Summary of the Geology of Rum

Introduction

The Paleocene Rum Central Complex (*c*. 60 Ma; (Figure 2)) is situated on a ridge composed of Archaean Lewisian gneisses and sandstones belonging to the Late-Proterozoic Torridon Group. The ridge is bounded to the east and west by basins filled with Mesozoic sedimentary rocks and Paleocene basalt lavas. On Rum, Torridon Group sandstones form the country rocks to the Paleocene central complex. Numerous north-west- to north-trending, predominantly basaltic dykes of Paleocene age traverse these sandstones, which are overlain in north-west Rum by Triassic sandstones and Paleocene lavas and conglomerates. Relict masses of Paleocene basaltic lavas, Jurassic sedimentary rocks, Torridon Group sandstones, and Archaean gneisses crop out within the central complex. The geological succession is summarised in (Table 1) (page 8).

The Rum Central Complex developed in two distinct stages. During Stage 1, central uplift on a major arcuate fault system (the Main Ring Fault, MRF) was accompanied by felsic and mixed felsic/mafic magmatism and the formation of a caldera which filled with silicic ash flows, tuffs, and breccias formed by collapse of the uplifted dome and the unstable caldera walls. The country rocks were strongly domed over the central complex, probably accompanied by contemporaneous lateral displacement of large masses of sandstone, while uplift within the ring faults brought masses of Lewisian gneiss and the basal members of the Torridon Group close to the present erosional levels, with later subsidence resulting in the preservation of Jurassic sedimentary rocks and Paleocene basaltic lavas. Slightly later, several microgranites were intruded, including the Western Granite.

Table 1: Sequence of faulting, folding and intrusion in the Rum Central Complex

Table:	Sequence of faulting, folding and intrusion in the Rum Central Complex
1	Pre-Palaeogene: tilt to west of Triassic and Torridonian strata; faulting in these successions; early movement on the Long Loch Fault?
2	Doming of the Torridonian strata around the central complex accompanied initial uplift, with formation of the Welshman's Rock and Mullach Ard faults as country rocks slid off the dome. Fault blocks broke up and behaved independently, the Welshman's Rock block rotating *c*.90°.
3	Initial uplift on the Main Ring Fault (MRF): Lewisian and basal Torridonian uplifted by as much as 2 km, also tilting of elevated block to the east.
4	Subsidence on the MRF: eruption of rhyodacite ash flows, intrusion of rhyodacite along the MRF, intrusion of tuffisites, collapse of caldera walls to form breccias and megabreccias, intrusion of the Am Màm Breccias; subsidence brings Broadford Beds and Eigg Lava Formation flows down *c*.1 km within the MRF.
5	Emplacement of the Western Granite (may have been associated with movement that formed the inner component of the MRF).
6	Final uplift on the MRF (inner component).
7	Emplacement of radial dykes, regional north-west-trending dykes, and cone sheets.
8	Formation of a Loch Scresort–Glen Shellesder Fault?

9	Emplacement of the Eastern and Western layered intrusions.
10	Emplacement of the Central Intrusion — re-activation of the Long Loch Fault?
11	Small radial faults within the Central Intrusion and Eastern layered intrusion.
12	Accumulation of the Canna Lava Formation (Skye Lava Group), with concomitant erosion of the Rum Central Complex.
13	Long Loch Fault (final movement); faults in Canna Lava Formation.

Stage 2 commenced with the intrusion of a set of basaltic cone-sheets and numerous basaltic dykes, many of which trend north-west to north-north-west and belong to the Rum Dykeswarm. Emplacement of the Rum Layered Centre (feldspathic peridotites, troctolites and gabbros) followed. On Hallival and Askival, in eastern Rum, these mafic and ultrabasic rocks form prominent, gently-dipping layers (generally termed 'Units') and comprise the Eastern Layered Intrusion (formerly 'Series'). Layered rocks also occur in south-west Rum where they form the Western Layered Intrusion. The Central Intrusion separates the Western and Eastern layered intrusions. This comprises a north–south belt of igneous breccias composed of blocks and megablocks of bytownite troctolite and feldspathic peridotite enclosed in matrices of similar compositions. The Central Intrusion is regarded as the feeder system for the Layered Centre. It is located along a major north–south fracture, the Long Loch Fault. Numerous sheets and plugs of gabbro and feldspathic peridotite intrude the layered rocks, and they are also found as plugs throughout the country rocks. A few dykes, including rare picrites, also intrude the Layered Centre.

After Stage 2: a major volcanic edifice was likely built over Rum during stages 1 and 2, but subsequent (and probably also contemporaneous) erosion rapidly reduced this to a hilly landscape. Evidence for this comes from north-west Rum where the Western Granite and sandstones of the Torridon Group are overlain by predominantly basaltic lava flows and intercalated fluviatile conglomerates, belonging to the Canna Lava Formation (*c*. 60 Ma). The flows and conglomerates have buried and preserved a hilly landscape dissected by steepsided valleys that drained central Rum. The interlava conglomerates contain abundant clasts of red sandstone and gneiss, together with rhyodacite, microgranite, troctolite and gabbro, all clearly derived from the central complex. Clasts derived from Rum have also been identified in conglomerates belonging to the Canna Lava Formation on Canna and Sanday (Emeleus, 1973) and in conglomerates interbedded with lavas belonging to the Skye Lava Group in south-west Skye. Since the Skye lavas pre-date the earliest gabbros of the Paleocene Cuillin Centre on Skye (59 Ma), the Rum Central Complex (60.5 Ma) was clearly extinct and thoroughly dissected before intrusion of the earliest members of the Skye Central Complex.

There is a gap in the geological record from the Paleocene until the Pleistocene Epoch, when the island was almost completely covered by the Main Late Devensian ice sheet sourced in mainland Scotland. At a later stage, during the Loch Lomond Stadial, it supported a local ice cap with several valley glaciers. The ice had gone by about 11,500 BP and there is evidence that Man arrived fairly soon thereafter; at Kinloch a recently excavated site yielded implements made from the bloodstone found in the lavas of north-west Rum. Remains from this site have been dated at about 8,500 BP.

Pre-Paleocene Geology

Lewisian Gneiss Complex

Archaean gneisses crop out along and within the Main Ring Fault (Figure 2; Tilley 1944; Bailey, 1945, 1956). They include interbanded felsic and mafic varieties and amphibolites after original mafic dyke or sheet intrusions. The outcrops are generally fault-bounded or cut by later intrusions but at a few localities gneiss is unconformably overlain by coarse-grained sandstone at the base of the local Torridonian succession; for example, in Sandy Corrie [NM 374 940], and near the Priomh-lochs [NM 370 986]. The gneisses have been thermally metamorphosed to varying degrees and felsic varieties may show signs of partial melting (e.g. Holness and Isherwood, 2003).

Torridon Group

The group is part of the more extensive Torridonian succession found on the mainland and is represented on Rum by a succession of sandstones, siltstones and, locally, sedimentary breccias totalling at least 2500 m in thickness, and several of the mainland formations are recognised (Figure 3). The rocks are largely unmetamorphosed, except in the vicinity of the central complex and adjacent to plugs and other minor intrusions (e.g. Holness and Isherwood, 2003). The group is best developed in the north of Rum where the beds dip consistently west to west-north-west at 10° to 30°, giving rise to the pronounced terrace featuring seen, for example, on Monadh Dubh (Figure 11); however, where affected by doming in the vicinity of the Main Ring Fault, the dips are commonly steep (Excursions 1 and 2).

Medium- to fine-grained feldspathic sandstones of the Applecross Formation form most of the Torridon Group succession on Rum. This formation lacks good marker horizons but members of other formations have distinctive lithologies that have proved to be of considerable use in elucidating the structure of Rum. They are the dark-coloured, fine-grained siltstones of the Laimhrig Shale Member (TCDL), the coarse-grained gritty sandstones of the Fiachanis Gritty Sandstone Member (TCDF) and the fine-grained sandstones and siltstones of the topmost Sgorr Mhòr Sandstone Member (TCSM), characterised by the presence of dark grey to black beds rich in heavy minerals (principally magnetite, but also zircon, garnet, sphene and rare green tourmaline) (Figure 3). The rocks of the Torridon Group on Rum are considered to have been laid down within a major fluvial braidplain (Nicholson, 1992, 1993).

Mesozoic strata

Sedimentary breccias, gritty sandstones and calcareous sandstones and siltstones of the Triassic Monadh Dubh Sandstone Formation crop out in small outliers in north-west Rum. Cornstones (caliches) are present and are particularly conspicuous at the angular unconformity with the Torridon Group rocks (Excursion 6). Rare ostracods and ill-preserved plant remains occur in the uppermost beds (Bailey, 1945; Steel, 1974, 1977; Emeleus, 1997). The Triassic rocks of Rum are probably the feather-edge of the Mesozoic Minch Basin (Binns *et al*., 1974; Fyfe *et al.*, 1993).

Coarse-grained grey marble, calc-silicate hornfelses, quartzite and baked mudstones crop out south of Allt nam Bà and on the northern slopes of Dibidil. Poorly preserved fossils of Early Jurassic age have been recovered from these rocks which are correlated with the Broadford Beds of Skye (Smith, 1985). These beds are preserved in fault-bounded slices on the Main Ring Fault. At Allt nam Bà, where they are in contact with Marginal Gabbro of the central complex, the hornfelsed rocks contain the calc-silicate minerals spurrite, tilleyite and harkerite, indicating high-grade sanidinite-facies thermal metamorphism (Excursion 7; Hughes, 1960b; Emeleus, 1997).

Paleocene

Pre-Stage 1

Basaltic lavas belonging to the Eigg Lava Formation probably covered much of Rum prior to initiation of Stage 1 of the central complex. These lavas are now restricted to faulted slivers of basalt within the Main Ring Fault in eastern Rum. Additionally, locally abundant xenoliths of basic granulite-facies hornfels ('beerbachites') up to 10 m long occur in ultrabasic rocks in the Eastern Layered Intrusion (Stage 2). They are considered to be foundered blocks derived from lavas that roofed the central complex (Excursion 3). Clots and veins in the xenoliths contain grossular, calcic plagioclase and iron-rich pyroxene (ferri-fassaite), possibly derived from the metamorphism of lava amygdales (Faithfull, 1985).

It is likely that some of the numerous north-west- to west-north-west-trending basaltic dykes that intrude the Torridonian beds pre-date the central complex since these and less common sheets are affected by movements on the Main Ring Fault. However, conclusive proof is elusive and the majority of the dykes on Rum probably belong to the early part of Stage 2 (see below).

The Rum Central Complex

Stage 1

The Am Màm Breccias

Evidence for some of the earliest activity within the central complex comes from the Am Màm Breccias in the Northern Marginal Zone (Table 1, page 8; Excursion 2). The breccias consist of abundant angular blocks in dioritic to granodioritic matrices, with textural relationships that suggest there has been mixing of felsic and mafic magmas. The xenoliths are commonly less than 1 m across but may be many metres in width. They comprise angular blocks of very coarse-grained gabbro, dolerite, rare feldspathic peridotite, baked sandstone and gneiss, and, additionally, there are small (up to 10 cm) rounded doleritic inclusions with diffuse margins. Areas of very coarse-grained gabbro several tens of metres in diameter are identical to gabbro fragments in the breccias. Gabbros east and west of Am Màm hill are cut by veins and more substantial bodies of breccia and maintain their coarse-grained character throughout, generally lacking any indications of chilled margins except at one locality east of Loch Gainmhich where gabbro grades into finer grained rocks at a contact with thermally metamorphosed Lewisian gneiss (pyroxene hornfels). These large areas of gabbro were previously considered to be plugs (e.g. Dunham, 1968) but are now interpreted to be megablocks in the Am Màm Breccia. Similar igneous breccias are present in the Southern Mountains Zone.

The Coire Dubh Breccias

Coarse sedimentary breccias feature prominently in both the Southern Mountains Zone (SMZ) and their type locality, the Northern Marginal Zone (NMZ), where they crop out abundantly in Coire Dubh, between Meall Breac and Cnapan Breaca (Excursion 2; (Figure 4)a). In the NMZ, the breccias consist of angular to subrounded blocks of sandstone and siltstone derived from the lowermost members of the Torridon Group, principally the Fiachanis Gritty Sandstone. Gneiss and dolerite clasts occur but are extremely rare in the NMZ. The breccias may be clast- or matrix-supported, the matrix commonly consisting of comminuted sandstone. The fragments vary in diameter from a few centimetres to over a metre and, at several localities, large rafts, or 'megablocks', of bedded sandstone appear to be enclosed by breccia, although in the absence of complete exposure it may be difficult to prove this interpretation. The clearest apparent examples of megablocks occur in the Southern Mountains Zone (SMZ, Excursion 8; (Figure 4)b) but they are probably also present in the NMZ (Excursion 2). The Coire Dubh Breccias are commonly chaotic, but locally display bedding, and stratigraphical successions have been established in both areas (Figure 15) and (Figure 70) (e.g. Troll *et al.*, 2000; Donaldson *et al.*, 2001). Tuffs, including crystal tuffs rich in plagioclase similar to that found in later porphyritic rhyodacite, occur in the breccias, with good examples to the east and north of Cnapan Breaca (Excursion 2). Coarse, pale grey, gritty sandstone is generally present at the top of the breccias. This sandstone, the Epiclastic Sandstone, formed when fines washed out of the breccias accumulated in areas of shallow water on the caldera floor (Excursions 2 and 7).

Despite their close proximity on the south side of Am Màm (at *c*. [NM 3817 9853]), the relative age of the Am Màm and Coire Dubh breccias is difficult to establish with certainty. However, on the north side of Meall Breac and in the SMZ there is evidence that the Am Màm Breccias were closely associated with porphyritic rhyodacite (Excursions 2 and 8).

The two breccias are of very different origins. The Am Màm Breccia is intrusive and has a thoroughly igneous matrix with the characteristics of a hybrid (mixed felsic/mafic) magma, whereas the Coire Dubh Breccia formed from debris that accumulated against the walls and on the floor of a caldera (Emeleus, 1997; Troll *et al.*, 2000; Donaldson *et al.*, 2001).

Porphyritic Rhyodacite

Large bodies of porphyritic rhyodacite (the 'porphyritic felsite' of Hughes, 1960a and Dunham, 1968) crop out in both the NMZ and the SMZ (Figure 4) and (Figure 6). The resistant rock forms Cnapan Breaca, Meall Breac and Am Màm in the NMZ (Excursion 2; (Figure 4)a), and Sgurr nan Gillean and Ainshval in the SMZ (Figure 4)b. The porphyritic rhyodacite contains variable amounts (20–50 vol. %) of phenocrysts of bipyramidal quartz, complexly-zoned plagioclase, opaque oxides and iron-rich pyroxenes (ferro-augite, ferropigeonite and Fe-rich hypersthene). The matrices vary from microcrystalline (devitrified glass) to fine-grained granular aggregates of quartz, plagioclase, alkali feldspar and amphibole. Rounded, lobate mafic enclaves occur in the rhyodacite. The inclusions are commonly several tens of centimetres in diameter and are abundant locally in both zones, as towards the north end of Meall Breac and in a major plug of rhyodacite north of Cnapan Breaca (Excursion 2, Locality 5). Rhyodacite of both intrusive and extrusive origins is exposed in the walls of corries on the south-west side of Dibidil; mafic enclaves are abundant at some localities (Excursion 8). The relationships in both areas are indicative of a mixed-magma origin for the rhyodacites (Troll *et al.*, 2004).

Streaky, banded structures in the rhyodacite (fiamme) occur on both outcrop and microscopic scales (Excursion 2). The banding was formerly attributed to the flow of viscous, degassed felsic magmas, but it is now recognised that the structures closely resemble fiamme and, in the devitrified glassy matrices, relict shards are readily recognised. Additionally, phenocrysts are commonly broken, and small, rounded pieces of basalt (< 1 cm diameter) are scattered throughout the rock. The rocks are now interpreted to be pyroclastic flow deposits that erupted from vents on or near the Main Ring Fault and accumulated on the floor of a caldera (Williams, 1985; Donaldson *et al.*, 2001). On Meall Breac, a flow feeder at the north end of the ridge has close-set, near-vertical banding (highly-attenuated fiamme) and may be traced southwards into a thick, extrusive mass of rhyodacite overlying the Coire Dubh Breccia. Nearby, on a shelf north of Meall Breac, a dyke-like mass of porphyritic rhyodacite cuts the Am Màm Breccia (Excursion 2). A few small intrusive bodies of porphyritic rhyodacite crop out on the Main Ring Fault and on the south-east slopes of Beinn nan Stac and in Coire Dubh.

Tuffisites

Irregular, thin (< 30 cm), dark-coloured dykes cut sandstones and the Coire Dubh Breccia in Coire Dubh and Dibidil. The dykes are generally xenolith-rich, with abundant small fragments of country rock and rare, bleb-like pieces of porphyritic rhyodacite. Microscopic examination shows the presence of rounded mafic inclusions with a fluidal structure, banded rhyodacite, altered basalt and dolerite, and crystals of quartz and zoned plagioclase similar to those in the rhyodacite. The dykes are examples of tuffisites. They either just pre-date the rhyodacite or are contemporaneous with it, and may represent the earliest rhyodacite magma cracking through to the surface, although this remains speculative (Excursions 2, 7 and 8).

Microgranites

The hills and coastal cliffs of west and south-west Rum are formed by the Western Granite, an intrusion of granophyric microgranite. Other small areas of microgranite occur near the Priomh-lochs (the Long Loch Granite) and on the south-west of Sgurr nan Gillean (the Papadil Granite, Excursion 9). The rocks are pale-brown or cream coloured, with small feldspar phenocrysts and drusy cavities visible on weathered surfaces. The phenocrysts are zoned plagioclase and the matrix is commonly microgranitic or of granophyrically intergrown quartz and dusty alkali feldspar. Pyroxenes (ferroaugite and ferropigeonite) are the principal mafic minerals, although both show varying degrees of replacement by amphibole and chlorite. A pale-weathering, cream-coloured variant of the granite near Harris contains fayalitic olivine and ferrohedenbergite. This may be a later member and, elsewhere, internal contacts have been noted.

The northern margin of the Western Granite is defined by the later Main Ring Fault. In the east, it is cut by mafic rocks belonging to Stage 2. Original intrusive contacts are limited to a small patch of thermally altered gneiss on the summit of Ard Nev and a strip of gneiss between the microgranite and feldspathic peridotite between Ard Nev and Ard Mheall. To the north-west, on Orval, lava flows belonging to the Canna Lava Formation rest on an irregular eroded surface of weathered microgranite (Excursion 5). Elsewhere, the Papadil Granite (Excursion 9) appears to cut porphyritic rhyodacite (Hughes, 1960a) and breccias of Am Màm type, indicating that the microgranites are probably the youngest members of Stage 1.

The Main Ring Fault

The Main Ring Fault comprises a number of arcuate faults that define the outer margins of Stage 1 and were probably utilised in part during emplacement of Stage 2 (Figure 2), (Figure 9). The faults may be traced from A' Bhrìdeanach in western Rum along the northern edge of the central complex to Cnapan Breaca (e.g. (Figure 6)), then south to Allt nam Bà and Dibidil, and west to Papadil where they are truncated by Stage 2 intrusions. Between Cnapan Breaca and Beinn nan Stac the margin of the later Eastern Layered Intrusion roughly coincides with, and is presumed to have been controlled by, the Main Ring Fault. Other mafic intrusions belonging to the Layered Centre breach the ring fault between Minishal and the Long Loch Fault, and north-east of the Priomh-lochs.

Movement on the Main Ring Fault was complex. The earliest events are most clearly visible on the northern edge of the NMZ and in the vicinity of Allt nam Bà and Beinn nan Stac. Here, Lewisian gneiss and basal members of the Torridon Group occur exclusively inside the ring fault, demonstrating that considerable uplift (as much as 2 km) has occurred within this fault system. For example, in Allt Slugan a'Choilich in Coire Dubh, sandstones from the Applecross Formation and dark siltstones from the stratigraphically lower, Laimhrig Shale Member are in juxtaposition (Excursion 2). A more complicated situation exists on the south-east slopes of Beinn nan Stac, where the Main Ring Fault (MRF) comprises Inner, Central and Outer branches (Excursion 7; Smith, 1985). In an east to west traverse the following are encountered (Figure 8): (i) Applecross Formation sandstone faulted against gneiss (Outer MRF); (ii) gneiss faulted against basalts of the Eigg Lava Formation overlying Lower Jurassic Broadford Beds (Central MRF); and (iii) Broadford Beds faulted against gritty sandstones and siltstones of the Diabaig Formation (Inner MRF). These relationships are interpreted to show initial uplift of > 1.5 km on the Outer MRF, followed by subsidence (> 1 km) on the Central MRF and caldera formation, and a final phase of uplift (> 1 km) on the Inner MRF.

Throughout most of its length the Main Ring Fault appears to be either essentially vertical or steeply inclined towards the central complex. Inward-dipping components of the system occur on the eastern slopes of Beinn nan Stac, and between the Bealach a' Bhràigh Bhig south of Fionchra and the western tip of Rum at A' Bhrìdeanach.

In eastern Rum several large masses of Torridonian strata have also been displaced along low-angle faults. The most obvious of these blocks is the steeply-dipping mass of sandstone (Applecross Formation) that forms Welshman's Rock. At Lochan Dubh, gently-dipping sandstone to the west is separated from the block by the clearly-defined Welshman's Rock Fault, which is inclined to the east at about 35o. Another mass of sandstones belonging to the Applecross Formation overlies a low-angled, easterly inclined fault at Mullach Ard on the south side of Loch Scresort. The dip of the sandstones is largly undisturbed, but the rocks are faulted against siltstones of the Laimhrig Shale Formation, and Nicholson (in Emeleus, 1997) estimated that a minimum downward displacement of 500 m accompanied by lateral movement towards the east-north-east is necessary to explain the present disposition of these rocks. The exact age of the movement on these two faults is difficult to determine but they post-date some of the minor intrusions, since crushed dolerite sheets crop out next to both faults. These blocks are interpreted to have slid off a dome that developed as felsic magmas ascended during Stage 1 of the central complex.

The southern tip of Rum, from Rubha nam Meirleach to the Main Ring Fault on the south of Sgurr nan Gillean, is formed by sandstones of the Sgorr Mhòr Sandstone Member and uppermost Scresort Sandstone Member at the top of the Torridon Group on Rum. Prominent dark beds rich in heavy minerals, characteristic of the Sgorr Mhòr Member, are magnificently exposed in the sea cliffs east of Papadil. When the position of these strata is compared with those in northern Rum, it is clear that this southern block has undergone considerable normal downward displacement. Some of the movement may be attributable to displacement on the Long Loch Fault, although this could only have been very limited (see below). The most likely explanation is that this large block also slid off the dome that developed over the central complex during Stage 1. Significantly, the beds in this block are cut by the MRF to the east of Papadil.

Minor intrusions: the commencement of Stage 2

Minor intrusions are abundant on Rum. Dykes are the most common, but there are also numerous plugs and cone-sheets, and less-common conformable sheets and sills. Almost all of the dykes are basaltic in composition. They generally lack distinctive characteristics in the field, although 'big-feldspar' and picritic varieties are readily recognisable. Dykes generally range in width from 0.2 m to 1.5 m. Over forty gabbro and peridotite plugs have been mapped, varying in size from 20 m up to 500 m. These are particularly abundant in the sandstones in the north and north-west of Rum and appear to radiate from the central complex (Excursion 6). The gabbros are generally olivine free and may be considerably altered. The peridotite plugs include feldspathic varieties and rare dunites. Bleaching and thermal metamorphism of the adjoining sandstones is common and is especially pronounced next to the gabbroic intrusions where some partial melting of country rocks has occurred (e.g. Holness, 1999).

The majority of the minor basaltic intrusions probably post-date both the Main Ring Fault and Stage 1 (but see Excursion 7). The cone-sheets are apparently unaffected by the Main Ring Fault, for example north-west of Am Màm, and they post-date deformation of the Torridon Group rocks adjoining the NMZ. In south-east Rum many north-west-trending dykes belonging to the regional swarm extend into the SMZ where they and the cone-sheets intrude porphyritic rhyodacite and earlier rocks (Emeleus, 1997; Excursions 7, 8, 9). However, several thick dolerite dykes on the lower south-east slopes of Beinn nan Stac probably pre-date Stage 1 since they are not found within the Outer MRF. A few north-west-to north-trending dolerite dykes intrude flows belonging to the Canna Lava Formation. They are distinct from the large number of north-west-trending dykes on the north-west coast of Rum, which are part of the Rum Swarm and do not cut the lavas. The post-Canna Lava Formation dykes also differ from the majority of igneous rocks on Rum in that several exhibit normal remnant magnetisation whereas most others are reversely magnetised (Dagley and Mussett, 1981).

Conformable basaltic sheets intrude members of the Torridon Group outside the Main Ring Fault. At least three different types may be distinguished. Sheets up to 3 m in thickness crop out in two areas. Those south-west of Kilmory are characterised by plagioclase and clinopyroxene phenocrysts, whereas those north-east of Papadil are aphyric (Excursion 9). Much thinner sheets of aphyric basalt (0.5 m and less) occur in both the northern and southern sandstone tracts. They are less common in the sandstones of eastern Rum, but examples of probable pre-Stage 1 age sills are cut by the Welshman's Rock and Mullach Ard faults.

It is difficult to determine when the plugs were intruded since few cut or are cut by dykes and none can be shown to be faulted. Gabbro and peridotite plugs do, however, cut the Main Ring Fault (e.g. near the Priomh-lochs; Excursion 2) and the Layered Centre (e.g. on Cnapan Breaca [Excursion 2] and Beinn nan Stac) and some of the plugs are amongst the latest intrusions in Stage 2. The elongate peridotite plugs in north-west Rum have a radiating pattern and appear to fan out from the Long Loch area, the possible site of the major feeder of the Layered Centre (see below). They frequently exert significant thermal influence on their immediate surroundings, e.g. Torridonian sandstone lithologies (cf. Holness, 1999, 2002).

Stage 2: The Layered Centre (formerly the 'Layered Suite')

Intrusions of feldspathic peridotite, bytownite troctolite (allivalite) and gabbro form the core of the Rum Central Complex. Three divisions, formerly termed 'series', are recognised: the *Eastern Layered Intrusion*

The Eastern Layered Intrusion (ELI)

The layered character of mafic rocks in the Layered Centre is most apparent in this intrusion in which a succession of gently dipping sheets of peridotite, allivalite and gabbro are magnificently exposed on Askival, Trollaval, Hallival and Barkeval (Figure 5), (Figure 6).

Up to sixteen layered units have been recognised (Figure 31). Ideally, a unit contains a basal feldspathic peridotite which passes upwards into troctolite (formerly 'allivalite') and anorthositic troctolite, with individual units separated by thin chromite-rich layers. The units were originally envisaged to have crystallised from discrete pulses of basaltic magma. Initially, dense magnesian olivine settled under gravity to form a basal peridotite. This was joined by increasing amounts of anorthite-rich plagioclase to make troctolite and, in some instances, anorthosite. Gabbroic facies with significant clinopyroxene occur towards the top of certain units. Currents disturbed the crystallising magma from time to time, accounting for the ubiquitous small-scale layering and accentuating plagioclase orientation (lamination) in the troctolites (Brown, 1956; Wager and Brown, 1968; (Figure 5); Excursion 3). The peridotites and gabbros are classic examples of igneous cumulates (Wager *et al.*, 1960). The units formed an upward-growing succession. Semiconcordant sheets of gabbro intruded the layered units, for example on the Askival Plateau (Brown, 1956; Excursion 3) and in the walls of Atlantic Corrie.

These interpretations were subsequently shown to be somewhat simplistic (e.g. Bedard *et al.*, 1988; Renner and Palacz, 1987). Several sheets of feldspathic peridotite intrude troctolite (Excursion 3) and there are instances of apparent intrusive behaviour by bytownite gabbro ('eucrite') that had been mapped as parts of units (Holness, 2005). Many of the layered rocks do, however, contain structures simulating those found in clastic sedimentary rocks. Of these, the most obvious is the layering, analogous to sedimentary bedding but in which the 'beds' generally reflect differences in modal mineralogy rather than grain size. Others include slump and load structures and rare cross-bedding (Figure 5). There is ongoing controversy about the origins of the structures. Some regard them as primary features related to crystal sedimentation in the magma chamber; others consider that they resulted from interaction between original cumulates

and later magmatic fluids generated, for example, from (or by) intruding peridotites (cf. Bedard *et al.*, 1988; Volker and Upton, 1990, 1991; Emeleus, 1997 and references therein; Holness, 2005; O'Driscoll *et al.*, 2007b). Structures resembling those found in highly deformed and sheared metamorphic rocks are also present, occurring especially in the more feldspathic troctolites. These distinctive rocks may have resulted from mass flow of poorly consolidated crystal mushes. Good examples are found in Units 13 and 14 close to the path on the north-west shoulder of Hallival (Excursion 3). The layered rocks represent the crystallised products of high-temperature magmas that cooled and consolidated over an appreciable time span; it is therefore most likely that early-formed structures and textures will have been modified and overprinted by later events, some of which were likely analogous to diagenesis in sediments. Present investigations are gradually unravelling these complex events (e.g. Holness, 2005; Holness *et al.*, 2005; Holness, 2007; Holness *et al.*, 2007a, b; O'Driscoll *et al.*, 2007a, b).

The Western Layered Intrusion (WLI)

This intrusion is largely composed of layered feldspathic peridotite, underlain by layered gabbro at Harris Bay (Wadsworth, 1961; Excursion 4b). The large-scale layering common throughout the ELI is less obvious in the WLI but small-scale layering is well developed and usually reflects variations in the proportions of olivine and plagioclase, sometimes accompanied by size variation and crystal lamination. In an unusual variety of layering, commonly up to 1 m in thickness, elongate crystals of olivine tens of centimetres in length appear to have grown upwards from a substrate of granular olivine, giving rise to 'harrisitic' textures (Figure 7, Excursion 4b). Good examples may be examined on the benches and low cliffs near the Harris Bay mausoleum, where harrisitic layers extend to within a metre or less of the edge of the intrusion (Excursion 4b). Excellent examples also occur on the southern slopes of Ard Nev and in exposures east of Ard Nev where small harrisitic olivines are present in layered peridotites, which also contain laminated layers with abundant platy olivine apparently broken off the tips of harrisitic olivines. The harrisitic olivines are considered to have grown rapidly from a fast-cooling magma supersaturated in olivine (e.g. Donaldson, 1974, 1976; O'Driscoll *et al.*, 2007a).

The Central Intrusion (CI)

This intrusion intrudes both the Eastern and Western layered intrusions (Figure 6), cutting a north–south swathe through them from the Long Loch to Papadil (Figure 2). Although layered peridotites and troctolites are present, the intrusion is characterised by igneous breccias (Donaldson, 1973). The breccias occur in approximately north–south zones, tens to hundreds of metres in width, in which angular to subangular blocks and megablocks of peridotite and troctolite are embedded in predominantly feldspathic peridotite matrices (Volker and Upton, 1990). The troctolite clasts commonly display layering, which dips steeply in all directions although generally remaining fairly uniform in direction within a clast. Large or small individual clasts may record complex events involving crystal sedimentation, or the disruption and/or replacement of layered structures. In turn, layered structures in the enclosing peridotite record considerable disturbance and disruption, commonly suggesting that clasts and blocks subsided into incompetent surroundings, probably crystal mushes (Excursion 4). Elsewhere, layered structures may appear slumped, or disturbed by avalanches of 'pebbly' peridotite debris and by dropstones (Excursion 4). Much of the debris within the breccias resembles fragments of peridotite and troctolite from the earlier intrusions. West and south of the Long Loch, large rafts of troctolite are many tens of metres in extent. These megablocks have steeply dipping layering and were probably derived from the ELI. Layered structures are especially well developed in the troctolites and feldspathic peridotite exposed in the CI west of the Long Loch where slump structures, graded bedding, flame structures and other features suggesting 'soft sediment' deformation are much in evidence (Excursion 4). On the western slopes of Trollaval there is a progressive increase of dip in the ELI units when traced westwards, indicating that at some stage substantial masses of layered rocks sagged towards the Central Intrusion and probably broke off and subsided into it (cf. (Figure 6), (Figure 43); Volker and Upton, 1990; Emeleus *et al.*, 1996; O'Driscoll *et al.*, 2007b).

A distinctive structure is found in feldspathic peridotites north-east of Loch MacIver (Loch an Dornabac). Radiating, bifurcating crystals of plagioclase up to 40 cm in length, enclosing myriads of minute olivine crystals, occur in seaweed-like masses as much as 1 m in diameter, scattered through the normal feldspathic peridotite. These 'poikilo-macro-spherulitic' feldspars grew *in situ*, possibly from a hydrous feldspathic magma (Excursion 4; Donaldson *et al.*, 1973). Other cases of *in-situ*crystallisation are apparent in the CI and around Harris where radiating crystals of olivine reach lengths of up to several tens of centimetres (cf. (Figure 7)).

During the original survey of Rum (Harker, 1908), many instances were found where the peridotites, troctolites and gabbros in the Layered Centre had been intruded by 'granophyre' (microgranite) and 'felsite' (porphyritic rhyodacite) from which it was concluded that the felsic rocks were the younger. At first sight the field evidence seems incontrovertible: wherever the mafic rocks are in contact with felsic rocks, there are spectacular breccias in which angular to subrounded mafic rocks are embedded in a network of veins and dykes of fine- to medium-grained microgranite that merge into the adjoining felsic rocks (Excursion 4). Many years later this interpretation was challenged and it is now known that the breccias are intrusion breccias, formed when hot mafic magmas chilled against but also melted or partially melted silicic country rocks. These were principally microgranite and porphyritic rhyodacite, but also sandstones and feldspathic gneisses (Hughes *et al.*, 1957; Hughes, 1960a; Emeleus, 1997). The relatively low-temperature, rheomorphic felsic melts had burst through and fragmented the chilled and contracting margins of the mafic intrusions, producing (rare) sinuous, rounded liquid-liquid contacts where still-liquid mafic magma chilled against the relatively low-temperature felsic liquids, while in some instances, hybrid rocks were formed when heated felsic magma was able to mingle with mafic magma. Thus, the rocks of the Layered Centre clearly post-date the felsic rocks of Stage 1 (Figure 6), (Figure 8). Additional supporting evidence comes from the minor intrusions; basaltic dykes and cone-sheets, which intrude the porphyritic rhyodacite, microgranite and feldspathic sandstones of the Torridon Group, can be followed into the contact zone where they underwent progressive thermal metamorphism and veining by thin silicic stringers. Ultimately, the dykes could no longer be supported by their weakened, partially melted felsic surrounding, whereupon they collapsed and disintegrated, contributing to the mafic blocks in the intrusion breccias. Some of the best examples come from fragmented cone-sheets in upper Dibidil (Hughes, 1960a) but convincing exposures may be examined in the contact zones at the south end of Meall Breac and Cnapan Breaca, at the ELI contact about 3 km east of Hallival, and at the WLI margin at the east end of Harris Bay (Excursions 2, 4b).

The scenario outlined above provides an explanation for the absence of good chilled margins to the constituents of the Layered Centre; they were simply destroyed during formation of the intrusion breccias (but see Greenwood *et al.*, 1990). The problem is a general one throughout the Hebridean Igneous Province so that the most promising localities to search for good chills (possibly representing rapidly cooled parental magma) are at gabbro/basalt lava contacts, which are lacking on Rum. The problem of the parental magma or magmas of the Layered Centre has exercised investigators since the original survey (e.g. Harker, 1908; Brown, 1956; Emeleus, 1997 and references therein), with the present consensus favouring a magnesium-rich basalt, possibly most closely represented by rare picritic dykes that post-date the Layered Centre (Upton *et al.*, 2002).

The Canna Lava Formation on Rum

Several small outliers of lava flows with interbedded conglomerates and gritty sandstones crop out on the hills of north-west Rum. These belong to the Canna Lava Formation that is part of the Skye Lava Group (Table 1, p. 8). Four members have been distinguished using field and chemical criteria: the Lower Fionchra Member (conglomerates with rare plant remains; flows of olivine basalt and hawaiite), the Upper Fionchra Member (conglomerate; gritty sandstone and siltstone with plant remains; flows of tholeiitic basaltic andesite with hyaloclastite deposits at the base), the Guirdil Member (conglomerate; flows of tholeiitic andesite ['icelandite'] and the Orval Member (flows of olivine-bearing basaltic hawaiite and hawaiite).

These lavas post-date the Rum Central Complex. This is in marked contrast to central complexes elsewhere in the Hebridean Igneous Province where the lava successions are almost invariably intruded by the central complexes. Conclusive evidence for their younger age emerged when Black (1952) excavated the contact between lava flows and microgranite on Orval. He found that the lavas rest on a surface of weathered microgranite (Excursion 5). Further evidence is provided by the clasts in the conglomerates. These include boulders, cobbles and pebbles of porphyritic rhyodacite, microgranite, gabbro, troctolite and tuffisite derived from the central complex, together with feldspathic sandstone, gneisses and amphibolite. The lavas and conglomerates have strikingly irregular outcrops (Figure 6), (Figure 58); Excursions 5 and 6), partly due to faulting but largely the result of their burying a succession of irregular palaeolandscapes. Consecutive members have infilled valleys excavated in pre-lava rocks and also in earlier flows, as on Bloodstone Hill and Fionchra (Excursion 5). The valleys were generally floored by coarse conglomerates, in places interbedded with gritty sandstones and sandstones. On Fionchra a basaltic andesite hyaloclastite breccia overlies plant-bearing siltstones, implying that from time to time the valleys may have contained shallow lakes. Plant remains have been recovered from these beds (Jolley, 1997). Since no lava feeders are known on Rum, the flows are assumed to have originated from external sources, ponding in valleys carved into the flanks of the Rum central volcano (Emeleus, 1985). Apart from a few basaltic dykes that intrude the lavas, the lava flows represent the latest igneous activity on the island.

Accumulation of the Canna Lava Formation overlapped with the unroofing of the Rum Central Complex and occurred within a short time span. An age of 60.53 ± 0.08 Ma (Hamilton *et al.*, 1998) has been obtained from the Layered Centre (Stage 2), which is very similar to dates from the Canna Lava Formation on Canna (60.00 ± 0.23 Ma; Chambers *et al.*, 2005) and the Skye Lava Group on Skye (58.91 ± 0.1 Ma). The earliest intrusion in the Cuillin Centre of the Skye Central Complex intrudes lavas of the Skye Lava Group and has been dated at 58.91 ± 0.08 Ma (Chambers *et al.*, 2005; Emeleus and Bell, 2005 and references therein). Thus, little over one million years separate the Rum and Skye central complexes which, in turn, bracket a period of intense erosion and lava effusion (e.g. Williamson and Bell, 1994).

Events post-dating the Rum Central Complex

The Long Loch Fault

This fault extends in a general north–south direction across Rum (Figure 2), (Figure 6), producing up to 800 m of right-lateral displacement of rocks that include the latest members of the Central Intrusion. It is not possible to estimate the amount and direction of any vertical displacement, but it is unlikely that there can have been a significant downthrow to the east. Had this occurred, members of the Canna Lava Formation would likely have been preserved to the east of the fault. Within the central complex, the fault follows the course of the Central Intrusion where it is marked by a shallow, steep-sided valley up to 50 m in width (Excursion 4). However, to the north the valley is noticeably wider in Kilmory Glen, where there is evidence that the zone of faulting is appreciably wider than within the central complex. It is suggested that the Long Loch Fault was already active prior to emplacement of the central complex, becoming re-activated during the Paleocene when it acted as a conduit for the mafic magmas of the Layered Centre (and probably earlier intrusions in the central complex; O'Driscoll *et al.*, 2007b), and hence probably for most of those erupted during Stage 2 (McClurg, 1982; Emeleus *et al.*, 1996).

Numerous small faults occur throughout Rum. Some may be relatively early, as for example the north-east-trending fault that affects Torridonian beds on Bloodstone Hill but which is overlain by lavas. Others are of later date, as at West Minishal where lavas and conglomerates are cut by a north-north-west-trending fault that also offsets the MRF. Small, north-north-west-to north-north-east-trending faults also offset layering in the ELI north of Barkeval.

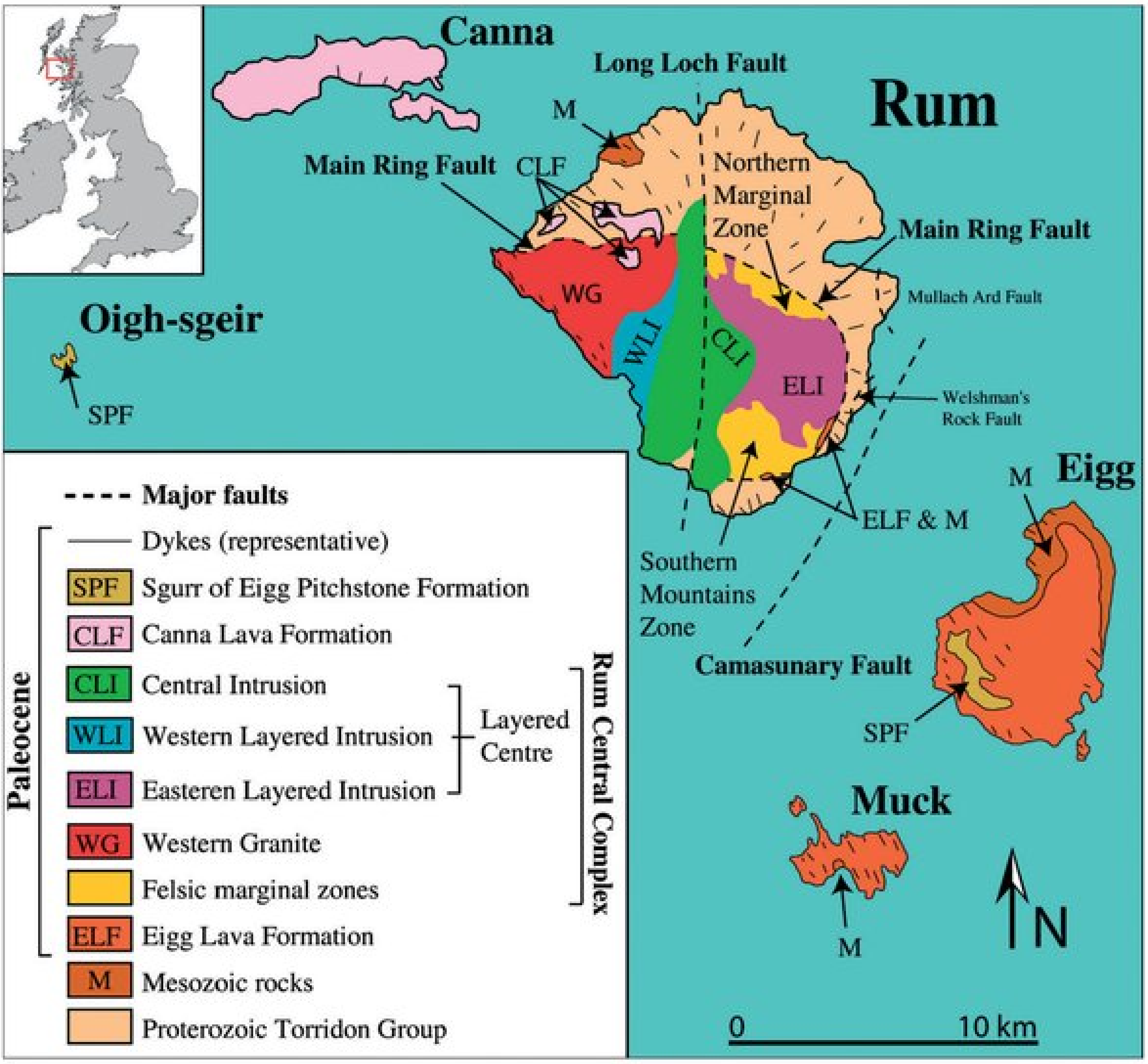
The Pleistocene and later

Rum was much affected by the Pleistocene glaciations and retains a record extending from at least 30,000 BP to the Holocene (Peacock, in Emeleus, 1997). The Main Late Devensian Glaciation enveloped Rum, when only the highest peaks formed nunataks. From the distribution of glacial striae and mainland erratics (mica schist and garnetiferous gneiss), which occur at heights of over 500 m on Barkeval and Ard Nev, it is concluded that the mainland ice sheet covered much of Rum except where diverted by local ice centred on the highest peaks. Prominent rock benches and sea cliffs are a feature of the western Rum coastline between Harris and A' Bhrìdeanach (Excursion 4b) and are present also in eastern Rum, north and south of Loch Scresort. The benches formed when sea level was appreciably higher than at present. In places they are covered by glacial deposits and they are therefore considered to be of pre-Late Devensian age. Other shoreline features of later date were formed during the Windermere (Late-glacial) Interstadial (*c*.14,700 BP). These include the small raised-beach deposits near Guirdil and those backing bays between Loch Scresort and Kilmory.

The most spectacular deposits dating from this time are the raised storm beaches at Harris Bay (Excursion 4b). Rum was the centre of a local glaciation during the Loch Lomond Stadial (*c*.13,000 BP). Numerous small corrie glaciers filled the valleys and clung to the hillsides, leaving moraines and hummocky till deposits.

Man inhabited Rum from an early date, and discovered bloodstone, a green-coloured chalcedonic form of silica with flecks of red, oxidised pyrite. The bloodstone, which is found in fissures and cavities in flows of the Upper Fionchra Member of the Canna Lava Formation, was brought from Bloodstone Hill to a site at Kinloch where numerous fragments have been recovered from a site and dated at about 8,500 BP (Wickham-Jones and Woodman, 1998). During the nineteenth century there was a fashion for items of jewellery made from bloodstone and the Rum deposits were worked once more. However, because of their precarious situation high on the cliffs at Bloodstone Hill, the workings were completely closed off. The best present-day source of bloodstone, and small banded agates, is in the beach gravels close to the Guirdil bothy.

References

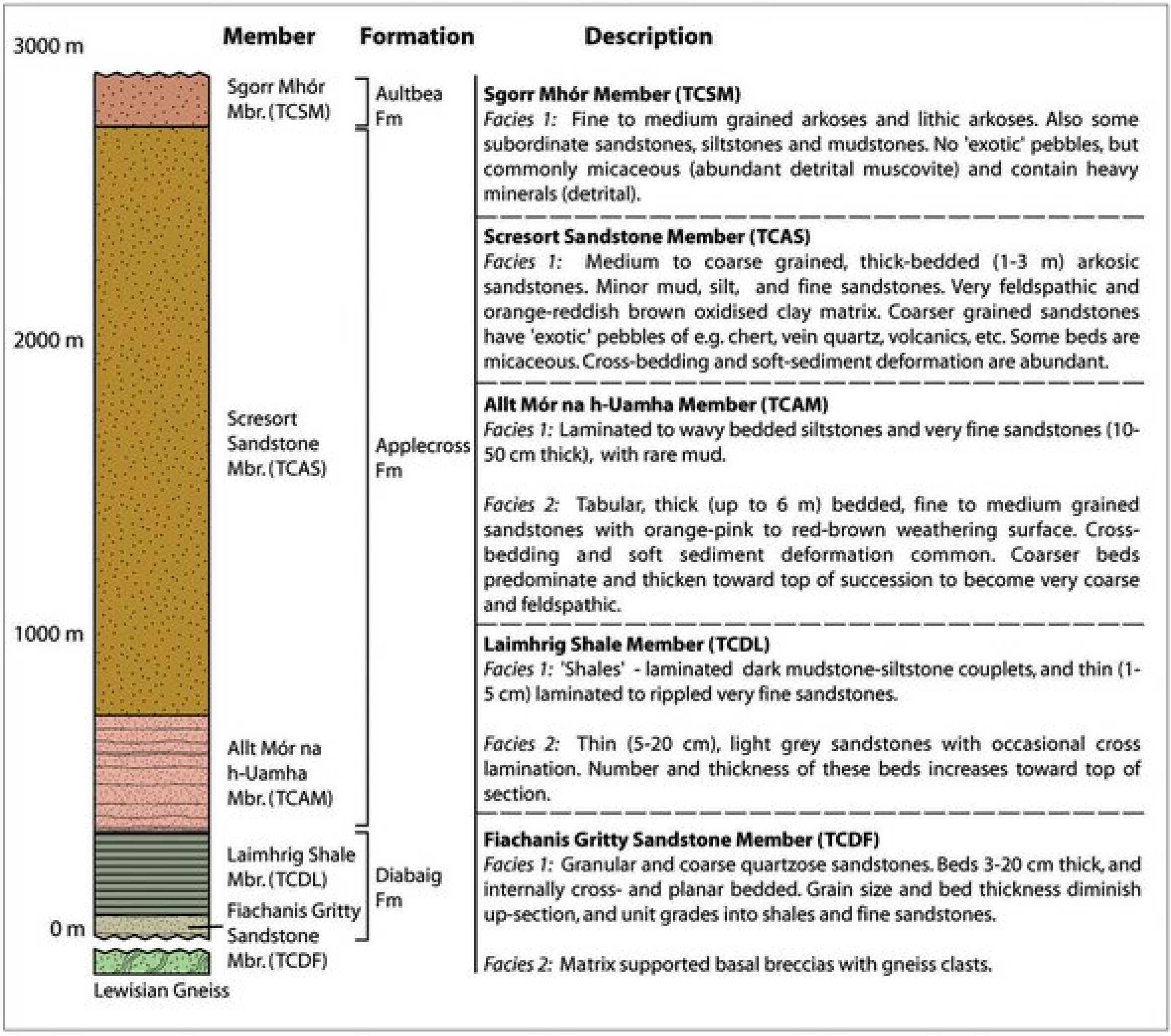


(Figure 2) Simplified geological map of Rum and adjacent islands.

Table 1: Sequence of faulting, folding and intrusion in the Rum Central Complex

1. Pre-Palaeogene: tilt to west of Triassic and Torridonian strata; faulting in these successions; early movement on the Long Loch Fault?
2. Doming of the Torridonian strata around the central complex accompanied initial uplift, with formation of the Welshman's Rock and Mullach Ard faults as country rocks slid off the dome. Fault blocks broke up and behaved independently, the Welshman's Rock block rotating *c.*90°.
3. Initial uplift on the Main Ring Fault (MRF): Lewisian and basal Torridonian uplifted by as much as 2 km, also tilting of elevated block to the east.
4. Subsidence on the MRF: eruption of rhyodacite ash flows, intrusion of rhyodacite along the MRF, intrusion of tuffisites, collapse of caldera walls to form breccias and megabreccias, intrusion of the Am Màm Breccias; subsidence brings Broadford Beds and Eigg Lava Formation flows down *c.*1 km within the MRF.
5. Emplacement of the Western Granite (may have been associated with movement that formed the inner component of the MRF).
6. Final uplift on the MRF (inner component).
7. Emplacement of radial dykes, regional north-west-trending dykes, and cone sheets.
8. Formation of a Loch Scresort–Glen Shellesder Fault?
9. Emplacement of the Eastern and Western layered intrusions.
10. Emplacement of the Central Intrusion – re-activation of the Long Loch Fault?
11. Small radial faults within the Central Intrusion and Eastern layered intrusion.
12. Accumulation of the Canna Lava Formation (Skye Lava Group), with concomitant erosion of the Rum Central Complex.
13. Long Loch Fault (final movement); faults in Canna Lava Formation.

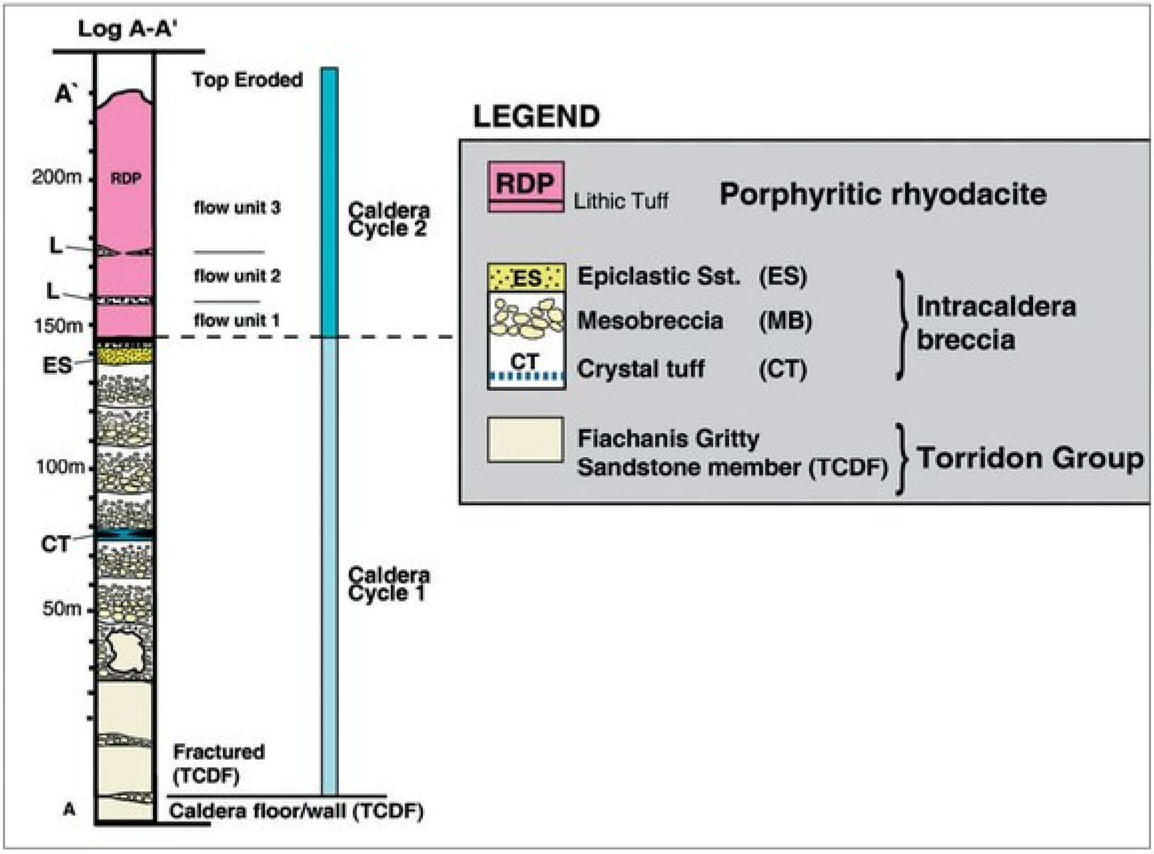
(Table 1) Sequence of faulting, folding and intrusion in the Rum Central Complex.



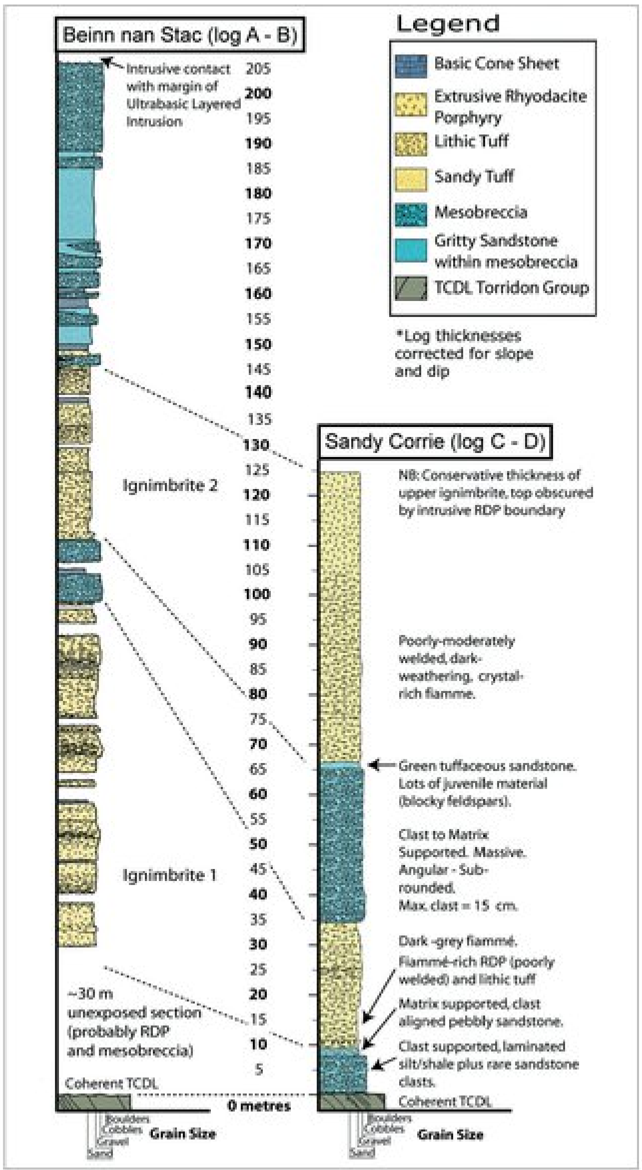
(Figure 3) Stratigraphy of the Torridon Group on Rum (after Nicholson, 1992).

(Figure 11) Regular west-north-west-dipping Torridonian sandstone beds on Mullach Mòr, with the Skye Cuillin in the distance.

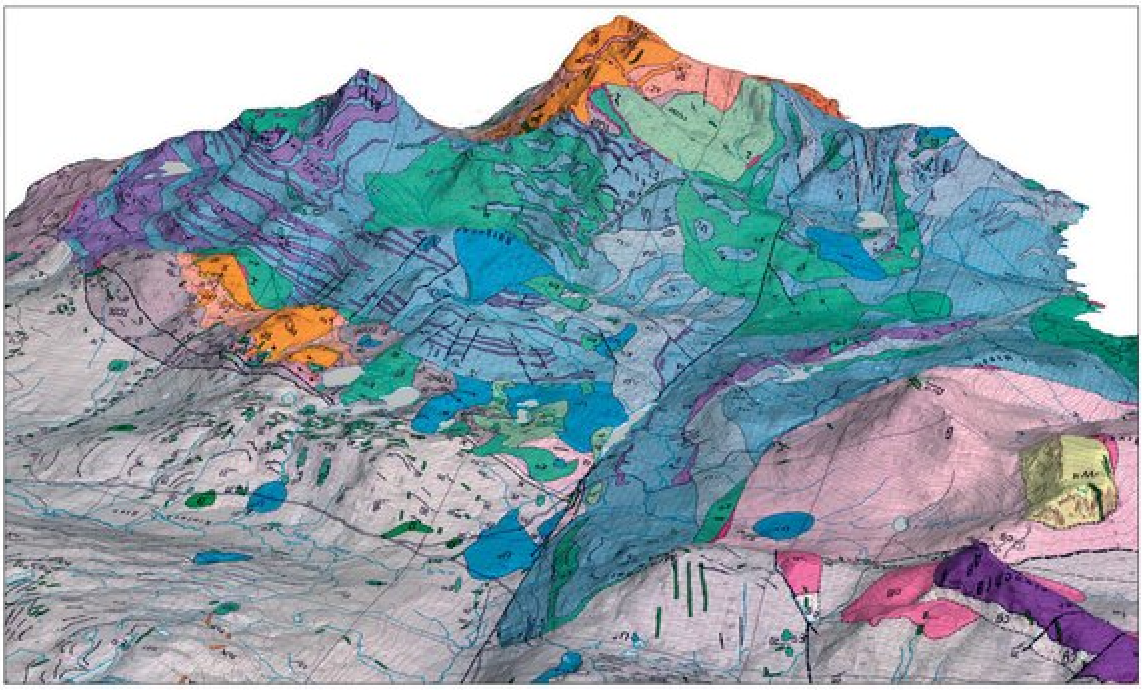
(Figure 4) Panoramic views of the Northern Marginal Zone and Southern Mountains Zone: a. Coire Dubh area with Cnapan Breaca and Hallival, viewed from the north-west. Rocks of the Northern Marginal Zone form the low foreground (Coire Dubh Breccia) and the pale crags and exposures on Cnapan Breaca (centre; rhyodacite ash flows). The base of the crags on Cnapan Breaca marks the position of bedded tuffs and fine-grained sandstone. The Marginal Gabbro of the Eastern Layered Intrusion forms the grassy area on the right-hand flank of Cnapan Breaca, and the terraced slopes leading up to Hallival mark the positions of 'allivalite' (bytownite troctolite) in layered units in this intrusion. a. Dibidil river valley. Rhyodacite ignimbrite sheets and sedimentary breccias make up the back wall of Nameless Corrie and the ridge to Ainshval on the left of the photograph. Layered units in the Eastern Layered Intrusion form the distinctive peak of Trollaval in the far centre. Faulted Lewisian gneisses and Torridonian sandstones crop out along the foreshore to the right.



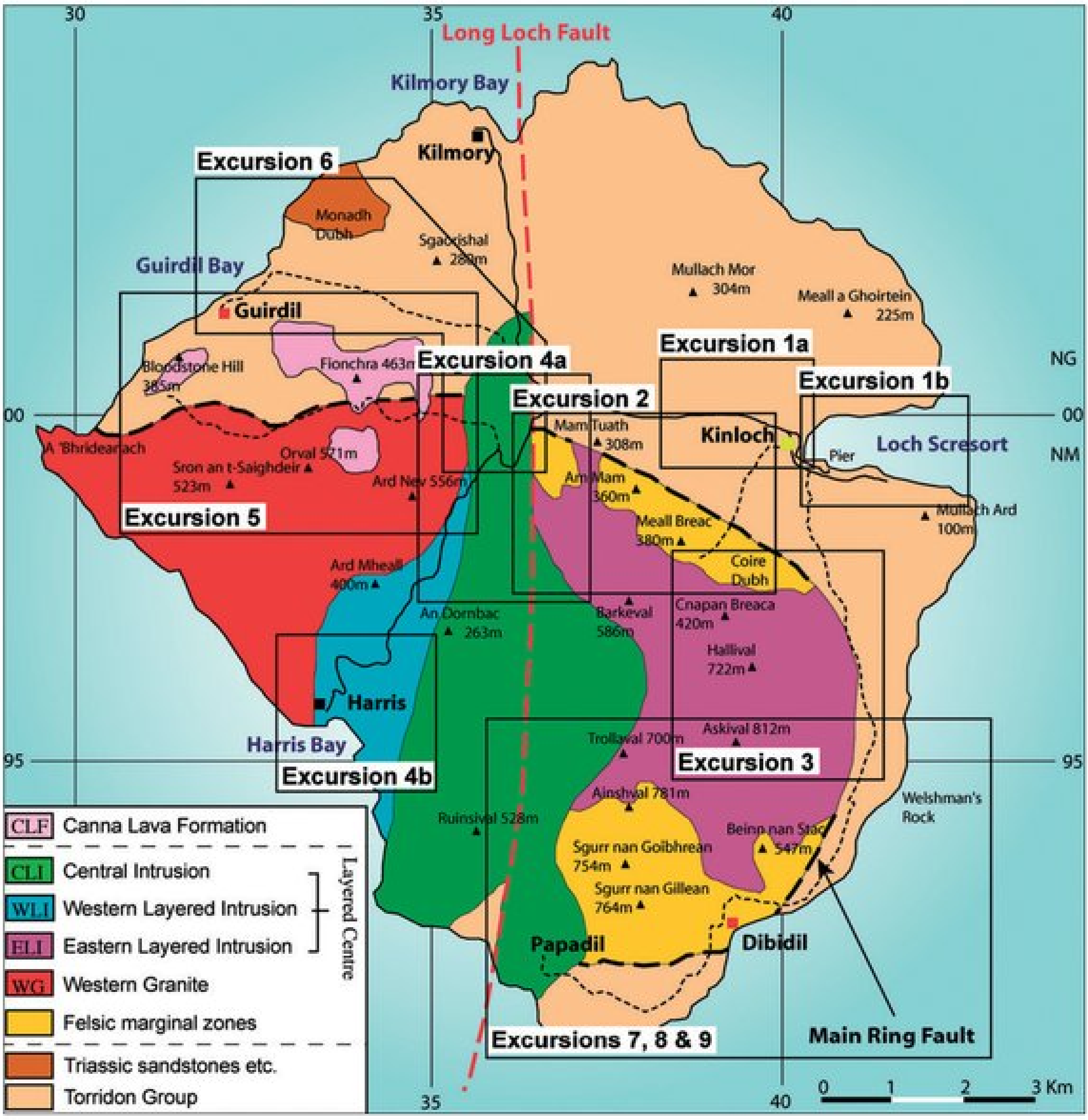
(Figure 15) Stratigraphical column of the Coire Dubh intra-caldera succession (simplified after Troll et al., 2000).



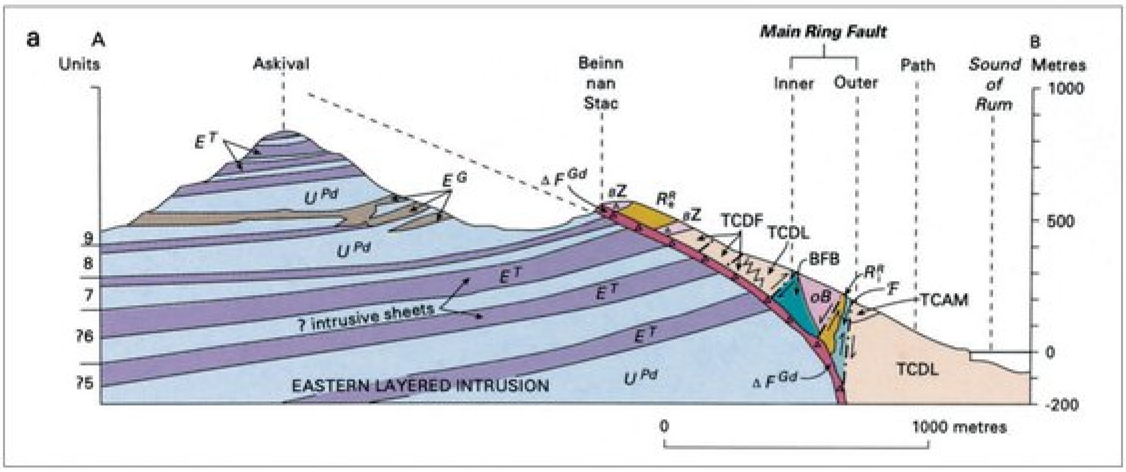
(Figure 70) Schematic log of caldera-fill ignimbrite successions on Beinn nan Stac and in Sandy Corrie (see (Figure 62) for log lines).



(Figure 6) Geological map draped over topography. Oblique view from the north-west (© Crown copyright/database right 2004; an Ordnance Survey/[Datacentre] supplied service. Courtesy of J. Barraud). The central complex is separated from the Torridonian country rock by a topographic shoulder that is also a geological boundary marking the Main Ring Fault. Note the pink and orange colours of Stage 1 rocks (rhyodacites and microgranites) being underlain and intruded by the ultrabasic rocks of Stage 2. Post- central complex igneous activity is marked by strong erosion and deposition of lavas of the Canna Lava Formation on the Western Granite and the MRF. ((Key) based on SNH 1:20,000 solid geology map; © SNH.)



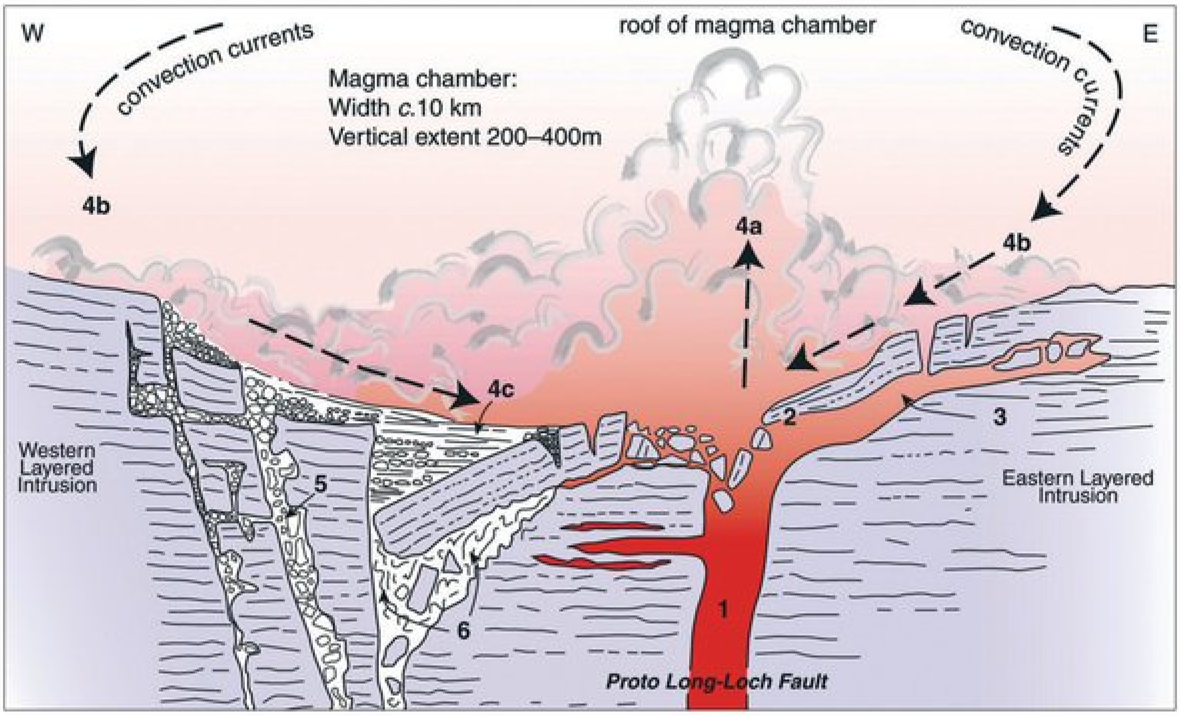
(Figure 9) Map of Rum showing the location of each excursion as a box.



(Figure 8) Cross-section through the south-east portion of the Rum Central Complex (Askival–Beinn nan Stac–Sound of Rum), illustrating relationships and tectonics along the Main Ring Fault system, after Emeleus (1997) (see pp. 148–49 for full (Key).) (© NERC)

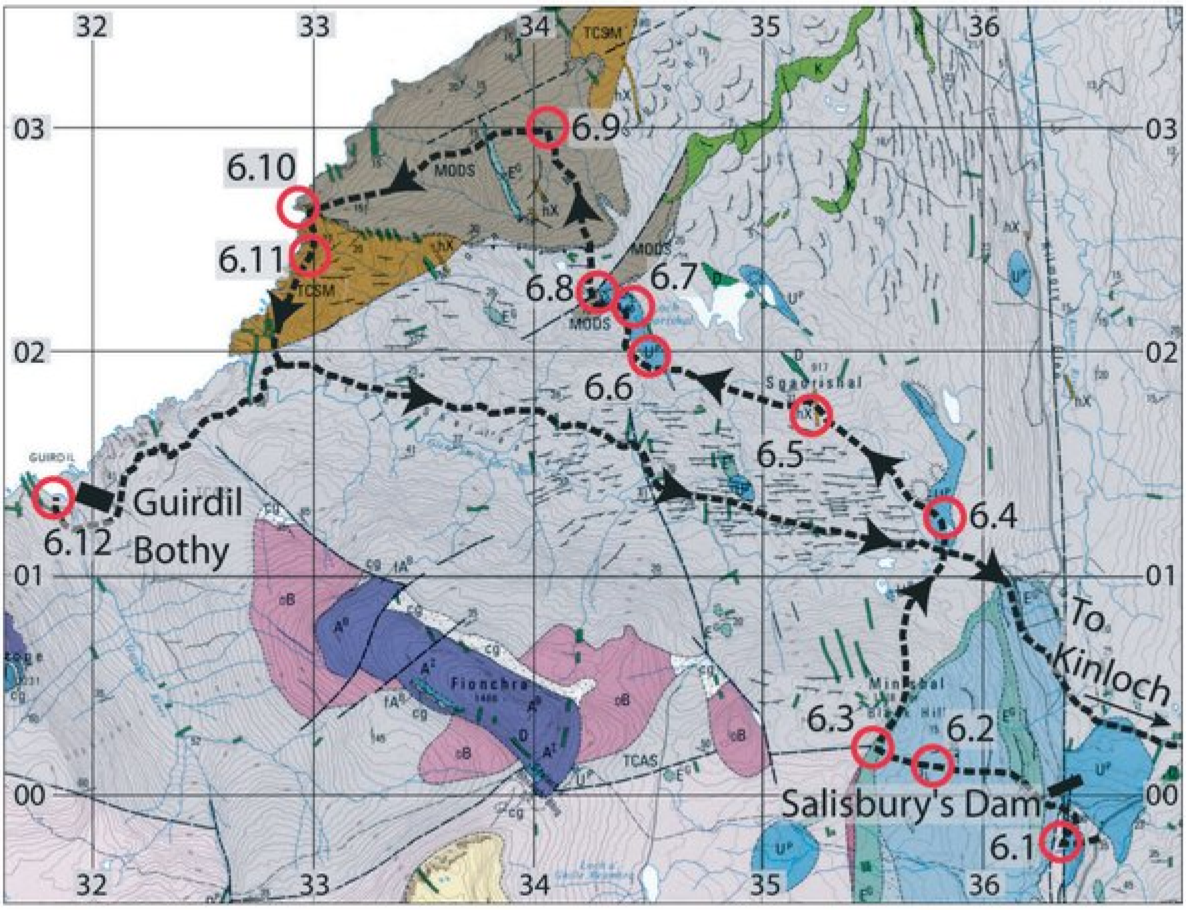
(Figure 5) Intricate layering in troctolites (allivalites), showing sedimentary-style features in the Central Intrusion. Locality 4.4, west of the Long Loch, central Rum. Scale: hammer shaft 30 cm. (ELI), the Western Layered Intrusion (WLI), and the Central Intrusion (CI) (Figure 2) and (Figure 6).

(Figure 31) View of west-dipping layered units in the upper part of the Eastern Layered Intrusion, south side of Hallival. Scale: about 120 m from grassy col to Hallival summit. Photo taken from Askival.



(Figure 43) Schematic representation of possible events leading to the formation of the Central Intrusion. Periodic replenishments of picritic magma (1) rejuvenated the magma chamber causing sliding and slumping (2) and intruded laterally into earlier cumulates (3). Magma fountaining into the chamber (4a) flows off the roof and down the sides as crystal-laden, gravity-driven currents (4b), dislodging crystal mushes as they move, then spread across the floor, reworking cumulate debris and depositing this material and primary crystals on the floor (4c). Movement on faults was accompanied by magma injection, thermal erosion of earlier rocks and their fragmentation to form breccia zones (5). Slides of coherent blocks of cumulate across partly liquefied cumulate led to spectacular slump mélanges (6). (Emeleus et al. [1996]. After Emeleus and Bell [2005].) (© NERC)

(Figure 7) Harrisitic olivines in the Central Intrusion. Individual crystals may reach over 60 cm in length. See text for details.



(Figure 58) Geological map of the north end of the Central Intrusion, Minishal and the country around Sgaorishal and the north-west coast of Rum. Excursion 6. (See pp. 148–49 for full (Key); based on SNH 1:20,000 solid geology map; © SNH.)