International Ridge-Crest Research: **Hotspot-Ridge Interactions**

KRISE-2000: Constraining the dynamics of plume-ridge interaction to the north of Iceland.

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The geodynamic interactions between mantle plumes and mid-ocean ridge spreading centres give rise to notable variations in ridge morphology, mid-ocean ridge basalt chemistry, crustal thickness, and presumably mantle flow. Iceland and the adjacent mid-ocean ridges - the Reykjanes Ridge to the south and the Kolbeinsey Ridge to the north - provide a natural laboratory for developing a comprehensive model of the dynamics of hotspot-ridge interactions. The influence of the Iceland hotspot on the adjacent ridges, which has been recognized since the 1970s, extends more than 1,000 km away from the plume's centre. Major- and trace-element studies at Iceland and along the slow-spreading Reykjanes and Kolbeinsey Ridges, support a decreasing extent of melting with distance from the plume (*e.g.* Schilling, 1999). In addition, along-axis gradients in trace-elements and isotope compositions suggest mixing between the plume and normal mid-ocean ridge basalt sources. Seismic measurements of crustal thickness within Iceland and along the adjacent mid-ocean ridges also support a decreasing extent of melt production with distance from the centre of the plume (Fig. 1 and references therein).

Despite considerable progress, the exact form of interaction between the Iceland plume and adjacent ridges is poorly understood. In particular, an observed north-south asymmetry in ridge axis elevation and geochemistry is not understood nor predicted by the geodynamic models. Bathymetric profiles show more rapid deepening of the ridge axis to the north along the Kolbeinsey Ridge than to the south along the Reykjanes Ridge (see Fig. 1,an excess of up to 1 km over 400 to 1200 km to the south and a deficit of almost 1 km over 100 to 500 km to the north). Though this topographic signature may be partly due to the reduction in spreading rate north of Iceland, an asymmetry in the effect of the plume on the spreading centre has been proposed. The current seismic measurements of crustal thickness hint at an asymmetry in melt flux at the ridge with crustal thicknesses greater along the Reykjanes Ridge than along the Kolbeinsey Ridge(compare fits I and II, in Fig. 1).

The Kolbeinsey Ridge Seismic Experiment (KRISE) was aimed at measuring the variation in crustal thickness, as an indication of melt flux, on transects north of Iceland, in a region that is poorly studied and critical to further refining geodynamic models of plume-ridge interactions in the North Atlantic region. Apart from being 2-3 times thicker, the crust of Iceland resembles the crust of the ocean basins. Existing seismic measurements of crustal thickness along the spreading system are sparse in the critical range of 200-400 km from the centre of the Iceland plume (Fig. 1). There is only one data point along the ridge to the north of Iceland and constraints on the past melt flux at the spreading centre north of the plume, recorded in the thickness of older off-axis oceanic crust, are sparse.

The Kolbeinsey Ridge formed at 26-36 Ma following a westward ridge jump from the now extinct Aegir ridge. The slow-spreading Kolbeinsey Ridge (full rate ~2 cm/yr) is bounded by the Tjörnes fracture zone to the south and the Jan Mayen transform fault to the north. The southern ridge axis, from the Tjörnes fracture zone at 66°50'N to the right-stepping Spar 34 km offset at 69°N, is clearly delineated by a continuous axial high (~30 km wide and ~500 m vertical relief) and a high-amplitude central magnetic anomaly. Spreading along the Kolbeinsey Ridge was initiated 15 Myr ago and magnetic anomalies can be clearly traced out to at least anomaly 5 (~10 Myr). Just south of the Spar offset, a smaller non-transform discontinuity offsets the ridge by 10 km in a right lateral sense at 68°43'N. Magnetic data show this offset has propagated northward through time and that the southern Kolbeinsey ridge has grown to the

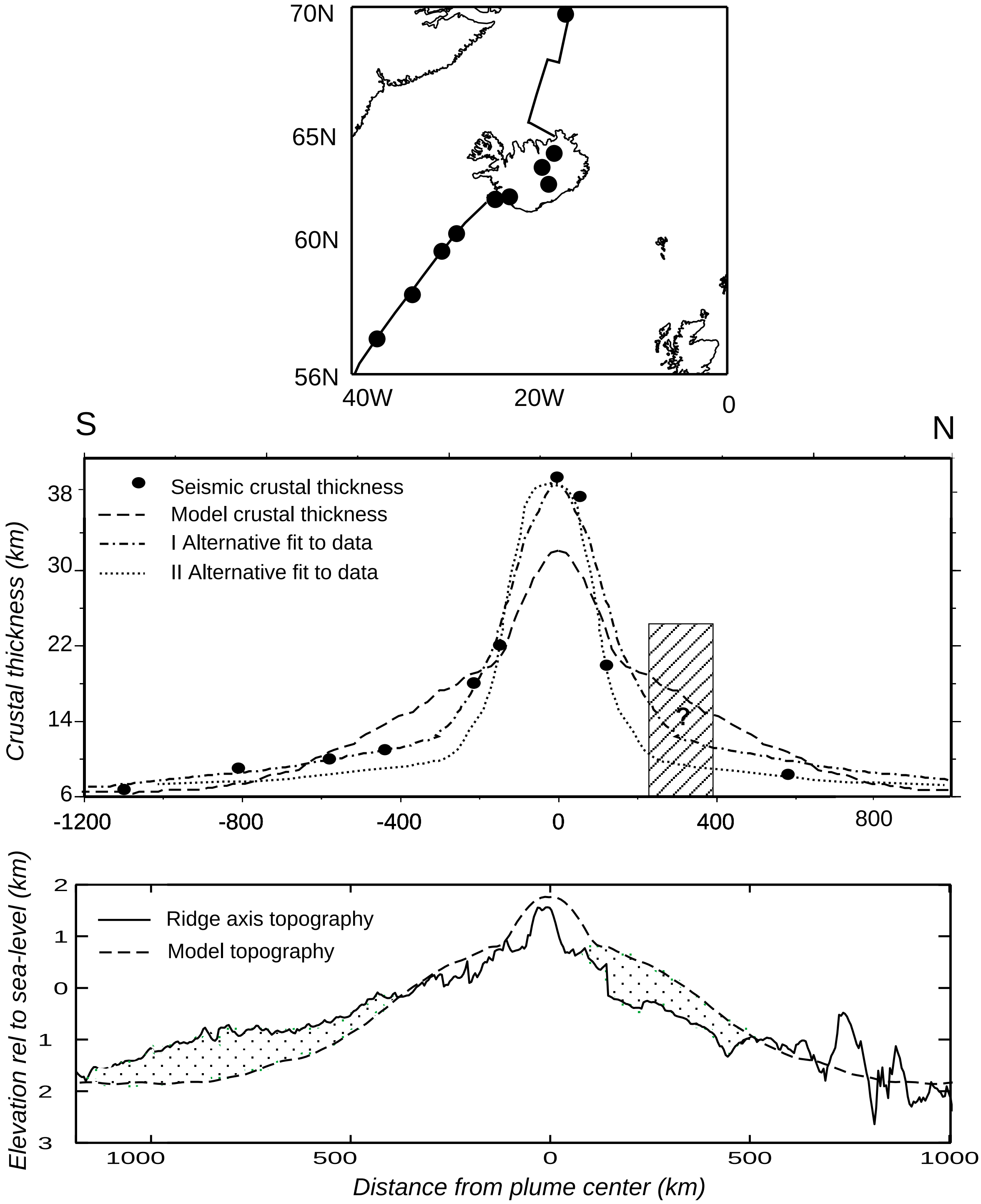

Figure 1. Comparison of predictions from the fluid dynamic model of *Ito et al*.(1999) (dash) with the observed along-axis crustal thickness (middle panel) and ridge axis elevation (lower panel) in the Iceland region, plotted against distance from the plume center (Bardabunga volcano, Iceland). Top panel: Locations of the crustal thickness determinations *(*Darbyshire *et al., 1998* and references therein*;* Weir *et al., 2000*). Middle panel: Two possible alternative fits to the seismic crustal thickness data are shown which have a more rapid reduction in crustal thickness at 200-500 km from the plume center than that predicted by the geodynamic models. The KRISE experiment measured crustal thickness from ~200-400 km from the plume (hatched box). Lower panel: Asymmetric differences between the observed ridge axis elevation and that predicted by the model (~1 km excess and ~1 km default observed to the south and north, respectively - dotted regions).

north at a rate of ~100 mm/yr (Apelgate, 1997). This rate is similar to the propagation rate of the V-shaped anomalies on the Reykjanes Ridge and may be caused by an increase in melting at the ridge over the last 6 Myr.

The experiment

The primary objective of KRISE was to collect P_g,P_n and P_mP arrivals along three seismic refraction profiles (Fig. 2). Crustal thickness variations in along-ridge lines may help constrain geodynamic models of the influence of the Iceland hotspot on the spreading centre, while variations in perpendicular directions may reveal temporal variability in the hotspot influence. We also collected magnetic, gravimetric and ministreamer reflection data for the sea floor and basement depths along the refraction lines. We surveyed a 230-km-long along-axis line (Line 1), situated about 10 km east of the Kolbeinsey Ridge, and two cross-axis lines (Lines 4 and 7) which were 138 and 710 km long, and located 180 and 70 km north of the Icelandic coast, respectively.

The three profiles were surveyed during June, 2000, in two OBS deployments using the University of Bergen research ship Håkon Mosby and the Icelandic Coast Guard Cutter Aegir. We used 33 OBSs from the University of Hokkaido, which recorded continuously, and of which 24 were digital instruments. The OBSs were nominally placed at 10 km intervals across the ridge axis, 30 km intervals east of the Iceland margin and at 15 km intervals elsewhere. The seismic source was a four-element airgun array with a total capacity of 4800 cu in mounted on the Håkon Mosby, and the shots were spaced at 200 m, or every 70 s, along the profiles.

The experiment was very successful and Line 7 was extended well into the Norway Basin, *i.e.* to the extinct Aegir rift axis. Initial inspection of the OBS data revealed that all but two of the deployments recorded. A total of 5389 airgun shots were fired during the experiment, all of them in very good sea conditions. In addition to the airguns, two large (M_s>6.5) earthquakes that occurred in the South Iceland Seismic Zone during the experiment were also recorded along Line 7.

First results

Ocean floor and basement reflections from each of the airgun shots were recorded on a~20-m-long mini hydrophone streamer which was towed behind the Håkon Mosby. The ministreamer profile joins up with an older profile (JM-17D-88), surveyed by the University of Bergen in 1988. After band pass filtering the data between 20-40 Hz with a 48 dB/oct drop off, we selected an AGC window of one second in order to bring out the strong basement reflection east of the Iceland insular margin (Fig. 3; top, right and bottom). This reflection is obscured by several strong water column multiples on the Iceland shelf. Assuming sediment velocities in the range of 2-3 km/s we can infer sediment thicknesses of 1-1.5 km on the western part of the Iceland Plateau, thickening to ~2 km at its eastern margin.

Further north, along Line 4, the sediments are much thinner (Fig. 3; top, left). An abrupt increase in sedimentary thickness is visible on each side of the ridge itself. To the east of the ridge the sediments are cut by more recent faults and extrusives. The refraction data will hopefully allow us to further determine the nature of the two small horsts east of the main ridge, which could be analogous to the V-shaped ridges present along the Reykjanes Ridge. Apart from these irregularities, the basement is fairly smooth.

The rougher basement, just west of the shelf break (Fig. 3; bottom), is most likely related to extension and tectonism associated with the southern extension of the Jan Mayenridge, which is considered to be a continental fragment, sliced off the Greenland margin at the initiation of the Kolbeinsey ridge. The 70-80 km wide rift we observe is characterized by numerous peaks rising 600-900 m above the sea floor. An intra-sedimentary reflector at this site could be of similar origin as horizon A, which has a thickness of 0.4-2 s further north on the Iceland Plateau and in the Norway Basin (Gairaud *et*

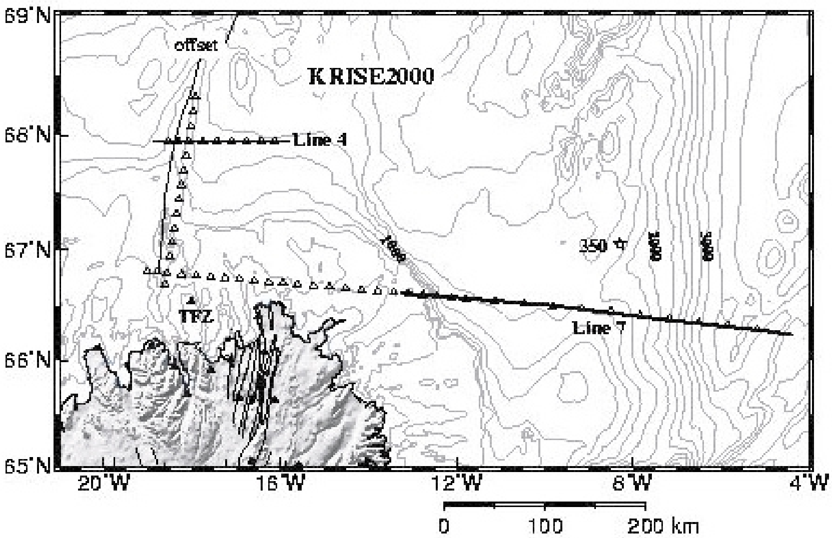

Figure 2. A map of the study area. OBS stations and stations on land, Iceland, are denoted by triangles and lines labelled Line 4 and Line 7 mark the location of ministreamer profiles shown in Figure 3. The location of DSDP-borehole 350 is denoted by a star.

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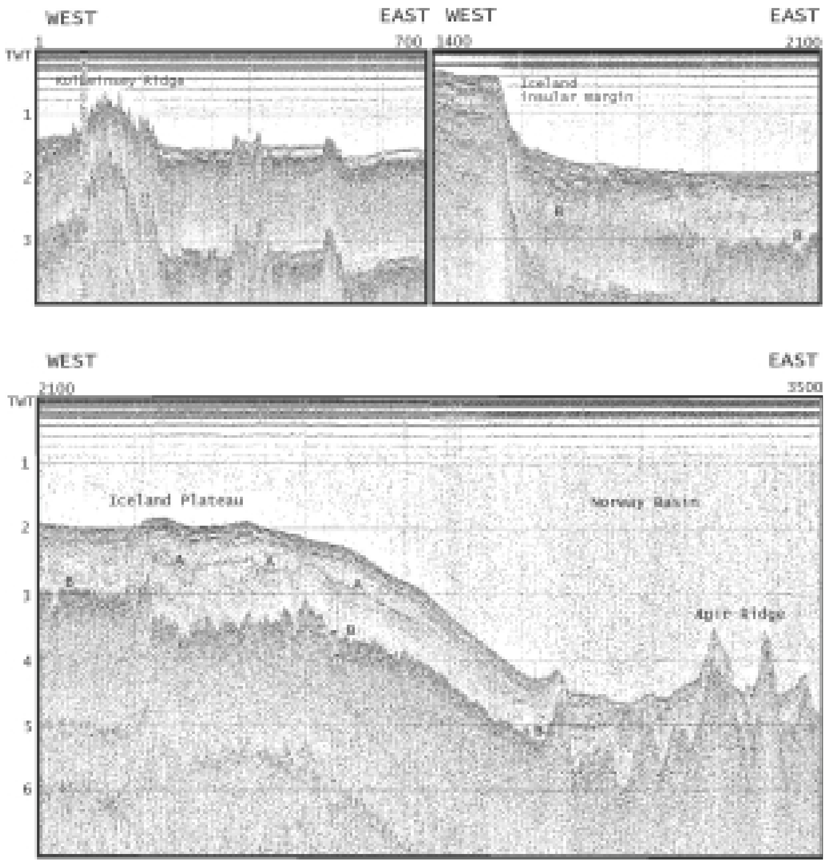

Figure 3. Ministreamer profiles across the Kolbeinsey Ridge (line 4; top, left), and from the Iceland Insular Margin (line 7; top, right) across the Iceland Plateau to the now-extinct Aegir Ridge axes (lower plot). The upper two profiles are close to 140 km (700 shots) each whereas the lower plot is approximately 280 km. The sediment-basement (B)reflector is only visible east of the insular margin, along the Iceland Plateau. Note the intra-sediment reflector (A) at the Iceland Plateau.

al., 1978). This horizon was penetrated at 226.5 m depth in ODP drill hole 350, which is located approximately 70 km north of our profile (Fig. 2). Horizon A is considered to mark the contact between Upper Eocene and the Oligo-Miocene.

The KRISE refraction data will allow us to determine the distance dependence of meltflux at the ridge in the critical range of 200-400 km from the plume centre and the temporal variability of the plume influence on the Kolbeinsey ridge from its initiation at 26-36 Ma. By comparing results from this experiment with the existing seismic data from the Reykjanes Ridge (see Fig. 1) we will be able to solve the issue of any asymmetry in the interaction of the plume with the spreading centres to the north and south and have the necessary data to constrain more refined models of these interactions. From comparison with previous refraction experiments in the Iceland area, we expect to have recorded converted shear wave arrivals which will allow better constraints on the structure and properties of the oceanic crust.

This joint American-Icelandic-Norwegian-Japanese endeavor provided a cost-effective opportunity to carry out the observations needed to further refine models of the effects of the upwelling plume on melting beneath the mid-ocean ridges.

Acknowledgements

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