of Geikie's and Bailey's general interpretations; at Bidean Boidheach, the site contains an excellent example of a valley system which has been filled by a pitchstone flow. The fluviatile conglomerates exposed at the base of the pitchstone at Bidean Boidheach have yielded clasts of arkosic and other sandstones of Torridonian age. Since the Eigg Tertiary lavas overlie a thick Jurassic succession it is likely that the provenance of these sediments was high ground west of the Camasunary Fault's southern continuation (Binns *et al.*, 1974). In this connection, it is of interest that a petrographically identical pitchstone is present well to the west of this fault, forming the islets of Oigh-sgeir (or Hyskeir; NM 156 963). The possible connection between these two pitchstones requires further investigation, as does the possibility that the pitchstones may be welded ash flows.

Conclusions

The lavas on Eigg represent some of the earliest volcanic activity in the BTVP, predating the nearby Rum central complex. As in the Fionchra site on Rum, the pitchstones, which are of special interest in this site, have interacted with a fluvial system and provide an excellently exposed example of the filling of a valley system which was carved into the earlier Tertiary basaltic lavas which now cover much of Eigg. An Eocene age (52 Ma) has been obtained from the pitchstone which is one of the youngest igneous rocks of the province.

CAMAS MÒR, ISLE OF MUCK

Highlights

This locality shows a well exposed sequence of interbedded tuffs, clastic sediments and lavas at the base of the Tertiary succession. It also shows that a 'giant' dyke of gabbro has produced a suite of high-temperature calc-silicate minerals by the thermal metamorphism of Jurassic sediments.

Introduction

The base of the Palaeocene lava succession overlies Jurassic sediments at Camas Mòr and these rocks are intruded by a dense swarm of NW-trending basalt dykes and by a large gabbro dyke. The general geology of the site has been described by Harker (1908) and the Camas Mòr gabbro and associated metamorphism of Jurassic sediments was the subject of a detailed investigation by Tilley (1947). The dyke swarm was included in the survey by Speight *et al.* (1982) and the Tertiary lavas, tuffs and sediments have been mapped and described by Allwright (1980).

Description

The exposures on the shores of Camas Mòr show an interesting sequence of basal Tertiary tuffs and sediments at the junction of the Tertiary lavas with Jurassic sediments (Fig. 3.18). Two localities are of special interest, the first is among the boulders on the foreshore below the An Stac cliffs, a few metres east of Sgorr nan Loagh where two horizons of bedded, water-laid tuffs occur. The exposures are terminated to the east by a dyke which has apparently intruded along a fault which throws the basal Palaeocene beds down against the Jurassic limestones. The second locality, at the eastern end of the An Stac cliffs (NM 403 789), is figured by Harker (1908) and has been reinvestigated by Allwright (1980) who produced the following succession:

		Approximate thickness
10.	Coarse plagioclase-rich basaltic lava in discontinuous flow units.	8.5 m
9.	Red laminated tuff infilling fissures in reddened scoriaceous lava.	0.75 m
8.	Plagiophyric basaltic lava.	7.10 m
7.	Finely brecciated flow top.	1.10 m
6.	Aphyric, very fine-grained, mugearite lava.	5.80 m
5.	Coarsely bedded, greyish-pink sediment enclosing numerous small basalt fragments.	0.95 m
4.	Gap (possibly the thin lava flow of Harker, 1904).	0.60 m
3.	Brown–red mudstone.	0.80 m
2.	Purplish-red, sandy tuffs often distinctly banded.	1.10 m
1.	Jurassic limestone with thin shales and concretionary sandstones.	

The Palaeocene sediments are predominantly air-fall deposits and the bedded units most probably originated through the deposition in shallow water of airborne basaltic ash and lapilli from adjacent fissures, perhaps by lava fountaining.

A complete sequence through the lavas of Muck is provided by a gully at the west end of An Stac and exposures above the cliff tops on the hillside towards Beinn Aireinn (NM 403 792). The lavas are transitional in composition between alkaline and tholeiitic basalts, they are mostly olivine-phyric, but with plagioclase-rich porphyritic types and a mugearite towards the base.

The cliffs and the beach on the eastern side of Camas Mòr, especially between NM 416 782 and NM 412 781, expose lavas and Mesozoic sediments in contact with a major olivine gabbro dyke trending NW–SE. The dyke rock is a relatively iron-rich, hypersthene-normative gabbro consisting of large titaniferous augites enclosing laths of zoned labradorite, irregular olivines and anhedra of titanomagnetite. This central facies locally develops centimetre-scale diffuse mafic and felsic layering, somewhat similar to that found in the Trotternish sills of Skye (Rubha Hunish). There is also a finer-grained marginal facies to the gabbro which is mildly nepheline normative. The dyke, which in places attains 50 m–100 m in width, has incorporated and partly assimilated some of the adjacent Mesozoic limestones, resulting in the formation of contact assemblages as reported by Tilley (1947); the assimilation is believed responsible for the undersaturated, nepheline-bearing nature of the marginal facies of the dyke (Tilley, 1952; Ridley, 1973).

Minerals recorded by Tilley from the contact zone include calcite, grossularite, wollastonite, monticellite, melilite (gehlenite), spurrite, merwinite, larnite, rankinite, cuspidine, tilleyite, periclase, brucite, spinel and perovskite and from the skarn zone where the limestones were soaked in solutions from the gabbro he noted

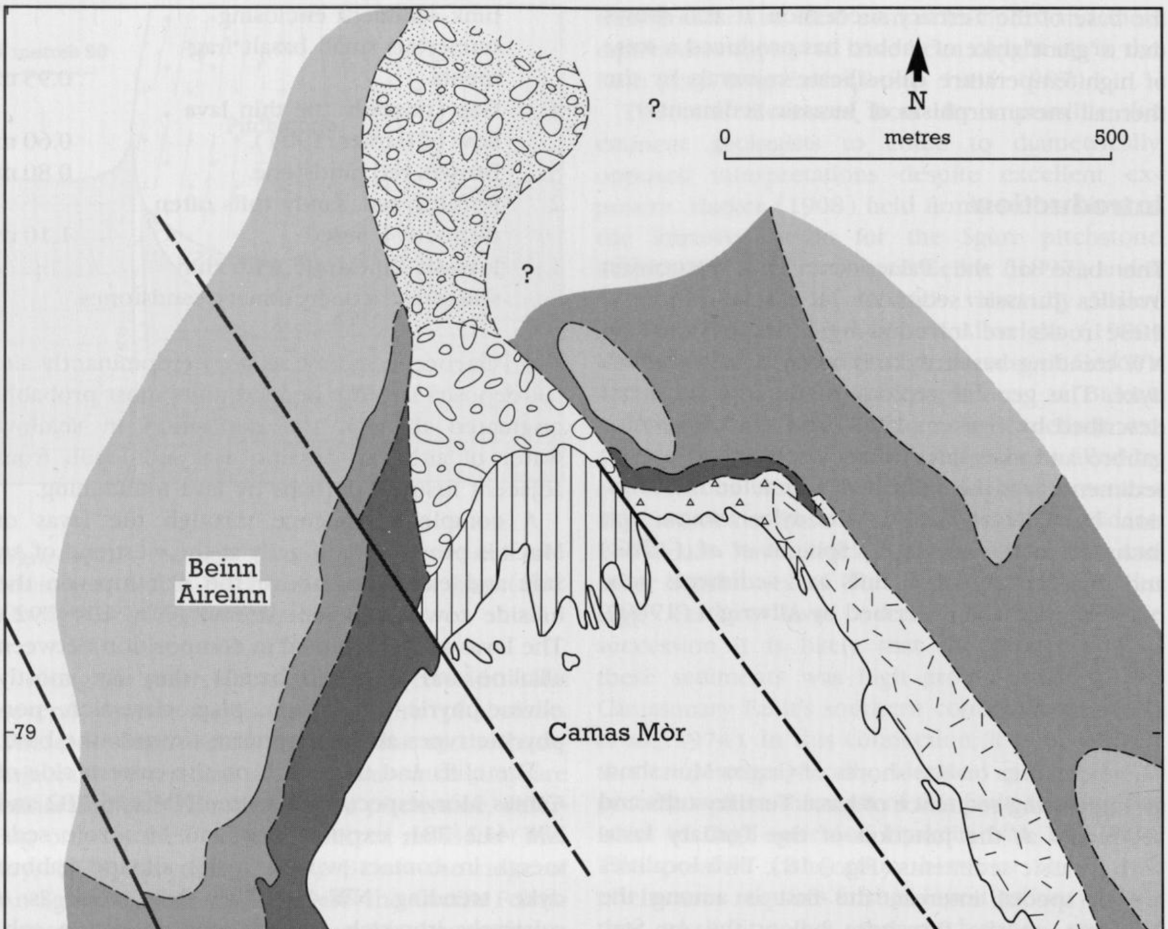


Figure 3.18 Geological map of the Camas Mòr site, Muck (after Allwright, 1980, fig. 2.2.2).

clinopyroxene, analcite, soda-sanidine and titanite (sphene). The gabbro is modified for a few centimetres from its contact with the sediments; pyroxenite is followed away from the contact by theralite (nepheline gabbro) with wollastonite, melilite and soda-sanidine and iron-rich olivine in segregations.

Immediately north of the dyke, the Mesozoic sediments are found to be extensively brecciated. Blocks of limestone, sandstone and black shale up to 1 m in diameter are set in a comminuted matrix of these rocks which is, apparently, free of any igneous material. Unbrecciated Palaeocene lavas margin the breccias but do not themselves show any disturbance. The origin of this breccia is uncertain; it may represent an early explosive vent immediately prior to lava effusion. It pre-dates intrusion of the olivine gabbro dyke.

Muck is characterized by a dense swarm of NW-trending basic dykes which are less alkaline than the lavas they intrude (Allwright, 1980). Harker (1908) recorded at least 40 dykes along the south coast between Camas Mor and Port Mòr with an aggregate width of about 60 m.

Interpretation

The Palaeocene lava successions in the BTVP frequently provide glimpses of interbedded sediments and thin pyroclastic deposits (Anderson and Dunham, 1966). This site clearly exposes a succession of water-laid sediments, fine-grained air-fall tuffs, possible volcanic breccias and basaltic lava flows which mark the onset of the Palaeocene volcanism. These rocks are cut by numerous basaltic dykes which represent a crustal dilation of *c.* 6%, not including the very thick gabbroic dyke at Camas Mòr. Tilley's (1947) examination of this dyke showed that, in addition to producing a suite of high-temperature, calc-silicate minerals in the country rocks, there had been a reaction between the hypersthene-normative basaltic magma of the dyke and the calcareous sediments to form a limited, marginal zone of nepheline normative, critically undersaturated rocks rather similar in nature to that described by Tilley from Scawt Hill, Co. Antrim (Tilley and Harwood, 1931). Ages of about 63 Ma obtained from the Muck and Eigg lavas are among the oldest in the BTVP (Mussett *et al.*, 1988).

Conclusions

Camas Mòr contains particularly good examples of basaltic lavas with interbedded sediments of volcanic origin and a dense swarm of basaltic dykes. A very thick gabbro dyke cuts the lavas and Jurassic sediments, altering them to high-temperature hornfelses with distinctive calc-silicate minerals. Reaction between the gabbro and calcareous sediments has resulted in a distinctive marginal zone of nepheline-normative rock and skarn mineral assemblages. The lavas are among the oldest in the Province, which accords with their pre-Rum Central Complex age.

EAST CANNA AND SANDAY

Highlights

The inter-lava fluvial sediments and pyroclastics exposed here are the best developed in the British Tertiary Volcanic Province, providing an essential link in a chain of sites in the study of the Tertiary volcanic history of the region. Derived clasts suggest that the Rum Complex is appreciably older than the Skye Cuillin centre.

Introduction

Agglomerates, fluvial conglomerates and other sediments closely associated with the volcanic succession of Canna, occur within this site and are the best developed and most extensive examples within the BTVP. These formations were the first such deposits within the Province to be described in detail. Geikie (1897) concluded that the conglomerates had filled a river channel cut into the lavas. The islands were later mapped by Harker (1908) who accepted the fluvial origin. Allwright (1980) has more recently interpreted coarse conglomerates on Compass Hill in terms of a nearby source of coarse pyroclastic debris which was possibly connected with a volcano which fed some of the lava flows.

Description

The spectacular sea cliffs, stacks and intertidal areas of south-eastern Sanday, Eilean a'Bhaird and eastern Canna contain good exposures of the interlava clastic sediments. In and near to the

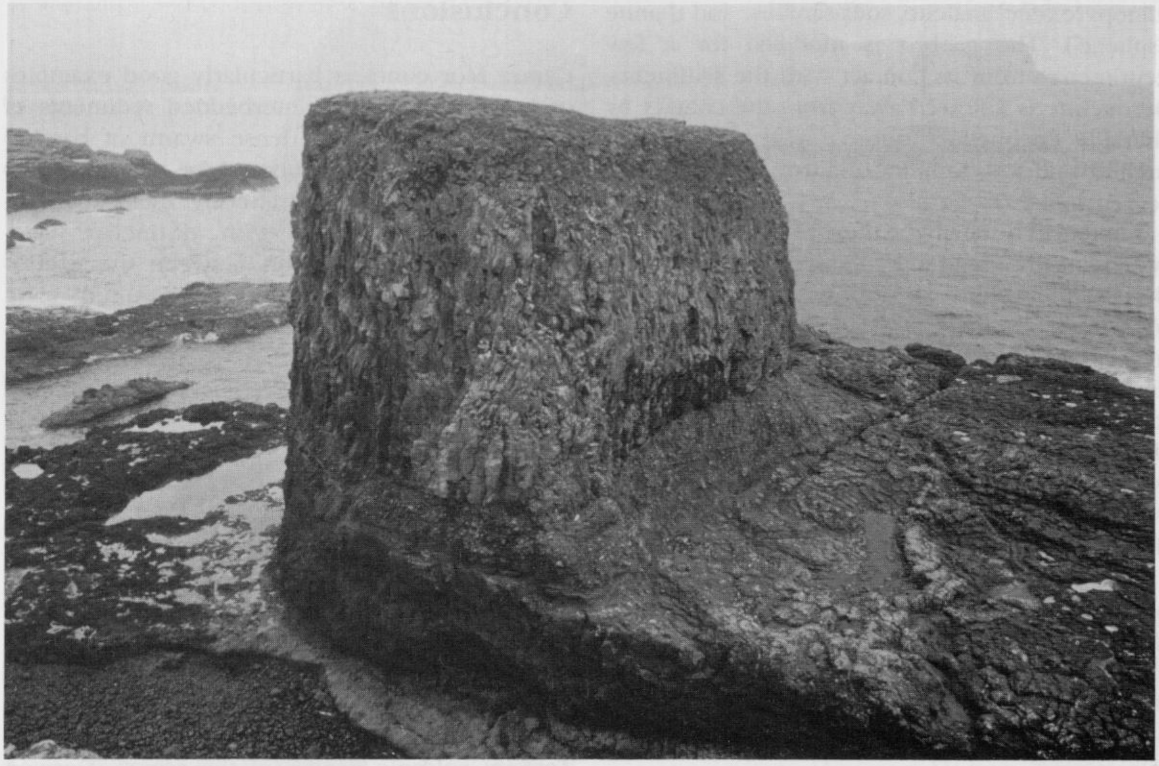


Figure 3.19 Stack of Dùn Mòr, Sanday, formed of basalt lavas with interbedded coarse conglomerates. The conglomerates contain rare granite pebbles from the Rum Central Complex. Canna–Sanday vicinity. (Photo: A.P. McKirdy.)

stacks of Dùn Mòr (NG 2877 0374; Fig. 3.19) and Dùn Beag (NG 2888 0375; Fig. 3.20), conglomerates occur beneath a thick, columnar basalt lava. On Dùn Mòr and in the adjacent cliffs, the conglomerates locally exceed 2 m in thickness and appear to blanket underlying vesicular basalts. On Dùn Beag, on the other hand, the conglomerates reach 15 m in thickness overlying amygdaloidal lavas and abutting directly against them. This important exposure was interpreted by Geikie as the wall of a river channel or gorge, against which the deposits were banked. The conglomerates of Dùn Mòr pass laterally into finer-grained tuffs and shales, the transition being accompanied by a marked reduction in overall thickness. Identical sediments and overlying lavas can be traced for some distance westwards along the cliffs of southern Sanday. The sediments are heterogeneous and comprise crudely bedded conglomerates (often exceptionally coarse, with boulders over a metre in diameter), thin-bedded, green/pink ashy shales, sandstones and tuffaceous mudstones. Carbonaceous streaks and organic remains have been reported by Geikie (1897) and Harker (1908). The clasts include Torridonian arkoses, Tertiary lavas, various types of schist, gneiss and granophyre, the last of these probably derived from the Rum western granite (Emeleus, 1973). The columnar basalt which overlies the sediments has a markedly chilled base; the occurrence of lobate structures with radial fractures and diffuse vesicles arranged concentrically, strongly suggests that the lava had flowed into and along channels occupied by waterlogged sediments. The sediments, lavas and conglomerates of south-east Sanday lie towards the base of the exposed volcanic succession (Harker, 1908; Stewart, 1965; Allwright, 1980).

The impressive hundred-metre-high cliffs and the coastal sections below Compass Hill (NG 280 063) in eastern Canna expose intercalations of basaltic lavas and pyroclastic rocks and the thickest development of predominantly water-laid sediments on the island (Fig. 3.21). These comprise conglomerates and sandstones derived largely from the erosion and transport of contemporaneous pyroclastic material. The sediments have been interpreted as deposits formed in fluvial and perhaps marginal lacustrine environments (Geikie, 1897; Harker, 1908; Allwright,

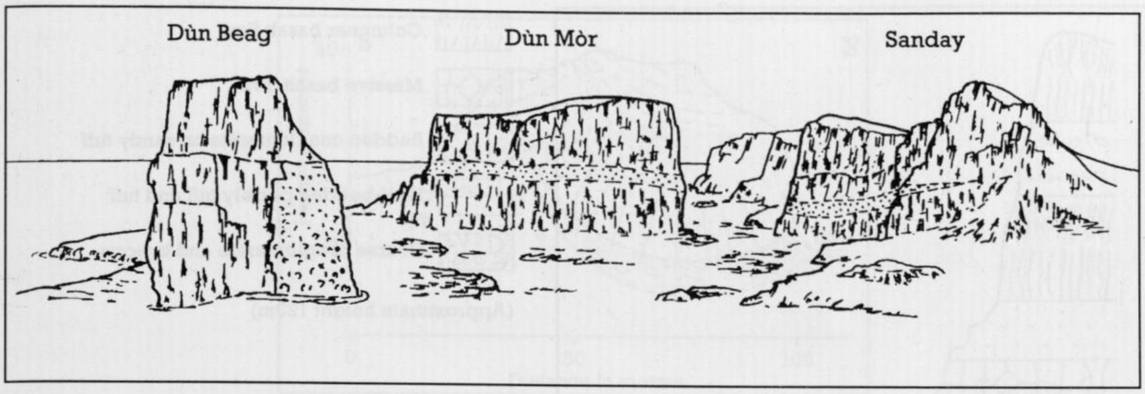


Figure 3.20 Sketch of Dùn Beag, Dùn Mòr and the cliffs of Sanday (after Harker, 1908, figure 12). Columnar basalt flows with interbedded conglomerate are seen on Dùn Mòr and the cliffs of Sanday. On Dùn Beag, lavas fill a steep-sided valley eroded in conglomerate.

1980). Compass Hill is significant in that it shows the intimate relationships between lavas, conglomerates and agglomerates. Lithologically, the conglomerates are similar to those on Dùn Mòr, no doubt owing to their closer proximity to agglomerates, and contain a higher percentage of basic igneous pebbles, whilst granophyre and gneiss pebbles are rare. Porphyritic felsite pebbles, similar to the Rum felsites, have been found here.

The sea stacks of Alman (NG 2805 0545) and Coroghon Mor (NG 2797 0554) expose confused masses of pebble conglomerates in basaltic lavas; the lavas have tended to nose their way into the sediments which must have been unconsolidated. No vent has been identified on Canna but the coarseness of the reworked conglomerates and 'agglomerates' suggest that one was nearby, possibly only a short distance offshore to the east, as indicated by the westwards thinning of the deposits. Large blocks of Torridonian arkose occur in the 'agglomerates' on the shore to the north-east of Compass Hill which indicates that the basal lavas may rest directly on Torridonian sediments.

Eilean a' Bhaird (NG 270 050) is a small island rising above the tidal flats of Canna Harbour. It contains the most evolved lava on Canna, a very fine-grained flow which is chemically of tholeiitic andesite rather than mugearite (Muir and Tilley, 1961; Ridley, 1973). The flow overlies a substantial thickness of very coarse conglomerates. They are identical to the others on Canna and appear to infill a small channel (Figs 3.22 and 3.23; Allwright, 1980).

Interpretation

The value of the Canna–Sanday site lies in the evidence that it provides for the development of extensive, vigorous river systems during the period of Palaeocene lava accumulation. Geikie (1897) placed particular emphasis on the palaeogeographical implications of the clasts in the fluviatile sediments; the occurrence of gneisses, schists and Torridonian clasts indicates erosion in the Palaeocene of a landmass containing lithologies similar to present-day western Scotland. The abundance of Torridonian fragments in the pyroclastic-derived deposits of Compass Hill might alternatively indicate a Torridonian basement to the Tertiary lavas, although it is surprising that no Mesozoic sedimentary fragments have been recognized, since Canna overlies a Mesozoic basin (Binns *et al*., 1974). The position of the Eilean a'Bhaird flow within the Canna sequence is problematic. Allwright argues that it must be fairly low in the stratigraphic succession of lavas; however, it could be one of the latest lavas in the area, since it overlies conglomerates filling a valley eroded in lavas and no examples of a lava of similar composition are known to be overlain by other lavas on Canna or Sanday.

The similarity between some of the Canna–Sanday lavas and those of north-west Rum (Emeleus, 1985), and the occurrence of clasts apparently derived from the acid rocks in the Rum complex, establishes a close connection with Rum. The site is a vital link in the chain of sites from Muck and Eigg, through Rum, to south-

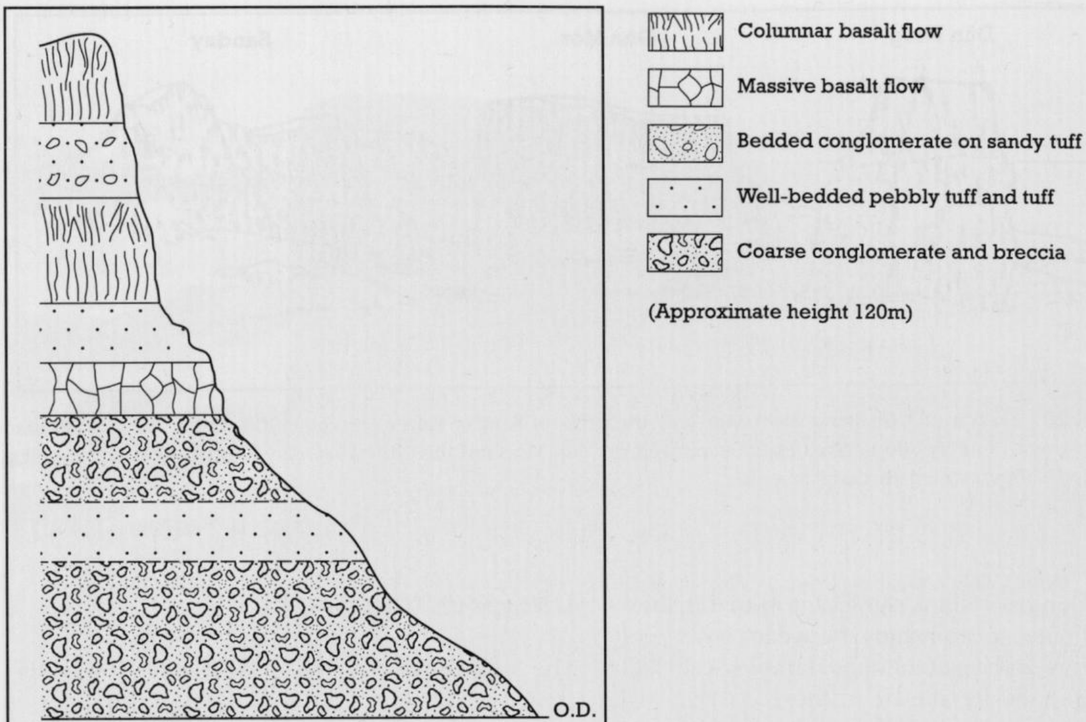


Figure 3.21 Cliff section at Compass Hill, Canna (after Harker, 1908, figure 8).

west Skye and Ardnamurchan which enables continuous, relative dating of igneous rocks across the British Tertiary Volcanic Province to be attempted, thus aiding assessment of the evolution of the Province (Meighan *et al.*, 1981; Dagley and Mussett, 1986).

Conclusions

The intra-lava sediments in the volcanic succession of east Canna and Sanday provide unequivocal evidence that a river system draining areas of gneiss, schist and probably Torridonian sediments, was established during periods when active effusion of basaltic and intermediate lavas was occurring. The rivers also drained Rum and probably extended to Skye, the distinctive pebbles laid down in the associated fluviatile deposits make it possible to conclude that the Skye Cuillin Central Complex almost certainly post-dated the Rum Central Complex.

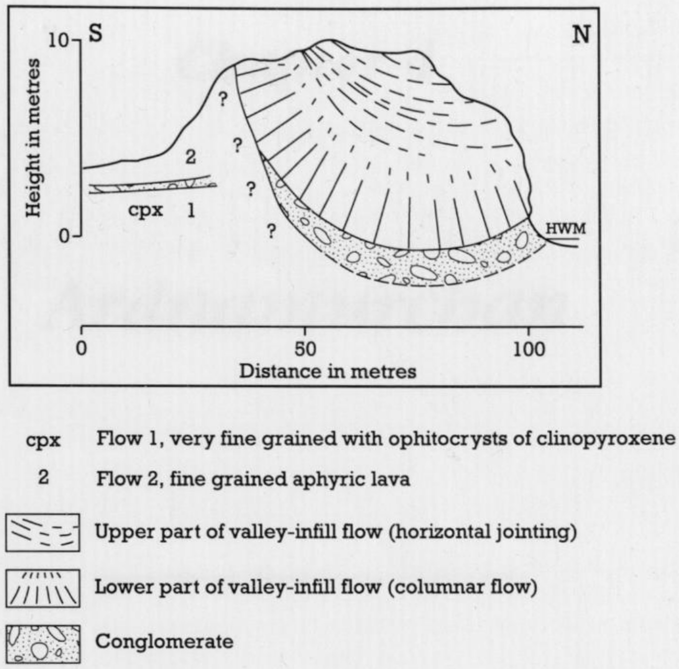


Figure 3.22 Canna Harbour: Eilean a' Bhaird from the east (after Allwright, 1980, figure 2.4.13).

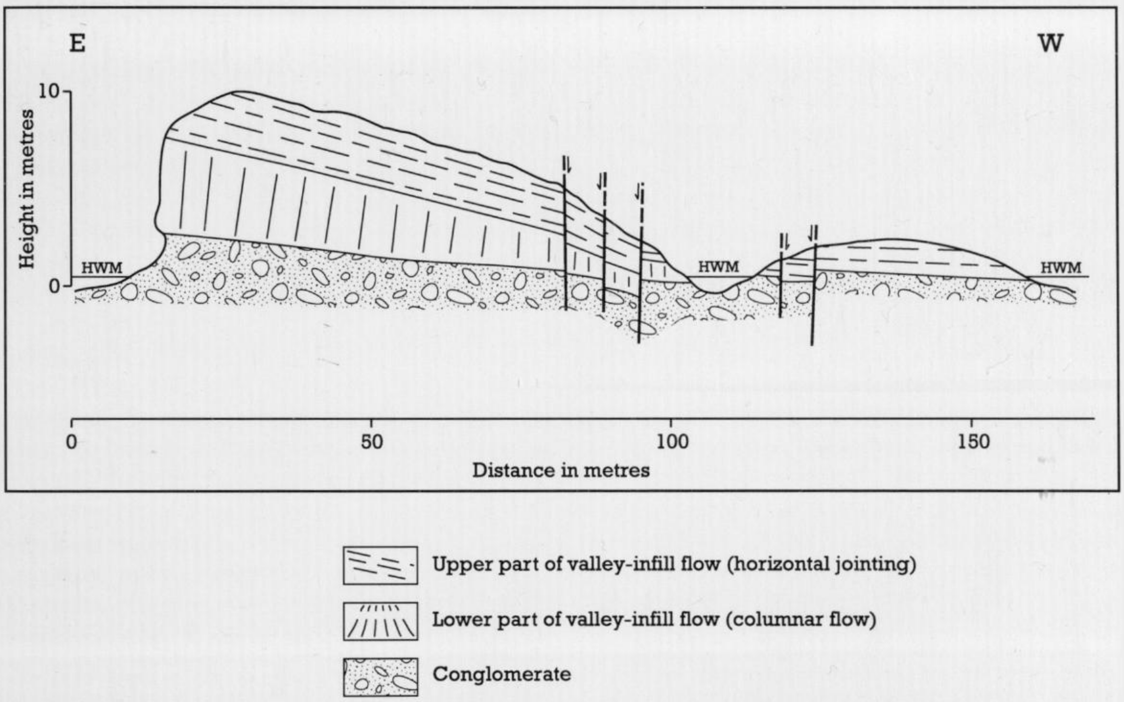


Figure 3.23 Canna Harbour: Eilean a' Bhaird from the north (after Allwright, 1980, figure 2.4.14).