The Fascadale Fault: A tectonic link between the Cenozoic volcanic centres of Rum and Ardnamurchan, Scotland, revealed by multibeam survey

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Synopsis

Current geological maps of the Ardnamurchan Central Complex show the Fascadale Fault as a short (1.2 km) NW-trending tectonic junction between a sliver of the superstructure of the former Cenozoic volcano and the western margin of its outermost quartz-gabbroic intrusion. To the south, the mapped fault appears to die out in an area of coalescing basic igneous intrusions, whereas to the north, it is buried by alluvium before passing offshore into Fascadale Bay. Detailed bathymetric data obtained from a marine multibeam echo-sounder survey north of the Ardnamurchan peninsula reveal that the onshore fault is in structural continuity with a similarly-trending linear bathymetric feature, which extends almost to the island of Rum. Sea-bed geological structures offset by this major lineament suggest that the segment of the Fascadale Fault mapped onshore marks the southern end of a Cenozoic dextral strike-slip fault (>22 km long), which extends between Ardnamurchan and Rum. Based on these observations, a tectonic model is outlined that suggests that the sites of volcanic centres in the British part of the North Atlantic Igneous Province are controlled by the interaction of NW-trending structures, like the Fascadale Fault, with NNE-trending (Caledonoid) structures in a Cenozoic strike-slip regime.

Introduction

Geophysical methods have been widely used on the UK continental shelf to investigate the structure and distribution of volcanism in the Hebridean Igneous Province, which constitutes the British part of the North Atlantic Igneous Province (Fig. 1). Offshore volcanic centres and their associated dyke swarms were first identified with the aid of gravity and magnetic data (Bullerwell 1972; McQuillin et al. 1975; Ofoegbu and Bott 1985). Later, 2D seismic reflection profiles, largely acquired in the course of hydrocarbon exploration, were used to map buried volcanoes and sills west of Shetland (Gatliff et al. 1984; Evans et al. 1989; Abraham and Ritchie 1991; Ritchie et al. 2010). More recently, 3D seismic reflection data from the Faroe-Shetland and Rockall basins have been used to study the detailed morphology of transgressive basic intrusions at depth (Davies et al. 2002; Thomson and Hutton 2004). This paper uses a new type of marine geophysical data to interpret the tectonics of Cenozoic volcanism in the Inner Hebrides Basin, NW Scotland.

The data consist of the processed results of a swath bathymetry survey carried out immediately north of the Ardnamurchan peninsula, the site of the only mainland Cenozoic volcanic centre in the UK (Richey and Thomas 1930; Emeleus and Bell 2005). The measurements of sea-floor depth were acquired using a multibeam echo-sounder system in 2008-2009, as part of the Civil Hydrography Programme on behalf of the Maritime and Coastguard Agency. The survey, identified as HI (Hydrographic Instruction) 1257, covers an area of approximately 760 km^2. It is centred on the islands of Eigg and Muck and extends westwards from the coast of the Scottish mainland around Arisaig to the southern shore of Rum (Fig. 2). Swath bathymetry systems are designed to provide a detailed estimate of sea-floor depth along a ribbon-shaped area (or 'swath') at right angles to the movement direction of a vessel-borne sonar transducer. Survey data are processed to create an areal image of the sea floor in the form of a colour-banded and light-illuminated Digital Terrain Model (DTM) that can be incorporated in standard digital mapping packages. The current work used Fledermaus software to display the sea-floor bathymetry and ArcGIS software to compare it with layers of extant bathymetric data, onshore digital terrain data and images of published geological maps (British Geological Survey 1986; 1987a; b). British Geological Survey (BGS) offshore solid geology maps were formerly compiled by combining gravity, magnetic and other geophysical data (largely obtained from sparker records), with the stratigraphical results of boreholes acquired during a marine shallow drilling programme. Multibeam data can be used to constrain some of these earlier interpretations.

Geological interpretation of Eigg multibeam data

The main geological features revealed by the multibeam survey are reviewed and compared with previous interpretations of the sea-floor solid geology, leading to a discussion of the implications of the new observations for Cenozoic volcanism and tectonics.

Moine platform, Sound of Arisaig

The sea-floor image shows that the nearshore area of the mainland around the Sound of Arisaig is a shallow platform with a high proportion of rocky outcrop. The broadly N-S trends in the platform rocks (Fig. 3) are consistent with the regional strike of the metamorphic rocks of the Moine Supergroup in the adjoining onshore area, although the presence of basic dykes linked to the Cenozoic volcanism on Skye (Speight et al. 1982) is also likely to impose a northerly trend on the outcrop. Prominent ESE-trending faults that intersect the Moine rocks form a conjugate set with less well-developed ENE-trending structures (Fig. 3). Some of these inferred offshore faults pass into lineaments revealed by the onshore digital terrain model. The age of these faults is not known, but they may be tectonically linked to a narrow and slightly sinuous E-W-trending submarine ridge near the centre of the Sound of Arisaig. This ridge has a similar orientation to the end-Carboniferous dykes that are widely intruded in Central Scotland and adjoining areas. A median trend of 280ºN for these dykes has been recorded in the region of Ardnamurchan and Moidart (Speight and Mitchell 1979). It has been suggested previously (British Geological Survey 1986) that the orientation of the Muck Deep, a glacially over-deepened marine trough whose head lies at the western margin of the survey area (Fig. 2), might be related in part to buried E-W-trending structures of Carboniferous age.

Torridonian platform, south of Rum

The island of Rum is dominated by the outcrop of a deeply eroded Cenozoic central complex, which is intruded into a 2.5 km-thick, WNW-dipping succession of Neoproterozoic breccias, sandstones and siltstones of the Torridon Group (Emeleus 1997; Emeleus and Troll 2008). Well exposed in the north of the island, the Torridon Group is more sporadically preserved in the south, where it is disrupted by Cenozoic intrusions and a set of ring faults that originated during the growth and collapse of the Rum central volcano. In places within the ring faults, the basal breccias of the Torridonian can be seen to rest unconformably upon Lewisian gneiss. The sea-floor image shows that the Torridonian outcrop in the southern promontory of Rum between Papadil and Dibidil continues to the south in a nearshore rocky platform (Fig.4). Cutting across the middle of the platform, a north-south-trending submarine gully marks the buried prolongation of the Long Loch Fault, a major dextral transtensional structure, which crosses Rum from north to south and displaces some components of the Cenozoic central complex (Emeleus 1997).

To the south-east of the Long Loch Fault, sparse rock outcrops are scattered across the sea floor as far as the Camasunary Fault, which is marked by a linear NNE-trending submarine escarpment. The Camasunary Fault extends northwards beyond the area of the survey towards Skye, where it forms the boundary of a westerly-dipping half-graben filled with Mesozoic sedimentary rocks (Fig. 1; Hesselbo et al. 1998). Onshore in the south of Skye, it passes between the silicic and basic components of the Cenozoic central complex near Blaven (Butler and Hutton 1994).

West and north-west of the Long Loch fault trace, the platform south of Rum becomes more difficult to interpret. The presence of curvilinear escarpments between rock outcrops and areas of featureless sea floor suggests that some of the local structure is probably related to the southern margin of the Rum Central Complex. Further south, Quaternary and Recent sediments mantle the sea floor and mask the underlying Torridonian, although a westerly-dipping Mesozoic sedimentary succession from the Sea of Hebrides Basin may form a feather edge, similar to the onshore Triassic sequence that onlaps the western flank of Rum (Emeleus 1997). In the south-western part of the survey area, the Torridonian possibly reappears in sea-floor outcrops around the head of the Muck Deep (Fig. 2). Here the rocks are cut by ESE-trending joints and there is a trace of a possible NW-dipping stratigraphy, similar to that of the Torridonian in the north of Rum.

Mesozoic sedimentary rocks of the Inner Hebrides Basin, Sound of Arisaig

The base of the Mesozoic succession in the Inner Hebrides Basin is exposed on Ardnamuchan, where it consists of conglomerates, sandstones, siltstones and thin interbedded continental carbonate rocks (cornstones) of Triassic age. At the western margin of the nearshore platform in the Sound of Arisaig, the sea-floor image shows an apparently bedded, westerly-dipping succession resting unconformably on the Moine (Fig. 3). This succession may also be of Triassic age, as it lies along strike from Triassic outcrops on the northern coast of Ardnamurchan (Richey and Thomas 1930; Gribble et al. 1976), but an alternative origin, as sills or other inclined basic intrusions of Cenozoic age, cannot be ruled out.

As water depth increases between the mainland and the island of Eigg, the sea bed beyond the rocky coastal platform becomes smooth and largely devoid of bedrock outcrop. The sea-floor image reveals a series of long wavelength bedforms with a NNE-trending strike, and sparker records confirm the presence of a cover of Quaternary and Recent sediments, in places more than 120 m thick (British Geological Survey 1987b). On closer inspection, the narrow troughs between the broad crests of the bedforms contain small, regularly-spaced pock-mark features that commonly form short linear chains (Fig. 5). Pock marks are often associated with the release of biogenic or thermogenic gas, and in this case may indicate the presence of hydrocarbon source rocks in a buried Jurassic succession. Liassic organic-rich sedimentary rocks are known from outcrops elsewhere in the Inner Hebrides Basin (Hesselbo et al. 1998).

Jurassic sedimentary rocks and Cenozoic basic intrusions, East of Eigg

A set of irregularly-shaped tabular rocky outcrops emerges on the sea floor off the eastern coast of Eigg from beneath the cover of Quaternary and later sediments (Fig. 5). The outcrops lie along the strike of the Inner Hebrides Basin and are interpreted as one or more Cenozoic sills intruded into the Jurassic basin fill. A borehole in this area (British Geological Survey 1986) recovered a section of coarse ophitic olivine basalt. A shallow saucer-like depression in the top of the largest of these bodies compares closely with the architecture of basic sills of the same age elsewhere in the igneous province, which have been mapped using 3D seismic data (Davies et al. 2002; Thomson and Hutton 2004). Similar sills crop out onshore along the north-eastern coast of Eigg, beneath the escarpment formed by the Eigg Lava Formation (Emeleus 1997). On the north-east coast of Skye, the Kilt Rock is a basic intrusion emplaced in an analogous stratigraphical position in a Jurassic succession, close below Cenozoic basaltic lavas of the Skye Lava Group (Emeleus and Bell 2005; Chambers et al. 2005).

Two kilometres north of Fascadale Bay, Ardnamurchan, a curved fan of NW-dipping sea bed features is interpreted as stack of Cenozoic basic sills intruded into the Jurassic succession of the Inner Hebrides Basin (Fig. 6), although comparison with the onshore volcanic structure of Ben Hiant (British Geological Survey 2009) suggests that other more complex interpretations are possible. The sills are cut by a set of ESE-trending faults and lie beneath the Paleocene Eigg Lava Formation that forms a lobe-like feature on the sea floor further to the north-west. Any Jurassic sedimentary rocks interleaved with the sills are likely to post-date the Blue Lias and Pabay Shale formations that crop out on the coast of Ardnamurchan (British Geological Survey 2009). Their possible equivalents along strike on Eigg are largely assigned to the Mid-Jurassic Great Estuarine Group. In the north of the island, beneath the basal Cretaceous unconformity, the younger Staffin Shale Formation (Callovian-Oxfordian) is preserved locally (Emeleus 1997).

A group of dolerite intrusions that make up the headlands east of Fascadale Bay can be seen to continue offshore as narrow segments of a sea-floor ridge that curves gently to the west around the Ardnamurchan Central Complex, before burial by Quaternary and later sediments in the Sound of Arisaig. These Cenozoic intrusions probably dip steeply to the west and cut across the strike of the Jurassic strata in the Inner Hebrides Basin at a high angle.

Jurassic sedimentary rocks and Cenozoic basic intrusions, south of Muck

The deepest part of the sea floor within the area of the survey lies to the south of Muck, where the cover of Quaternary to Recent sediments in the Inner Hebrides Basin is thinner than that further to the north-east (Fig. 7). Here the sea-floor image reveals sparse rocky outcrops, probably composed of Jurassic sedimentary rocks, that dip westwards beneath a submarine platform capped by rocks interpreted as the Eigg Lava Formation. Rock outcrop is more widespread further south, closer to the coast of Ardnamurchan (Fig.6), where the nearshore platform consists of closely spaced curved ridges concentric with the gabbro and dolerite ring-intrusions of Ardnamurchan Centre 2 exposed onshore (British Geological Survey 2009). Some of the coastal platform rocks may be equivalent to the Mull Plateau Lava Formation, a succession of basaltic lavas overlain by and interbedded with widespread breccias deposited during the mass-wasting of the superstructure of the original Ardnamurchan volcano (Brown and Bell 2006; 2007; Brown et al. 2009).

Eigg Lava Formation platforms, Eigg and Muck

At the centre of the multibeam survey area, a continuous shallow rock platform around Muck and south of Eigg is interpreted as consisting mainly of Cenozoic basaltic lavas of the Eigg Lava Formation (Figs. 2; 7; Emeleus 1997). South-west of Muck, the sea-floor image shows evidence of gently-curving strike in a series of northerly-dipping supposed volcanic rocks, while the eastern margin of the rocky platform is marked by a sinuous escarpment facing the deeper waters of the Inner Hebrides Basin (Fig. 7). The scalloped edge of the escarpment closely resembles the morphology of the Quiraing area of the Trotternish peninsula of northern Skye, where tilted blocks of the Skye Lava Group have detached and collapsed over the underlying Jurassic succession to leave a series of coalescing slump scars (Harker 1904; Emeleus and Bell 2005). Muck consists almost entirely of Cenozoic volcanic rocks (up to 140 m thick), with a small area of the Jurassic rocks beneath exposed in a bay on the southern coast (Emeleus 1997). It has been estimated that more than 8% extension would have been required within the lava pile on the island to accommodate the volume of Cenozoic basic intrusions (Speight et al. 1982)

Further north, the Eigg Lava Formation escarpment emerges from the sea along the eastern coast of Eigg where it forms an east-facing cliff (Fig. 5). Onshore, the pile of lavas is up to 400 m thick and dips gently (<5º) to the south-west. South of Eigg, the sea-floor image shows the margin of the lava platform extending in two broad lobes towards Ardnamurchan (Figs. 6; 7).

A possible occurrence of the Sgurr of Eigg Pitchstone Formation, SW of Muck

South of Muck, the sea-floor image shows a sinuous ridge (> 5 km long and ~ 15 m high) resembling a meandering channel (Fig.**7**) overlying the submarine platform. Comparison with the geology of Eigg suggests that this feature may be of volcanic origin. The summit of the Sgurr of Eigg, the highest point of the island, is a massive crag consisting of Cenozoic pitchstone that occupies a palaeo-valley cut into the top of the Eigg Lava Formation. In places, the pitchstone rests upon a patchily preserved fluvial conglomerate (Emeleus 1997). Elsewhere, it displays typical welded ignimbrite features, and it is now considered to have originated mainly as one or more valley-filling pyroclastic flows. A smaller outcrop of pitchstone is known from the islet of Oigh Sgeir, 18 km west of Rum (British Geological Survey 1986; Emeleus 1997). Radiometric age dates originally suggested that a lengthy episode of erosion separated these silicic and basic igneous episodes, but new analyses have indicated an age for the pitchstone on Eigg of 58.72 ± 0.07 Ma, only slightly younger than that of the base of basaltic lava succession at 60.44 ± 0.07 Ma (Chambers et al. 2005). Although valley-filling basaltic lavas are known on Skye and are likely to be widely developed in the Hebrides (Emeleus and Bell 2005), the geology of Sgurr of Eigg suggests that the sea-floor ridge south of Muck might be another example of inverted topography associated with the Sgurr of Eigg Pitchstone Formation.

The Fascadale Fault, a NW-trending structure between Ardnamurchan and Rum

The lava platforms around Eigg and Muck are separated by a conspicuous linear feature that extends more than 20 km north-westwards between Ardnamurchan and Rum (Figs. 2, 6-9). Along most of its length, this structure forms a SW-facing escarpment that sharply truncates minor bathymetric features of the Eigg lava platform (Figs. 7; 8). In contrast, immediately north of Ardnamurchan, the lineament consists of a NE-facing structure that dextrally offsets concentric features on the northern flanks of the Ardnamurchan Central Complex (Fig. 6). The preservation of a deep basin between Muck and Ardnamurchan suggests that the lineament acted as a barrier to the southward progradation of the Quaternary-Recent fill of the Inner Hebrides basin,

At the southern margin of the area, the lineament reaches the mainland in Fascadale Bay, where it is revealed to be an extension of the Fascadale Fault, a minor onshore structure that juxtaposes part of the superstructure of the Ardnamurchan Central Complex with some of its associated basic intrusions. The landward section of the Fascadale Fault in Ardnamurchan is only 1.2 km long, but 2 km to the east, the parallel Loch Mudle Fault can be traced across most of the peninsula (Figs. 6, 9; British Geological Survey 2009). Cenozoic faults comparable to the Fascadale Fault occur in the volcanic area of northern Skye, where the Loch Harport and Loch Snizort faults extend north-westwards from the Cuillin Centre and define a half-graben in the Skye lava field (Doubre and Geoffroy 2003). Elsewhere on Skye, a set of steep NW-trending transfer zones has been inferred to connect the NNE-trending Camasunary and Raasay faults through the Sound of Raasay (Butler and Hutton 1994). Major faults of similar trend occur nearby in parts of onshore NW Scotland and include the Loch Maree Fault, (Fig. 1; Peach et al. 1907; Stewart 1991) and the Langavat Shear-zone of South Harris (Graham 1980), which both have pre-Cenozoic histories as dextral strike-slip faults.

The Camasunary Fault is usually interpreted as the bounding fault of the Mesozoic Inner Hebrides Basin (Butler and Hutton 1994; England et al. 1993). The development of similar Mesozoic half-grabens on the continental shelf of NW Scotland has been related to the extensional reactivation of former Caledonian thrusts (Brewer and Smythe 1984; Evans 1997). The Sea of the Hebrides Basin (Fig. 1), for example, is bounded by the Minch Fault that is related to the reactivation of the Outer Isles Thrust (Butler and Hutton 1994). The trace of the late-Caledonian Moine Thrust must pass through the area covered by the Eigg multibeam survey. It is a cryptic structure to the south of Skye, but is inferred to cut through the Sound of Iona, west of Mull and, by extrapolation, probably lies beneath the middle of the Inner Hebrides Basin, east of Eigg (Thigpen et al. 2010). In the area of the current study, outcrops of Moine rocks are confined to the eastern part of Ardnamurchan and adjoining parts of the mainland (Fig. 3); in the west of the peninsula, the buried Moine Thrust might have exerted a structural control on the Ardnamurchan volcanic centres.

The Fascadale Fault cuts and offsets the lava platforms around Muck, Eigg and Ardnamurchan and is clearly of Cenozoic or later age. The new bathymetric data reveal that the Camasunary Fault is also likely to have been reactivated since the Mesozoic, as it forms a sea-floor escarpment that offsets the nearshore platform to the east of Rum. The angular relationship between the Fascadale Fault (~145ºN) and the Camasunary Fault (~ 25ºN) suggests that they are conjugate riedel shears. Sandbox experiments have demonstrated that such faults are commonly the first structures to form in strike-slip zones in the presence of a ductile horizon (Sims et al. 1999; Atmaoui et al. 2006). From the orientation of the riedel shears, it follows that the local direction of maximum horizontal stress during the early Cenozoic was ~175ºN. This is consistent with the orientation of the Long Loch Fault, a contemporaneous northerly-trending transtensional fault bisecting the island of Rum. Extension on the Long Loch Fault is thought to have controlled the intrusion of the main parts of the Rum Central Complex (Emeleus 1997). Sandbox experiments modelling the effects of volcanic loading have shown that the additional load of a volcanic pile can be sufficient to induce extensional faulting in a strike-slip zone, by supplementing the vertical intermediate stress (van Wyk de Vries and Merle 1998).

The direction of maximum horizontal stress deduced from the Cenozoic riedel shears is parallel to the Minch Dyke, a major basic intrusion (possibly more than 1 km wide) inferred from offshore geophysical data north of Skye (Ofoegbu and Bott 1985). It also corresponds to the orientation of a regional lineament between the focus of volcanism on the Faroe Islands (Waagstein 1988) and the main Cenozoic volcanic centres in the UK, stretching from Skye to the Cenozoic granite of Lundy in the Bristol Channel (Emeleus and Bell 2005). The common orientation of these structures differs from the direction of maximum horizontal stress calculated from regional dyke data by England (1988).

The multibeam survey shows that the onshore and offshore parts of the Fascadale Fault constitute a major structural feature (>22 km long) that forms a potential tectonic link between the Cenozoic central complexes of Ardnamurchan and Rum (Fig. 10). Although the trace of the Fascadale Fault apparently dies out north-westwards, before reaching the Camasunary Fault, its symmetrical relationship with the two igneous complexes, and the fact that it passes onshore into a structural boundary within the Ardnamurchan ring-intrusions, provides additional evidence for a genetic relationship between Palaeogene tectonism and volcanism.

It appears that a regional zig-zag pattern of conjugate faults can be traced through the Inner Hebrides, with central complexes developed close to fault intersections (Fig. 1). From northern Skye, a series of NW-trending faults within the lava field pass southwards into the Skye Central Complex. From there, the Camasunary Fault trends SSW and intersects the Fascadale Fault between the southern coast of Rum, and the thick Eigg Lava Formation preserved on Eigg. Extending northwards from this intersection, the Long Loch Fault is interpreted as an extensional structure, possibly induced by volcanic loading, which controlled the emplacement of the Rum Central Complex, while towards the SSE, the Fascadale Fault passes between the islands of Muck and Eigg before dying out onshore within the gabbroic-intrusions of Ardnamurchan Centre 3 (British Geological Survey 2009). Here the fault forms the contact between a normal gabbroic intrusion and a 'fluxion' gabbro, in which the plagioclase crystals have been aligned by flow during emplacement. It is possible that contemporaneous tectonic movements linked to the Fascadale Fault contributed to the formation of this distinctive igneous facies, although it is also known to occur elsewhere within the Centre 3 lopolith (O'Driscoll et al. 2006; O'Driscoll 2007). To the south of Ardnamurchan, a swarm of faults within the NW-trending Sound of Mull may provide a link with the Great Glen Fault, a major Caledonian structure, but this has yet to be investigated by multibeam data. If confirmed, the Mull Central Complex would lie close to the intersection of these faults. The Blackstones Bank is a large submarine central complex along the strike of the Caledonian structures SW of Mull (McQuillin et al. 1975; Dickin and Durant 2002).

The important position NW Scotland came to occupy in the development of ideas about volcanic structures was primarily a result of the geological mapping of the Cenozoic igneous complexes and lava fields of Skye, Rum, Ardnamurchan and Mull carried out by Harker (1904), Bailey et al. (1924) and Richey and Thomas (1930). Working partly from their observations in the Hebrides, Anderson (1936) explained the formation of cone-sheets and ring-dykes in terms of varying magmatic pressures, as volcanoes evolved from growth to collapse. Subsequent mapping revealed that the forms of the concentric intrusions and the nature of their bounding faults are not always consistent with these models (Phillips 1974; Walker 1975; 1993; O'Driscoll et al. 2006; O'Driscoll, 2007). The brief regional analysis presented here suggests that movement on the Fascadale Fault and on a series of related strike-slip and extensional faults, helped to accommodate the intrusion of the main central complexes in the Hebrides. This interpretation contrasts with those of Anderson (1936) and

Phillips (1974), in which uplift and subsidence associated with variations in magmatic pressure played the dominant role in the emplacement process.

Conclusions

The geological boundaries defined on earlier offshore maps of the area around Eigg (British Geological Survey 1986; 1987a; b) are broadly confirmed by the present multibeam survey. Some minor changes are required, particularly where the detailed bathymetry improves the resolution of the margins of the lava platform. The morphology of Cenozoic volcanic rocks at the sea floor suggests that sills, rather than lava flows, crop out east of Eigg, while a sinuous sea-floor ridge south of Muck may be formed by a new occurrence of the Sgurr of Eigg Pitchstone Formation. The Fascadale Fault is revealed as a major regional structure forming a possible conjugate of the Camasunary Fault. These faults are part of a regional system of intersecting riedel shears, which controlled the distribution and emplacement of Cenozoic central complexes in the Inner Hebrides by local extension in a strike-slip regime. This model may have implications for the location of similar concentric igneous intrusions and calderas elsewhere.

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Figures

Figure 1: A simplified geological map showing the distribution of Jurassic basins, major faults and Cenozoic central complexes around the Inner Hebrides Basin, NW Scotland (modified from British Geological Survey maps 1986; 1987; Hesselbo et al. 1998). The area of the Eigg multibeam survey is outlined. Faults: CMF Camasunary; CSF Colonsay; DAF Dubh Artach; FF Fascadale; GGF Great Glen; LMF Loch Maree; LHF Loch Harport; LNF Lennan; LSF Loch Snizort; MNF Minch; SCF Strathconnon; ?SMF Sound of Mull (conjectural); SVF Skerryvore.

Figure 2: A swath bathymetry image of the sea floor around Eigg obtained by a multibeam survey (Maritime and Coastguard Agency number HI 1257). A light-illuminated digital terrain model shows the topography of the adjacent onshore area. In this paper, the conspicuous NW-trending lineament halfway between the islands of Eigg and Muck is identified as an extension of the Fascadale Fault on the Ardnamurchan peninsula.

Figure 3: Swath bathymetry of the Sound of Arisaig, showing a nearshore platform interpreted as largely composed of Moine metamorphic rocks. Labelled features referred to in text; a) local northerly trend of Moine Supergroup and Cenozoic dykes; b) example of ESE-trending fault passing into onshore lineament; c) example of ENE-trending structure; d) E-W-trending sea floor ridge, possibly a dyke of Carboniferous age; e) Possible base of westerly-dipping Mesozoic sedimentary succession, unconformable on Moine rocks.

Figure 4: Swath bathymetry of the sea floor south of Rum, showing a rocky nearshore platform contiguous with the outcrop of Torridonian rocks between Dibidil (D) and Papdil (P). A sediment-filled gully marks the offshore extension of the Long Loch Fault (LLF). The position of the Camasunary Fault (CMF) is defined by a submarine escarpment. Curved structures in the western part of the image may be linked to the Rum Central Complex that onshore is bounded by a set of concentric faults (RRF Rum Main Ring Fault).

Figure 5: Swath bathymetry of the sea floor east of Eigg. Most of the sea bed is mantled by a thick cover of Quaternary and Recent sediments that are prograding to the south across the Inner Hebrides Basin. Sets of pock marks are widely developed in the troughs between the crests of the bed forms, commonly in short linear chains, as indicated at P. These features are generally interpreted as a sign of fluid or gas escape. In this case, they may relate to the

presence of gas associated with organic-rich horizons in the rocks of early Jurassic age beneath. The offshore solid geology of this area largely consists of Cenozoic basic sills (S), although some interleaved Jurassic sedimentary rocks may crop out in places.

Figure 6: Swath bathymetry of the sea floor north of Fascadale Bay, Ardnamuchan. Area (a) is interpreted as a pile of NW-dipping Cenozoic basic sills interleaved with Lower and Middle Jurassic sedimentary rocks and cut by a set of ESE-trending faults. Area (b) is likely to consist of rocks of the Mull Lava Formation and basic ring-intrusions of the Ardnamurchan Central Complex, interleaved with Lower Jurassic sedimentary rocks. The Fascadale Fault is shown to continue offshore, where it truncates the sea-floor outcrop interpreted as the Eigg Lava Formation.

Figure 7: Swath bathymetry of the sea floor around Muck. The shallow rocky platform around the island is interpreted to consist largely of the Eigg Lava Formation and is separated from a similar platform south of Eigg by the Fascadale Fault. In area (a), gabbroic ring-intrusions of Ardnamurchan Centre 2 are likely to crop out on the nearshore platform around Ardnamurchan, while area (b) probably consists of Mull Lava Formation and associated doleritic cone sheets interleaved with Lower Jurassic sedimentary rocks. Feature (c) is a sinuous sea-floor ridge possibly forming an extension of the Sgurr of Eigg Pitchstone Formation, which crops out onshore as valley-filling pyroclastic flows (yellow polygon) at the Sgurr of Eigg. The bathymetric deep south of Muck appears starved of Quaternary sediment compared to the adjoining area of the Inner Hebrides Basin to the NE of the Fascadale Fault (Figs.5; 6).

Figure 8: A 3D perspective view of the swath bathymetry between Ardnamurchan and Rum, looking along the trace of the Fascadale Fault (trending ~145ºN).

Figure 9: Summary map of selected elements of the offshore solid geology around Eigg, based on the swath bathymetry of the sea floor. Onshore geological boundaries are taken from British Geological Survey maps (1986; 2009). Also shown are the positions of the more detailed bathymetric images (Figs. 3-7).

Figure 10: Simplified structural setting of the Rum and Ardnamurchan central complexes. The Fascadale and Camasunary faults are interpreted as conjugate riedel shears, with the Long Loch Fault forming as a predominantly extensional structure, possibly in response to loading caused by the Eigg Lava Formation. The Minch Fault is a Mesozoic basin-bounding

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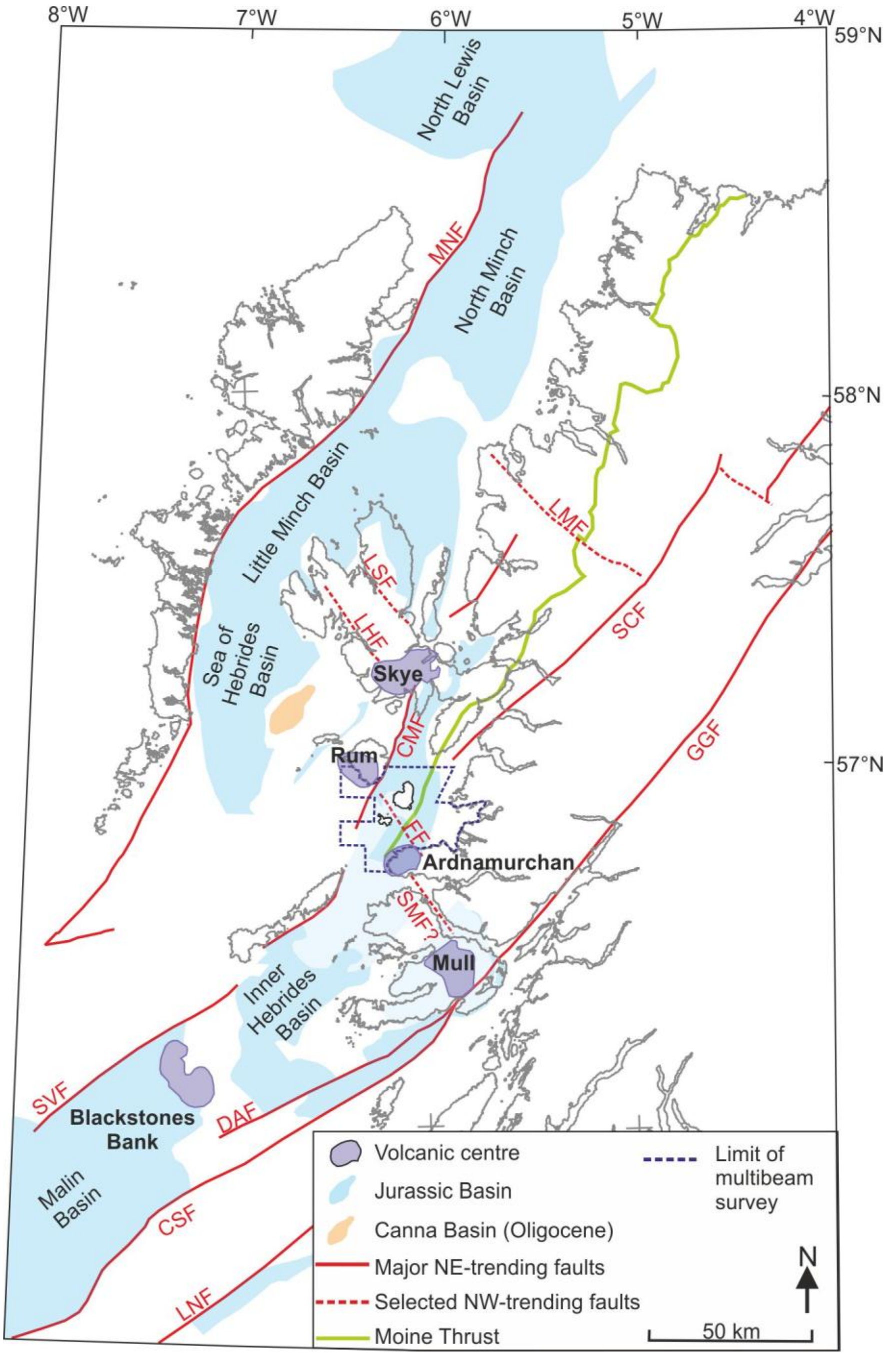

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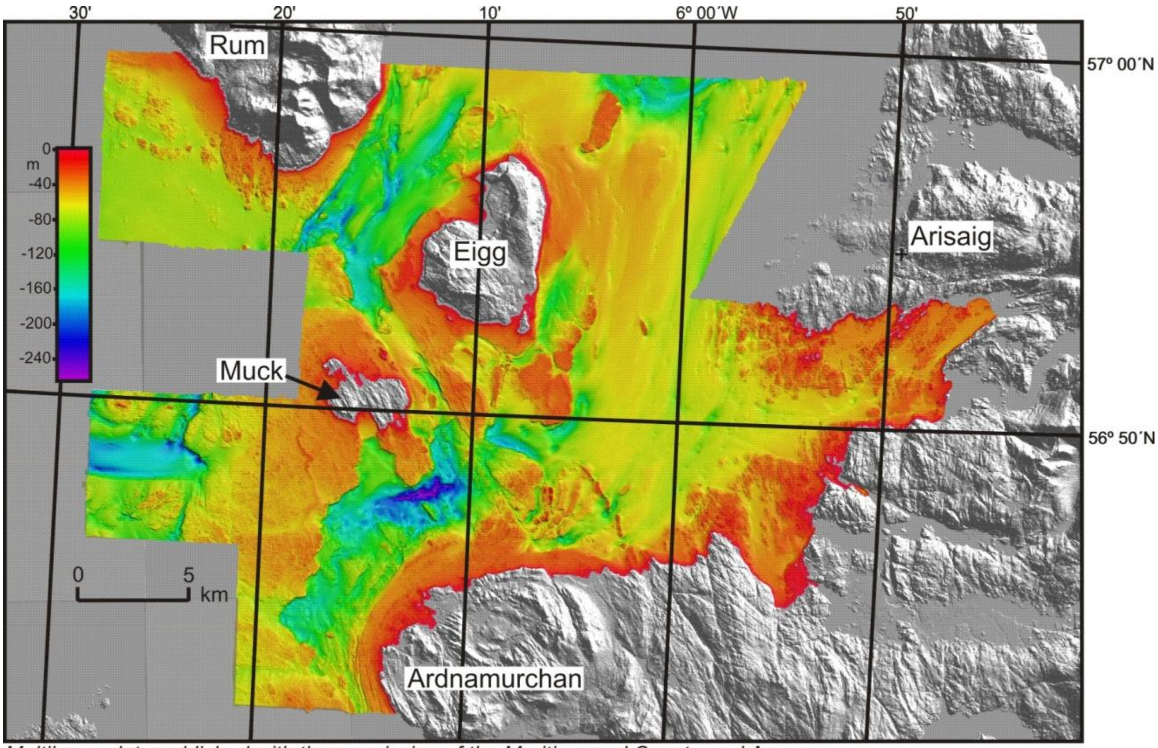

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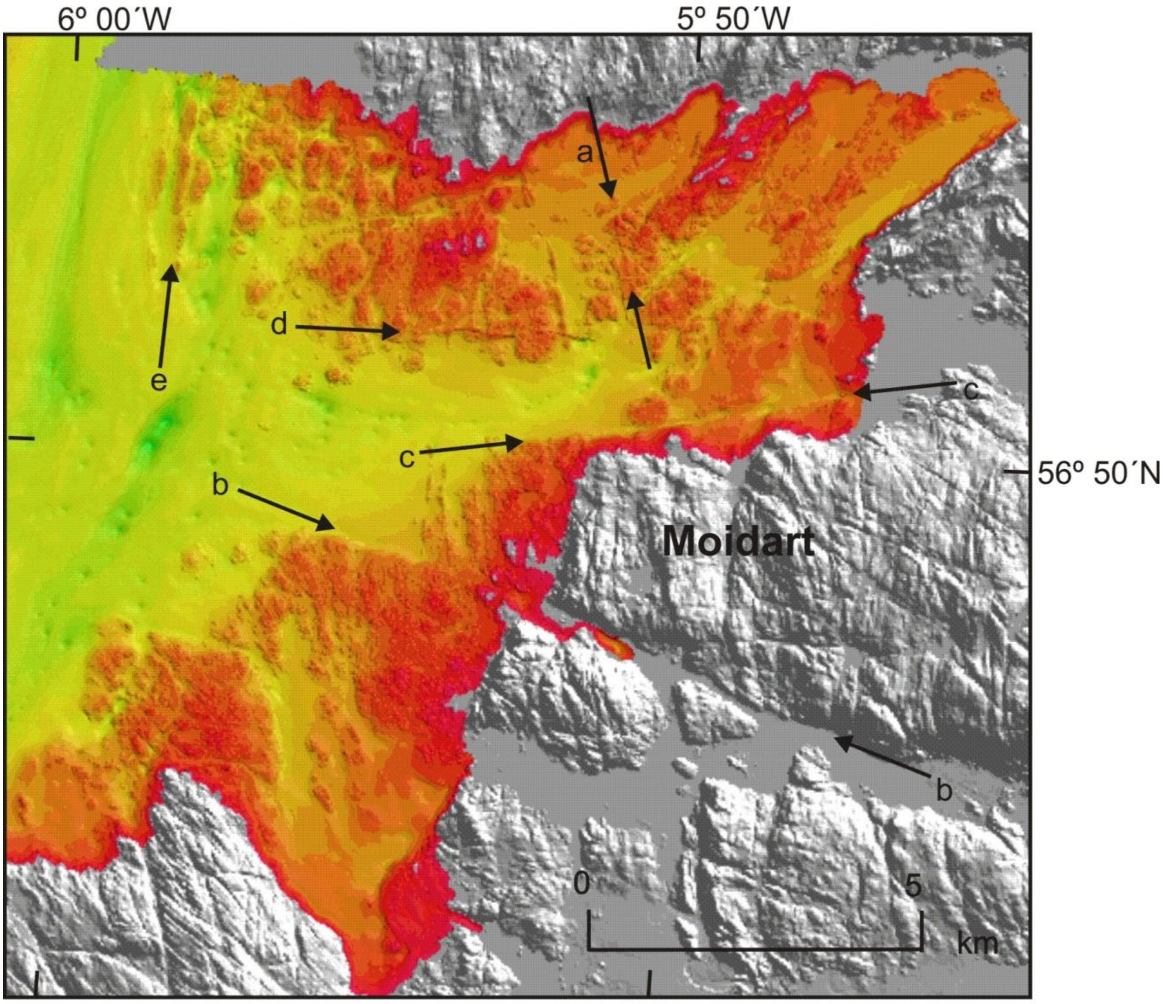

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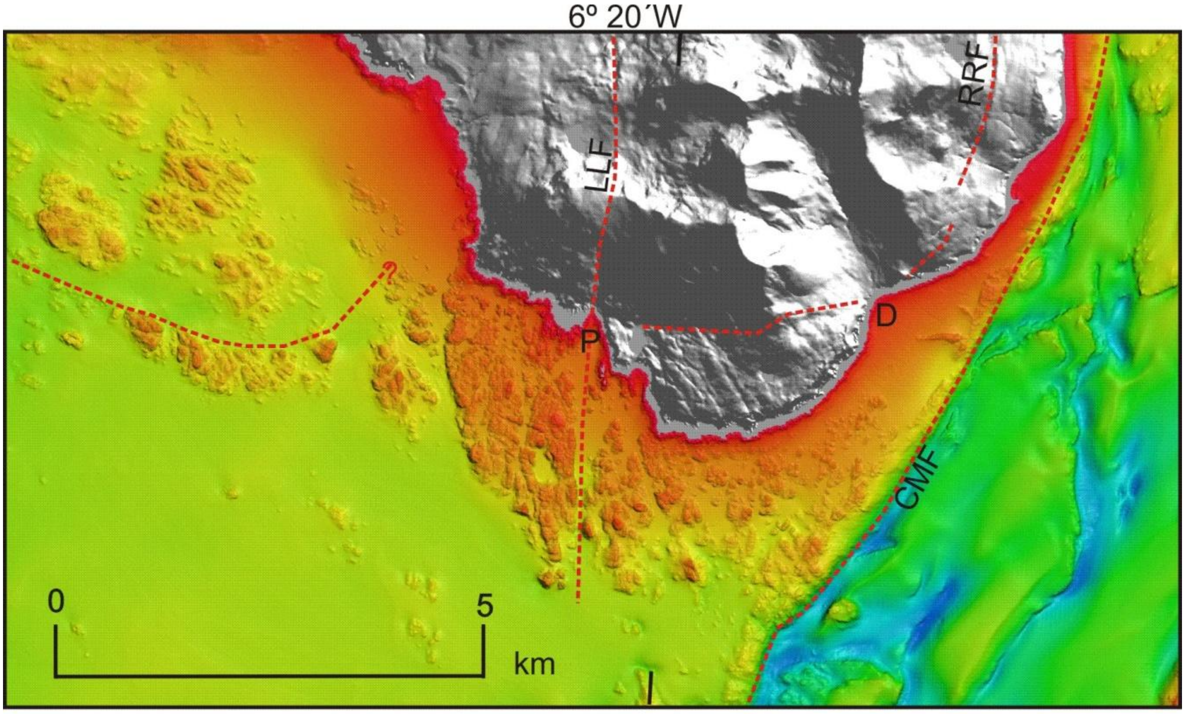

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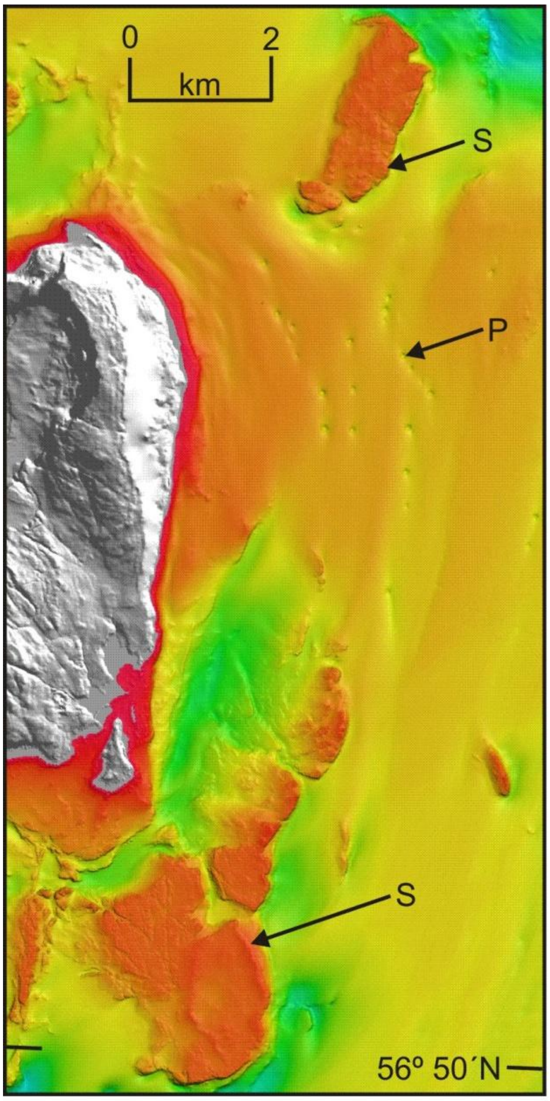

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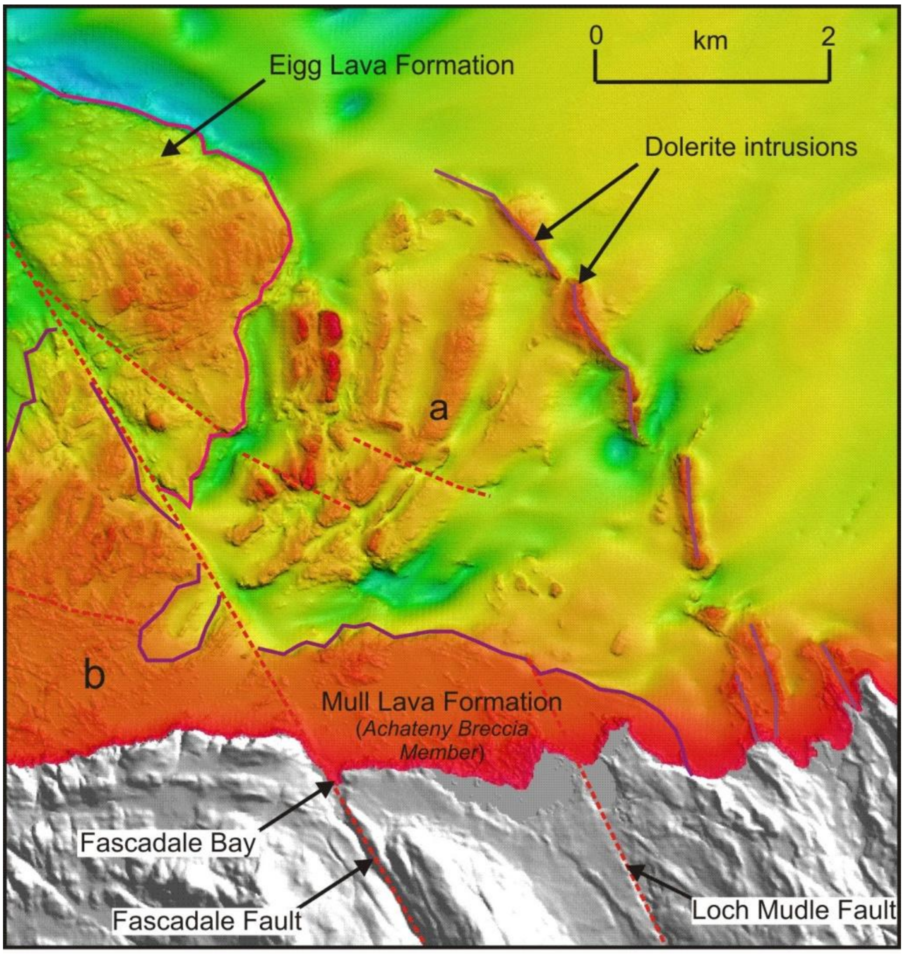

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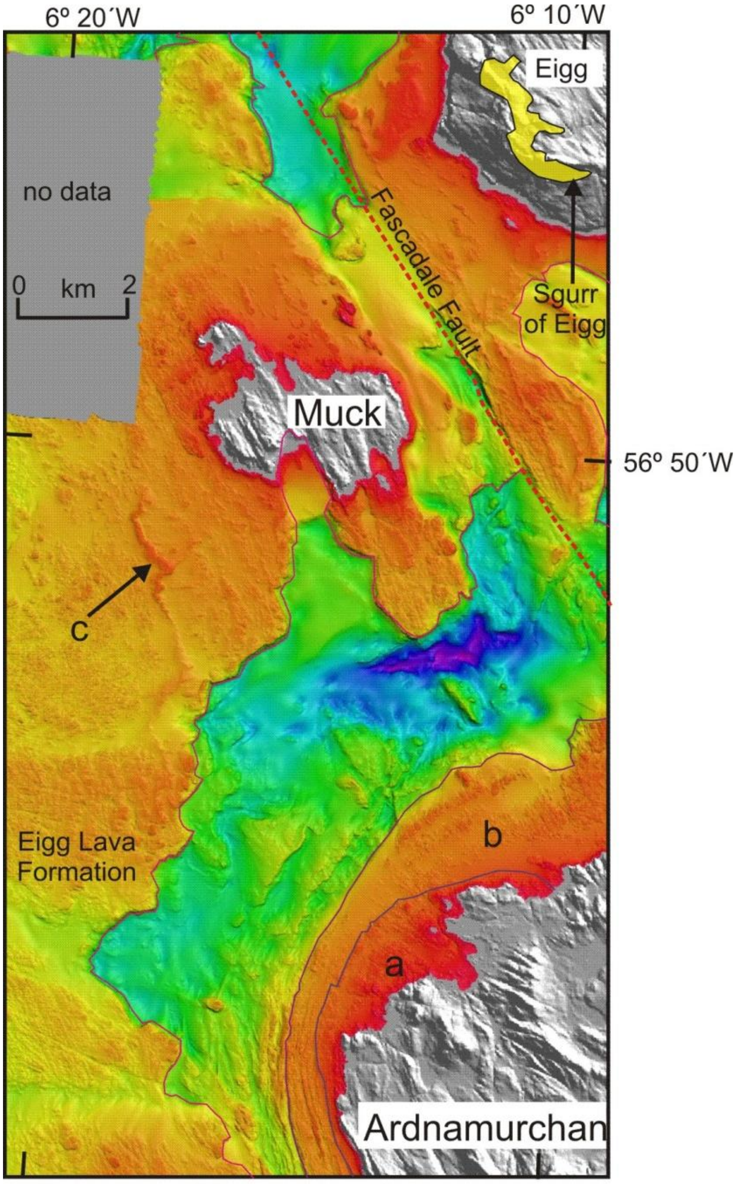

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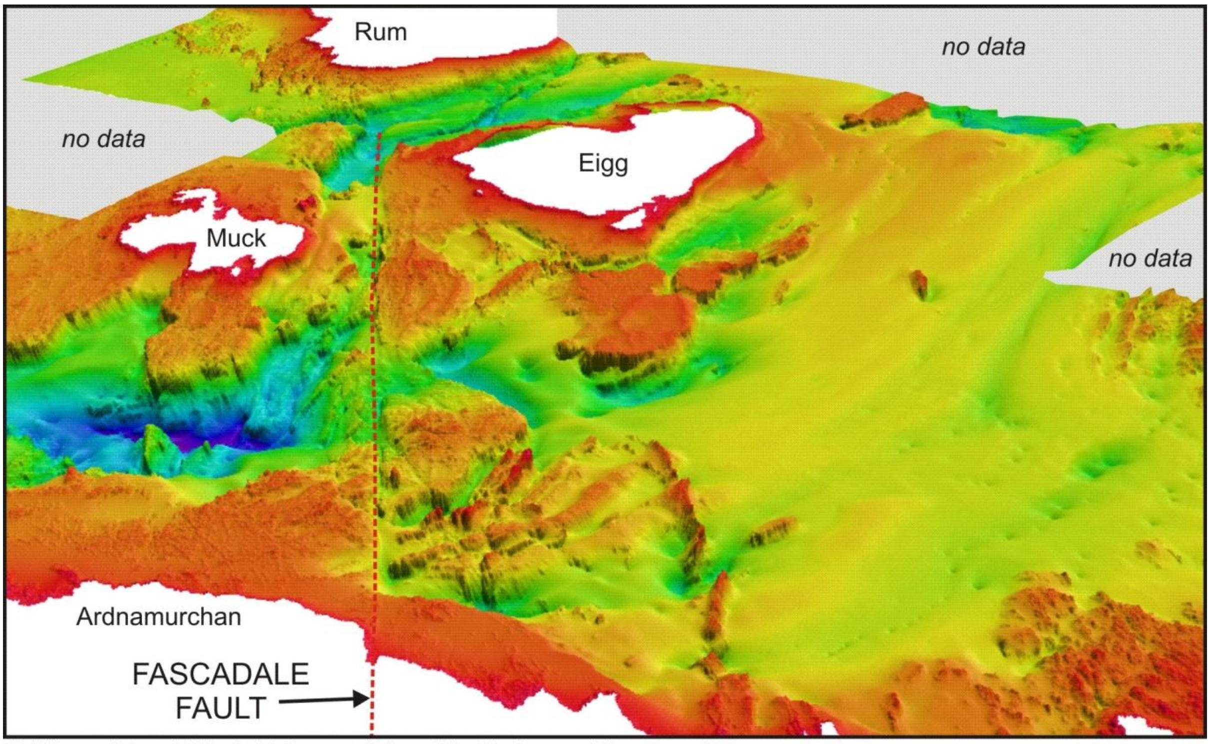

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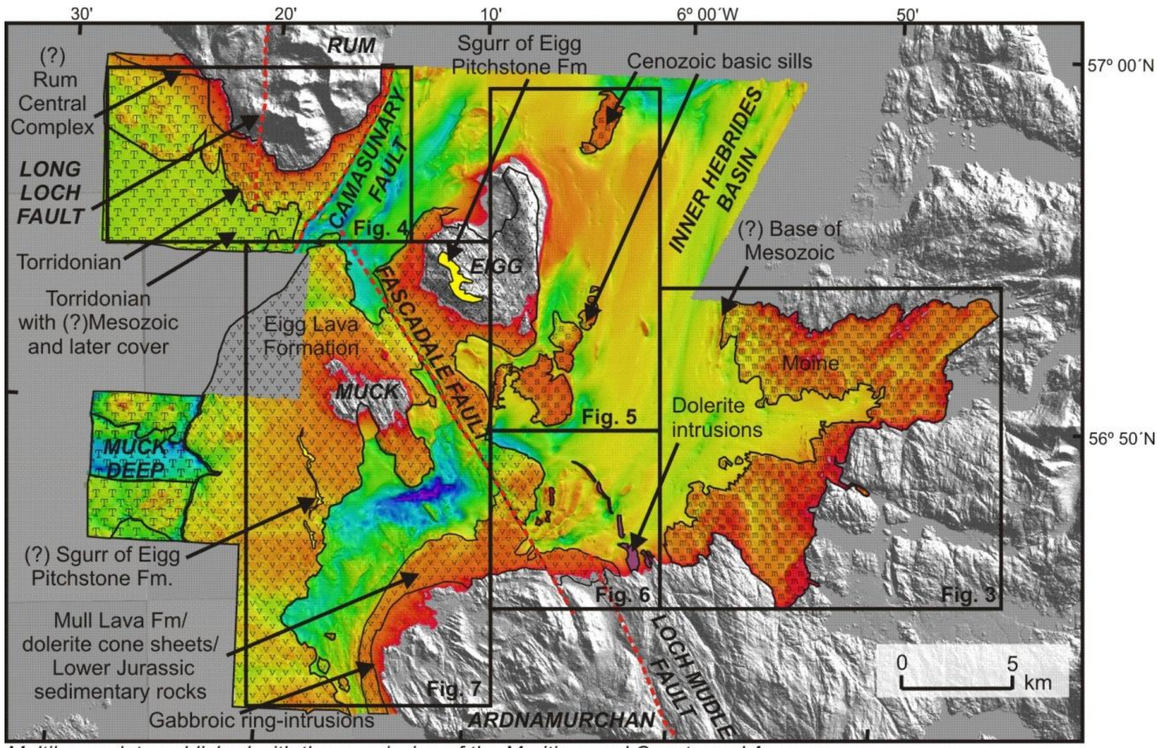

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