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Observations of the Morphology and Structure of the Sea Floor South and West of Iceland

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Abstract. Two submarine canyons with well developed levees are present on the insular margin of southern Iceland. In response to the Coriolis force the western levee predominates, except near the source region. Active redistribution of bottom sediment is apparent in the Denmark Strait, and also along the flanks of the Reykjanes Ridge. Data from a multi-channel seismic reflection line may be interpreted to indicate rocks of recent volcanic origin present on the shelf west of Snaefellsnes peninsula. An anomalous flat reflector on the eastern flanks of the Reykjanes Ridge may represent extrusive basaltic layers.

Key words: Iceland – Insular margin – Seafloor morphology – Submarine canyons – Sediment ridges – Shelf structure.

Introduction

Iceland is geographically part of the mid-ocean ridge; however, it is anomalous in that it is subaerial, although it may be no more atypical than other segments of the ridge. Volcanic and tectonic activity on Iceland distributed over a broad complex zone does, however, depart from the simplicity of the typical Mid-Oceanic Ridge. This has led to speculation that Iceland sits astride a hot spot in the Earth's asthenosphere. As a classic example of the geodynamic processes, a plethora of scientific articles have appeared about various aspects of the geology/geophysics of Iceland and environs in the last decade. Rather than cite a long list of notable articles, the reader is referred to Kristjánsson (1974) and Pálmason and Saemundsson (1974).

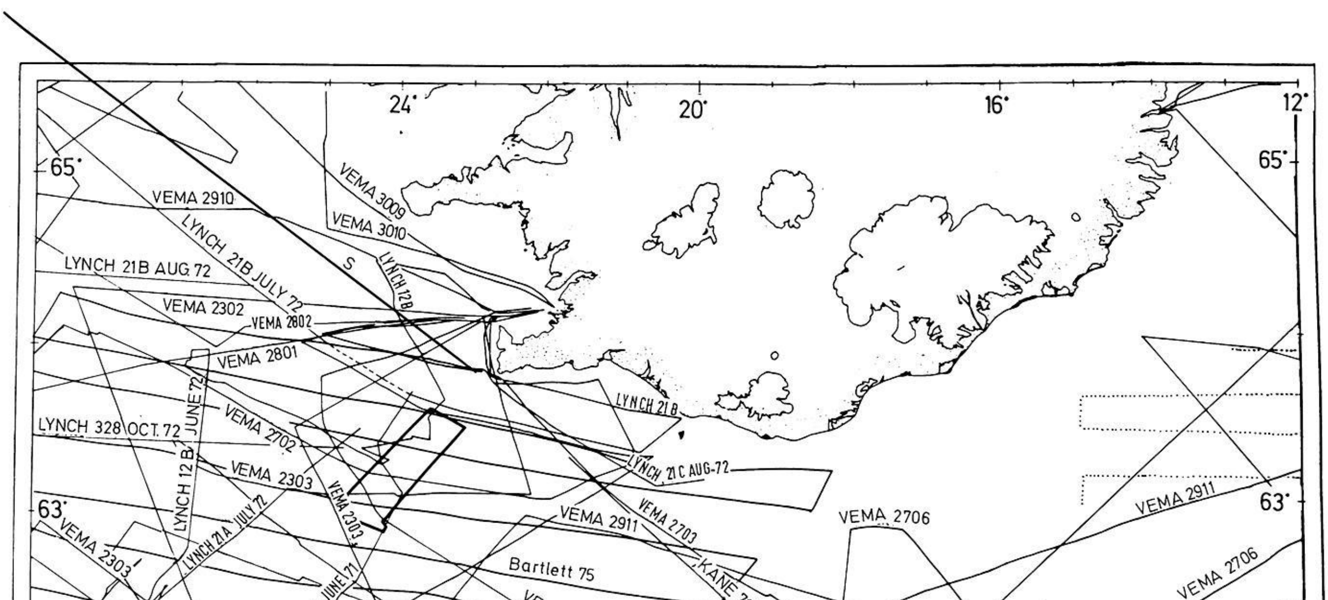

Fig. 1. Seismic records taken in the vicinity of Iceland which were utilized in this study. *Dotted lines* are KEATHLEY data (Johnson and Tanner, 1971). *Boxed area* is detailed study (Jakobsson and Johnson, in preparation). *Heavy line*, marked 'S', denotes location of Fig. 8

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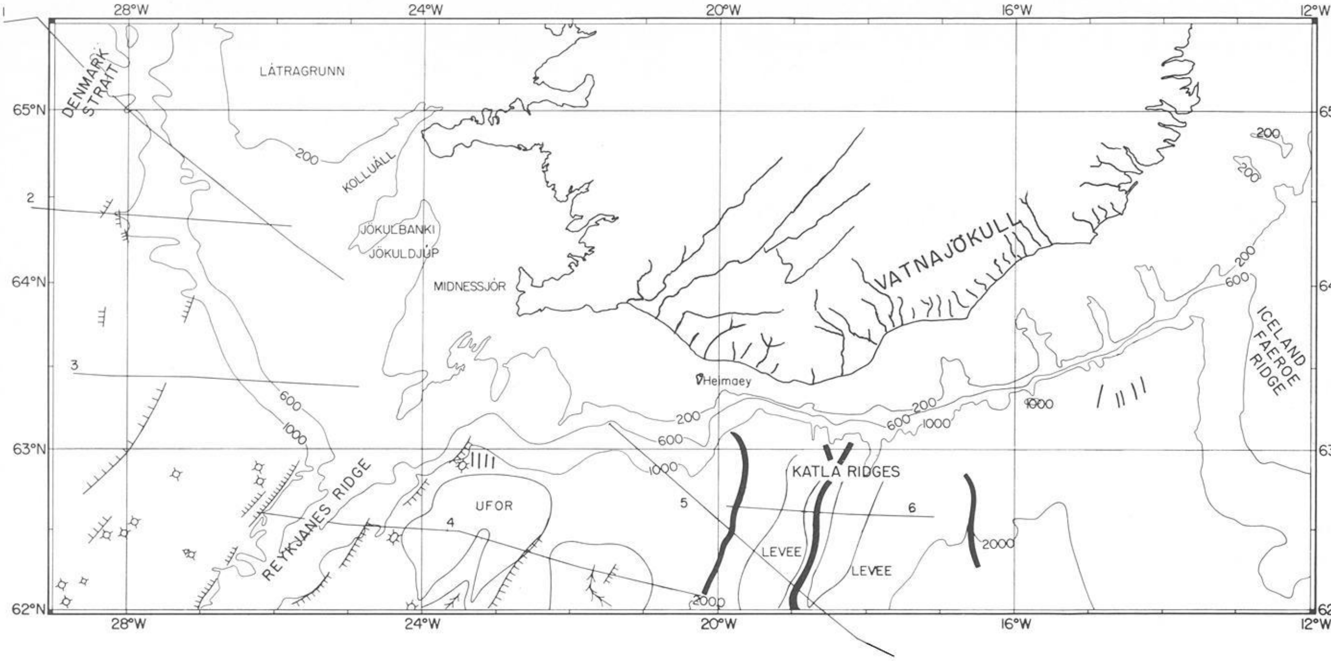

Fig. 2. Location of seismic lines shown in Figs. 3, 4, 6, and 7 and physiographic and structural features mentioned in the text. Submarine canyons are shown by *solid black lines*, sedimentary drifts by connected inverted v's to delineate axes. *UFOR* denotes areas of ultra-flat opaque reflectors

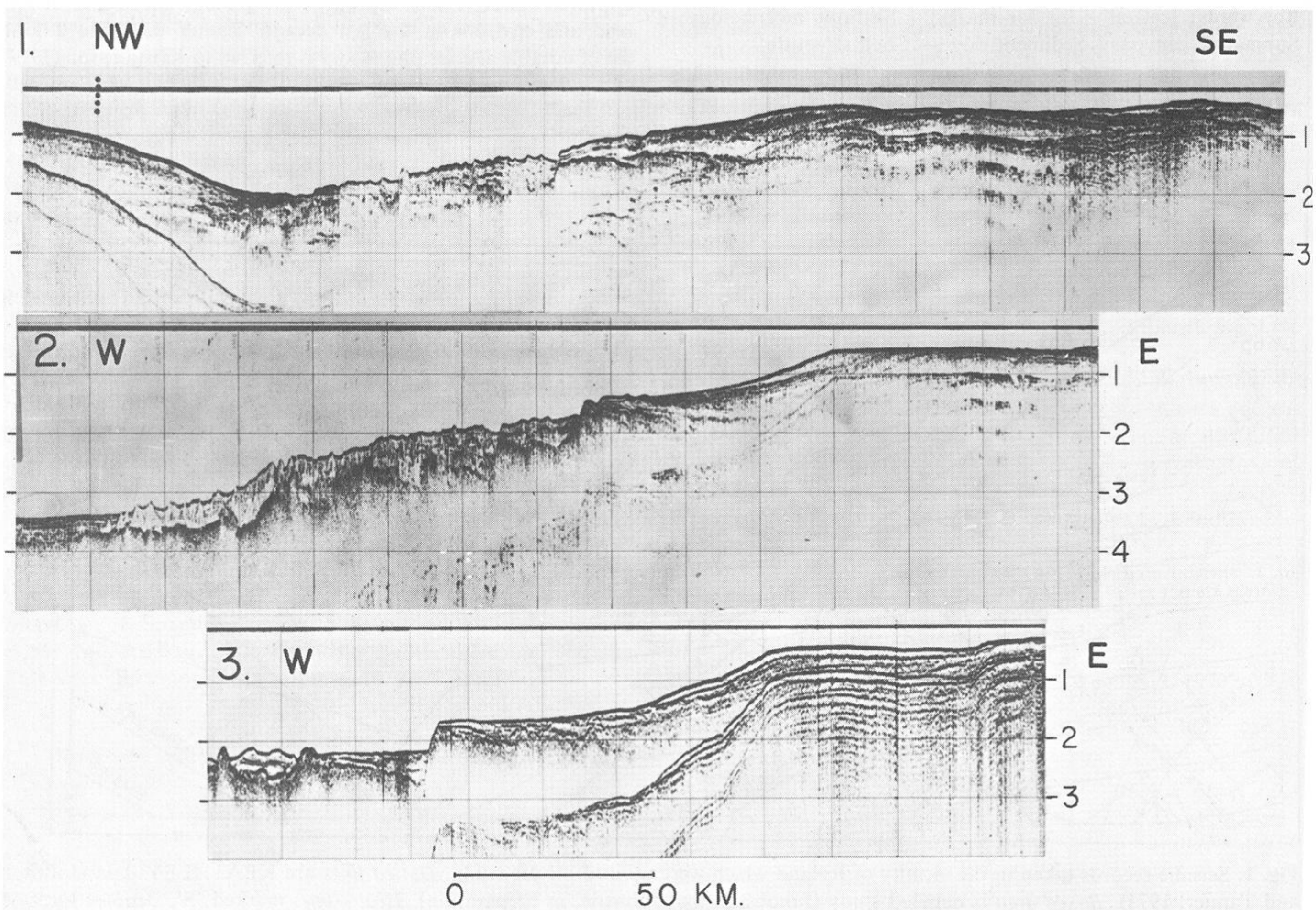

Fig. 3. Seismic reflection lines crossing the southwestern insular margin of Iceland. One second of travel time equals about 1 km. See Fig. 2 for index

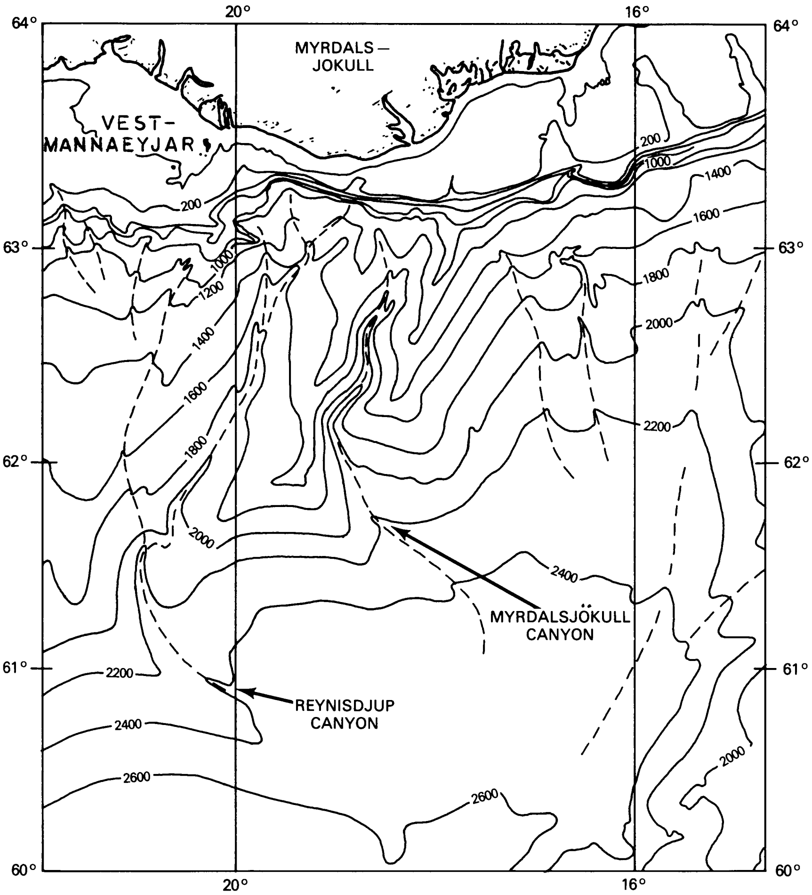

Fig. 4. Bathymetric contour chart of the southern insular margin. Basic chart courtesy of J. Gilg, U.S. Naval Oceanographic Office. Depths in meters

The purpose of this paper is to examine the insular margin of Iceland (with emphasis on its southern margin) and its evolution and relationship to the adjacent island and sea floor. Figure 1 shows some ship tracks in the area. In addition, a survey of the shelf to a distance of about 100 km from the coast was made in 1972–1973 with a line spacing of about 10 km.

Morphology

Shelf and Slope

Iceland is surrounded by a shelf of shallow depth, mostly 100–300 m, with an area larger than that of Iceland itself. The shelf is in some places relatively narrow, especially in the south where its width is 15 km. The bathymetry is more complicated where the crest of the Mid-Atlantic Ridge enters the shelf and a series of *en echelon* elongate topographic highs are present. In some parts of the shelf shallow, wide valleys are found with a relief of 100–150 m, many of them located in front of the main present-day rivers on the shore (Fig. 2). The insular slope is steep on the southeast margin averaging 1:15. This may be a reflection of swift bottom currents scouring the sea bed. The slope to the west is more gentle averaging 1:120 which is gentler than defined continental slopes (Profiles 1–3, Fig. 3), (Heezen et al. 1959). An extensive study of the continental shelf and environs based on seismic reflection data is found in Egloff and Johnson (1979).

The southeastern insular slope and rise are dissected by an extensive submarine canyon system which is of interest.

Submarine Canyons

The Maury Channel is the major sea floor canyon system in the Northeast Atlantic (Ruddiman et al. 1972). The northern continuation of Maury Channel is a broad trough (with two deep axes) which contains Maury Fan. One axis points northeast toward the Faeroe Bank Channel. The second deep axis turns north-northwest toward large youthful canyons cut into the southeast slope of Iceland.

This study reinforces the suggestion by Davies and Laughton (1972) that probably the major headwater canyon is presently incised into the insular slope and rise of southern Iceland. This canyon (Mýrdalsjökull) has a subsidary yazoo canyon (Reynisdjúp) along the base of its western levee (Figs. 4–6). Numerous smaller canyons are also present on the insular rise (Fig. 3), all of which contribute turbidite debris to the Maury Fan. These are the tributaries of the Maury Channel system which disperses Icelandic sediment, introduced mainly by subaerial and subglacial eruptions (jökulhlaups) as far as the Iberian Basin. Ruddiman et al. (1972) have suggested that the total volume of Maury Channel and Fan sediments is over 30,000 km^3, excluding sediment which has been carried south to the Biscay Abyssal Plain.

The major canyon is named Mýrdalsjökull Canyon, after an ice cap on the shore which covers the central volcano Katla. Katla has probably erupted about twenty times since the settlement of Iceland, the last eruption in 1918 causing discharges of water estimated to have reached a maximum of 100,000–200,000 m^3/s (Einarsson, 1978). Such enormous discharges are believed to be the prime source of this major submarine canyon.

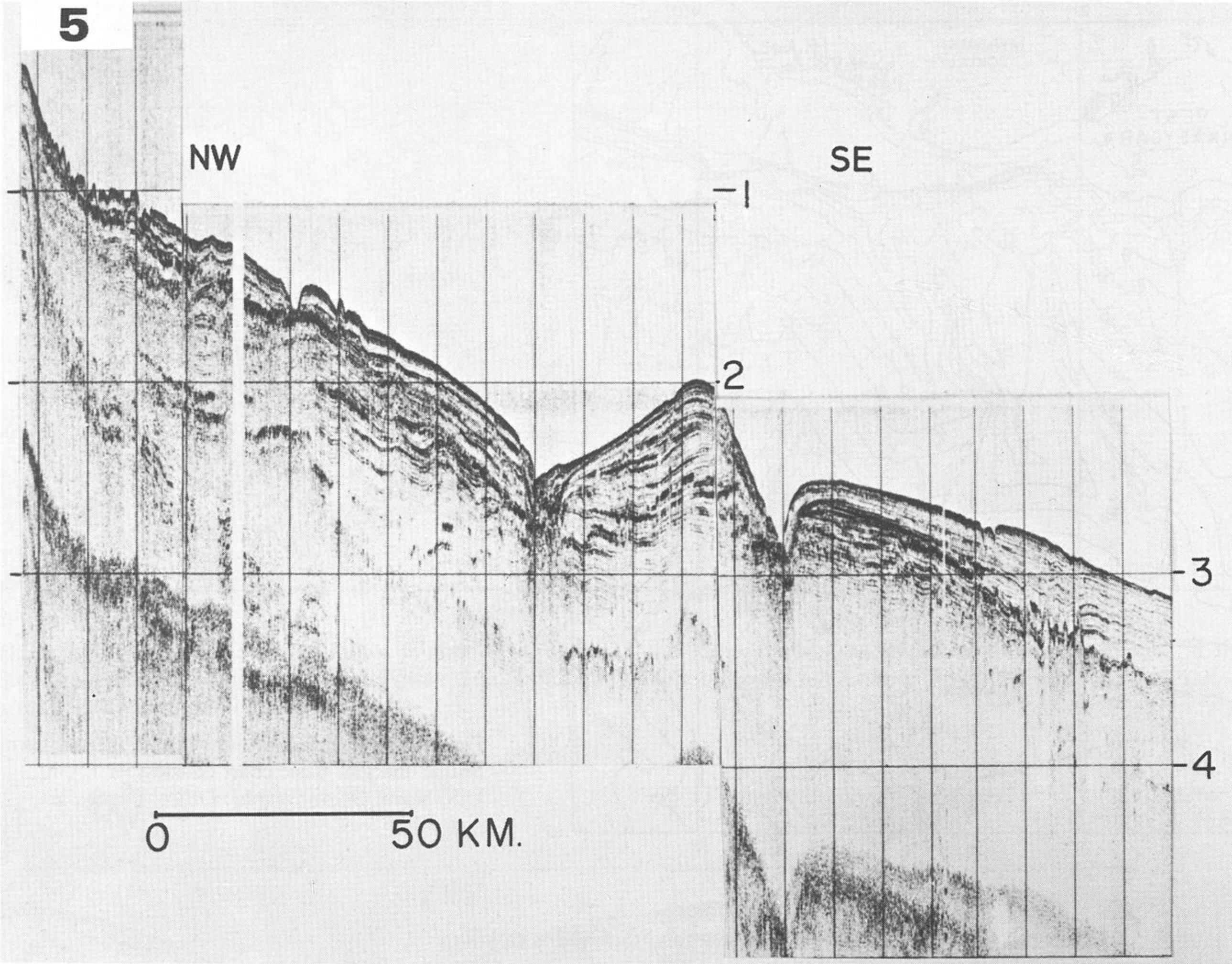

Fig. 5. Seismic reflection line across Mýrdalsjökull and Reynisdjúp Canyons. One second of travel time equals about 1 km. West is on the left. See Fig. 2 for index

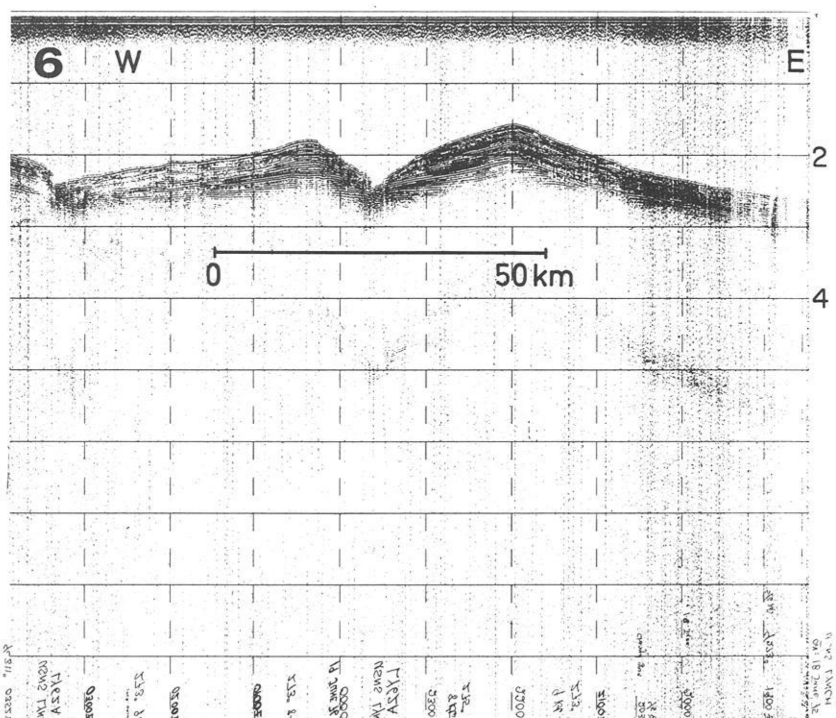

Fig. 6. Seismic reflection line across Mýrdalsjökull and Reynisdjúp Canyons. One second of travel time equals about 1 km. Profile length 140 km. See Fig. 2 for index

The levees (Katla Ridges) of Mýrdalsjökull Canyon, except within 40 km of the shelf, are higher on the western side (Figs. 4–6). Since a bottom current flowing down the canyon should tilt upward from left to right (looking downstream in the northern hemisphere) and thus deposit sediment preferentially on its western levee, the differential bank heights can be explained as an effect of the rotation of the Earth (Coriolis force). This effect is well documented in the Northwest Atlantic Mid-Ocean Canyon (Heezen et al. 1969). As can be seen in Fig. 6 along the base of the canyon, active erosion or at least non-deposition has formed a small western scarp whereas to the east the canyon floor/wall is more gentle. This is presumably caused by the core of the turbidity current being held against the western bank by the Coriolis force. Neither canyon appears to have buried axes at depth suggesting they are of Plio-Pleistocene origin. Some westward migration of Reynisdjúp Canyon is apparent in Fig. 6; this is presumably a response to the upbuilding of the western levee of Mýrdalsjökull Canyon as well as the Coriolis force. Mýrdalsjökull Canyon apparently has not migrated although deeper sedimentary layers of the eastern levee show some evidence of western migration (Fig. 5). Mýrdalsjökull Canyon is eventually forced to flow eastward along the axis of maximum depth where it is assumed to join the Maury Channel system and eventually debouch in the Biscay Abyssal Plain (Fig. 4).

Reykjanes Ridge

Dietrich (1959) and Ulrich (1960) first defined the morphology of the Reykjanes Ridge. Talwani et al. (1971) extended the knowledge base and related the morphology to other geophysical parameters. In the area of this study the crustal zone is bounded by steep scarps giving a horst-like profile (Fig. 7). As noted by Johnson et al. (1976), this morphologic shape is characteristic of the Mid-Ocean Ridge near hot spots such as Galapagos and Bouvet. North of 63°25′ the horst type topography gives way to *en echelon* linear ridges and occasional volcanic cones (Jakobsson and Johnson, in preparation).

The ridge flanks have generally subdued relief with redistribution by bottom currents the dominant dynamic force (Egloff and Johnson, 1979). This tends to mask prominent crustal scarps (Fig. 7) which occur on both sides of the ridge axis. The more distant scarps, about 135 km equidistant from the axis, are located on magnetic anomaly 6 (21 Ma) (Herron and Talwani, 1972) (Fig. 2). The faults bounding the central horst are coincident with anomaly 2 (3 Ma). Prominent scarps, too, are present on the western insular margin of Iceland (Fig. 3, Profiles 2 and 3). These scarps appear to be regional rather than local and occur in sediment covered, shoaling, rough basement forming the Iceland Plateau (Fig. 2). In Profile 3 (Fig. 3) the fault block is an excellent example of antithetic faulting.

Sediment Cover

Shelf and Slope

The seismic reflection data on the shelf and slope of Iceland is limited primarily to data obtained with single channel equipment

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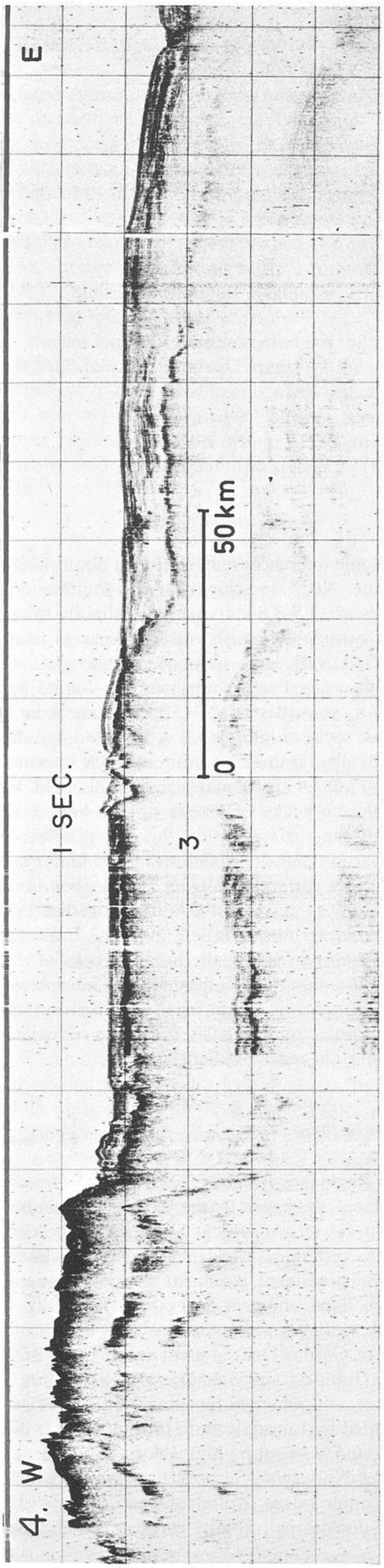

Fig. 7. Seismic reflection line across the crest of the Reykjanes Ridge and UFOR province. Line courtesy of J. Egloff. One second of travel time equals about 1 km. Profile length 248 km. See Fig. 2 for index

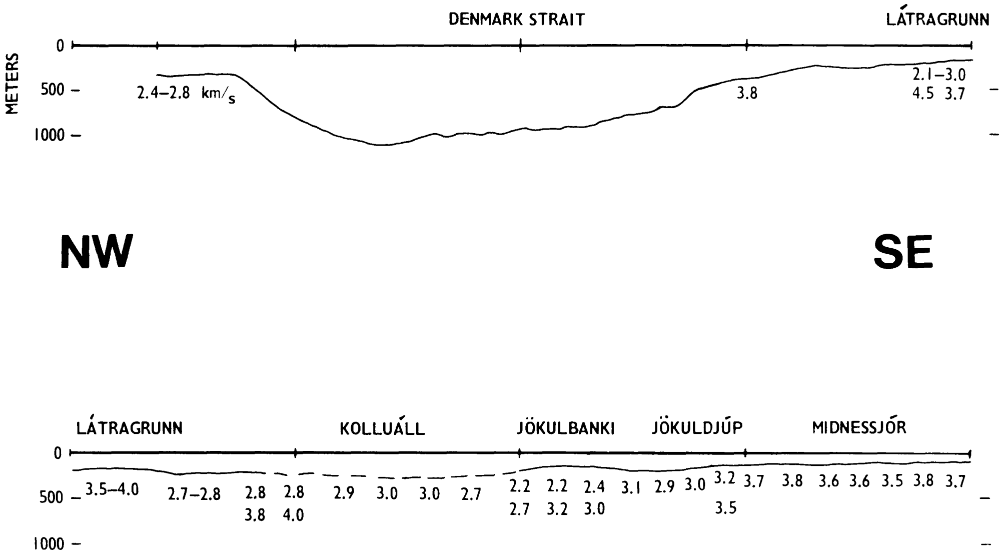

Fig. 8. Subbottom seismic velocities along line S (Fig. 1) based on multi-channel seismic survey. Data courtesy of Shell Oil Co

which has only limited penetration. It is possible, however, to determine that at least west of 25° W the shelf consists of seaward dipping truncated strata overlain by approximately 100–200 m of horizontal layers (Fig. 3, Profiles 2 and 3). The erosion of the deeper layers is most probably caused by scraping by the Pleistocene insular ice sheet and subsequent wave erosion as sea levels rose with retreat of the glaciers. A similar geologic sequence is present on the Jan Mayen Ridge although in that case, the overlying horizontal layers consist of 100–300 m of Pleistocene to middle Late Oligocene sediment (Johnson, 1975).

Total-intensity magnetic anomalies reported by Kristjánsson (1976) reflect a change in the structure of the southern Iceland shelf at 20° W, which was also noted by Pálmason (1974). The western part has subdued magnetic relief indicating basement (basalt) depth of at least 400 m. On the eastern part of the shelf there occur pronounced edge anomalies, apparently due to a basement step of at least 1 km mean thickness and of mean width 3–4 km (Fig. 2).

Supporting evidence of the nature of the southern Iceland shelf comes from a 1565 m-deep hole, drilled in 1964 in Heimaey (Pálmason et al., 1965; Tómasson, 1967). The uppermost 180 m are volcanics forming the base of the Westman Islands. This is followed by about 600 m of mostly sediments, containing foraminifera shells, and thus deposited in a marine environment (Einarsson, 1978). The lowest 500 m or so in the hole are basalt lavas, considered to be of Tertiary age.

The available data as summarized by Pálmason (1974) indicate that the shelf is built chiefly of basalts and that sediments from land have been deposited mainly in front of the shelf margin. Volcanic activity and glacial action has then later modified the edge of the shelf (Egloff and Johnson, 1979). The shallow, more or less constant depth shelf would have been the combination of the above with shore erosion and isostatic readjustments. Figure 5 shows that the base of the insular slope of southern Iceland contains in excess of one kilometer of sediments. The stratification probably represents pulses of glacial erosion. The transparent layers reflect periods when pelagic or hemipelagic sedimentation dominated.

A single multi-channel seismic reflection line across the western shelf (S in Fig. 1) gives information on subbottom velocities at shallow depth (Fig. 8). By comparison with seismic velocities on land (Pálmason, 1971) some inferences may be drawn about likely rock types along the line. At Midnessjór, near the southeastern end of the line, velocities are 3.5–3.8 km/s which is slightly lower than for surface basalts outside the active volcanic zone on land, and might point to a relatively large amount of hyaloclastites or sediments in the basalt series. Farther northwest, in Jökuldjúp, Jökulbanki and Kolluáll, velocities of 2.7–3.2 km/s are found. This is typical of volcanic rocks of interglacial age on land, basalts and hyaloclastites. At Jökulbanki this is overlain by a few hundred meters of low velocity (2.2–2.4 km/s) material, which could be either sediments or volcanic rocks of recent origin, similar to the rock types found at the surface within the active volcanic zone on land. At Látragrunn higher velocities (3.5–4.5 km/s) are again found, typical of older surface basalts on land. A few hundred meters of low velocity material (2.1–3.0 km/s) overlies this near the shelf edge on Látragrunn. Profile 1 in Fig. 3 indicates that this material is sediments overlying the basaltic rocks of the shelf. The seismic velocities along line S may well be interpreted to indicate rocks of recent volcanic origin on the shelf southwest of the Snaefellsnes peninsula, on the basis of similar velocities in rocks of the active volcanic zones on land.

Reykjanes Ridge and Basin Floor

The crestal zone of the Reykjanes Ridge is nearly devoid of sediments. On Fig. 7, sediment thickness to the east of the central horst is variable. Up to 400 m are present adjacent to the east of the central Block. Proceeding eastward, the average thickness is about 200 m until the prominent basement scarp whereupon the thickness increases to 700 m and near the eastern end of Fig. 7 to over 1 km. This thick wedge of sediments probably represents the northern most part of Gardar Drift, a great sedimentary drift in the Eastern Atlantic (Johnson and Schneider, 1969). Figure 2 delineates two separate regions where sedimentary drifts have accumulated. As documented by Lonsdale and Hollister (1976), the insular rise of South Iceland is swept by high velocity (> 20 cm/s) thermohaline currents of Norwegian Sea overflow water, which have constructed large outer ridges (drifts) of hemipelagic sediment, and is crossed by downslope turbidity currents, which have eroded deep valleys.

The pelagic sedimentary cover of the Reykjanes Ridge and adjacent sea floor (Figs. 3 and 7) is not uniformly draped over the basement, but forms an undulating relief which is not directly related to the underlying basement. Ruddiman (1972) noted this on the eastern flanks of the Reykjanes Ridge and ascribed it to reworking of sediments by bottom currents. Talwani et al. (1971) noted the same effect in this region and deduced from sediment distribution patterns that bottom flow is strong enough to inhibit sedimentation in some areas, and preferentially deposit in other areas. From these studies, the authors suggested the existence of a relatively strong bottom current flowing southwestward along the eastern flank of Reykjanes Ridge and northeastward along the western flank.

Figure 3, Profile 1 across the axis of Denmark Strait shows a highly reflective channel flanked on the eastern side by a 60 km stretch of disturbed sediments. The undulations of the sea floor are believed to be caused by bottom currents creating sea-floor dunes (Johnson and Schneider, 1969) and active sculpturing of the sea floor by the southward flowing bottom currents (Shor and Poore, 1978).

Ultra-Flat Opaque Reflectors (UFORs)

As is apparent on Fig. 7, a peculiar seismic reflector, anomalously flat and opaque, hereafter referred to as a UFOR (Ultra-flat opaque reflector) is present. The difference between UFOR and normal basement is rather striking. The areal extent of these reflectors within our study is charted on Fig. 2. The UFORs seem to be arranged in slightly tilted terraces, separated by scarps, valleys, or stretches of normal basement. Within each such terrace, basement dips do not exceed 1.500. The traversed portions of the UFORs lie 2.1–2.5 km below sea level, and are buried by 0.3 to 0.5 km poorly stratified sediment, evidently reworked by strong bottom currents. These values assume an average velocity of 2.0 km/s in the sedimentary column. Water depth varies from 1,200 to 1,600 m, and crustal age is 3 to 4 Ma (Vogt and Johnson, 1973). Possible explanations for the UFORs include: 1 The reflector represents a highly consolidated sediment layer or a sill intruded more or less horizontally into a preexisting sediment layer; however, this is considered unlikely (Fridleifsson, 1977). 2. The reflector is volcanic ash, either directly deposited (pelagically draped) or redeposited, in nearly horizontal sheets, by by turbidity flow.

There is no mirror image of UFORs on the western side of the ridge axis, and therefore they cannot have been formed at the axis. Windows through which basement can be seen have been reported (J. Egloff, 1979, personal communication and therefore the volcanic ash hypothesis suggested by Vogt and Johnson (1973) may be valid. Therefore, until the reflector is drilled, the best estimate of its nature is that of extrusive basalt, but with an atypically low initial viscosity, or extruded at a higher than average rate and total quantity, such that the effects of rapid cooling and lithification in the submarine environment were overcome.

A much more detailed discussion of the various hypotheses of UFOR origin is contained in Vogt and Johnson (1973). They note that low inherent viscosity as well as rapid, voluminous discharge are characteristic of plateau basalts extruded on Iceland in middle to late Neogene times and, 60 to 55 Ma ago in the Faeroes, west and east Greenland, and Baffin Island. Similar flood basalts have occurred at various places during geological time, presumably all as the surface manifestation of mantle convection plumes or hot spots. There is every reason to expect similar flood basalts adjacent to oceanic hot spots such as Iceland. Other UFOR occurrences are in the North and central Atlantic and are found on anomalous crust created during proposed (on independent grounds) peaks in hot spot activity-around 80-60 and 140-110 Ma ago. This makes sense if the UFORs are submarine flood basalts (Vogt, 1972).

Conclusions

Dynamic geologic processes have been active in the area of this study. Sediment redistribution by bottom currents is the rule, with dune and drift structures being formed in the regions of maximum activity. Submarine canyons with well developed levees attest to the vigorous erosion of the insular platform.

Fault scarps parallel to the Reykjanes Ridge spreading center are conspicuous, as are areas of anomalous flat basement. The latter, found on the eastern flank of the Reykjanes Ridge, may represent extrusive basaltic layers.

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