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Crust–mantle transition and Moho model for Iceland and surroundings from seismic, topography, and gravity data

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Abstract

An increasing data set exists on the nature and thickness of the Iceland crust. This paper relates topography, i.e., elevation and bathymetry (TOP), Bouguer gravity anomalies (BA) and Moho depths to each other to assess the consequences of the "thick crust model" for Iceland in the context of the North Atlantic.

Results of regression of TOP and BA vs. Moho depth are converted into "Airy densities" $\Delta\rho^*$ (mantle crust density contrasts in the case of ideal Airy isostasy). For Iceland, $\Delta\rho^*$ is very low (105 ± 10 kg/m^3); for the adjacent continental margins and relicts, it is high and intermediate for the Jan Mayen Ridge. The values are affected by lithosphere cooling and systematic variations of internal crustal structure, and reductions for these effects are applied. For Iceland, the thermal reduction leads to slightly enhanced value of $\Delta\rho^*$ (112 ± 8 kg/m^3), thus part of the observed topography is due to the cooling effect, while the upper crust reduction reduces the value, implying that part of topography is compensated by internal crustal structure. With both reductions combined, $\Delta\rho^*$ is 103 ± 10 kg/m^3. The differences between gravity- and topography-derived values are compatible with undulation widths similar to Moho depths (half-wavelengths of order 30 km).

Regional variations of $\Delta\rho^*$ values in Iceland suggest differences in crustal generation and evolution. "Modern" Iceland (MI; surface lava ages $\leq$3.1 Ma) produced from the currently active and recent axes is remarkably homogeneous while the extinct Skagi–Snaefellsnes zone has extremely low values and the older Westfjords and East Iceland regions have slightly enhanced values. The Iceland–Faeroe Ridge (IFR) resembles Iceland (after thermal reduction) while the Greenland–Iceland Ridge has extremely high values. The Iceland "Moho" and the Iceland "lower crust" are special features of ridge–plume interaction and differ from continental Moho and lower crust. Lower crust, only 100 kg/m^3 less dense than uppermost mantle, is assumed to be a plume-generated transitional layer which, directly above the plume centre, belongs rheologically to the asthenosphere.

The regionalized regression results are used to construct a new Moho depth map from the gridded topography file. It compares reasonably to other recent maps. A notable feature is a band of crustal thickening along the SE Iceland shelf edge continuing northward across eastern Iceland to the Jan Mayen Ridge. This and other features suggest an evolution of the North

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Atlantic where a continental edge splinter carried into eastern and perhaps northern parts of Iceland, beside the Jan Mayen Ridge.

Keywords: Iceland; North Atlantic; Crust; Evolution; Topography; Gravity; Seismic data

1. Introduction

Iceland is the "tip of an iceberg" on the Mid-Atlantic Ridge (MAR), where ocean crust is produced in anomalously shallow North Atlantic (Vogt et al., 1990). Regional-free air gravity and the geoid are positive in a broad region. How deep are the sources of these "anomalies"? Is thick crust or deep mantle upwelling the cause of these anomalies? The present controversy of warm "thin" vs. cool "thick" crust is central to these questions. What is the Iceland "Moho", what is the nature of the lower crust and the uppermost mantle material, what is crust–mantle transition and evolution? All these phenomena require extra heat, affecting density and melting, difficult to explain without an Iceland plume—another ongoing controversy.

RRISP Working Group (1980) and Gebrande et al. (1980) estimated a "thin" Icelandic crust of order 15 km above an anomalous mantle. Since the 1990s, new data suggested a "thick" crust (up to at least 40 km) based on wide-angle (WA) reflections (Staples et al., 1997; Darbyshire et al., 1998; Menke et al., 1996, 1998; Smallwood et al., 1999). Combining the "new" crustal thickness values with topography, Menke (1999) assumed Airy isostasy and estimated a low-density contrast at the "Moho" requiring either a low-density, partially molten, top mantle or a high-density, cool lower crust, or a combination of both, difficult to reconcile. Petrology, geochemistry, and high velocities in basaltic crust favor low temperatures, and so does a V_p/V_s ratio of 1.76 and Q_s of 150–225 (300) in the lower crust of central SW Iceland (Menke and Levin, 1994). The mechanisms of effectively, and quickly cooling the crust above a hot mantle are unclear; Menke and Levin suggest hydrothermal cooling of the crust.

The aim is to distinguish or "separate" effects of surface topography and deep processes and to understand the dynamics. At least three components contribute to the prominence of Iceland: (1) spreading of the MAR and lithosphere generation, (2) uplift by anomalously hot, light mantle plume material and plume flow generating dynamic topography (deviation from isostasy), and (3) production of a thick basaltic crust by enhanced melting, generating the Iceland Plateau. Decompression melting of rising plume mantle was estimated to produce 30-km crust (McKenzie and Bickle, 1988; White and McKenzie, 1995; White, 1997) affecting also the surrounding ocean crust (Ritzert and Jacoby, 1985; Darbyshire et al., 1998). The "thick-crust model" poses the question of crustal nature (e.g., Kaban et al., 2002).

Our strategy is to combine topographic (and bathymetric), gravity, and seismic data bearing on crustal thickness and Moho depth and on the "isostatic" situation. We concentrate on the relations topography–Moho depth and gravity–Moho depth. Density–velocity relations must be kept in mind where, e.g., oceanic regions, data are sparse. Data sources are mainly digital topographic and gravity files, published seismic profiles, receiver functions (RF), and surface wave inversions, furthermore, sediment thickness, age, and geological structure.

The study area is 1200×1200 km^2 centered at 18°W, 65°N in Iceland and extending from 59.5°N to 70.5°N and from 5°to 31°W between Greenland, Jan Mayen, the Faeroe Islands, and Hatton Bank. The Iceland Plateau covers nearly one third of the area and is traversed by the spreading North Atlantic Ridge and the aseismic Greenland–Iceland–Faeroe Ridge (GIFR). Moderately deep basins lie between sediment and basalt-loaded continental margins or relicts.

2. Review of the data

The study area is shown in Fig. 1 with geographical names (or abbreviations) and the locations of the seismic data along profiles and at points of Moho depth; wide-angle reflections and stations with derived receiver functions are distinguished.