Remarks on Crustal Structure in Iceland

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In connection with a recent theory of crustal drift and crustal structure in Iceland (Bodvarsson & Walker 1964) it seems desirable to discuss further some facts concerning the gravity field, seismic boundaries, and the geological history of Iceland.

The Bouguer anomaly map is shown in Fig. 1 (after Einarsson 1954 with later additions of gravity stations by the same author, in the northern and northwestern parts). The main feature is a slightly oval bowl, about 75 milligals deep. This bowl may be said to be a mirror picture of the topography and a good first criterion for isostatic equilibrium. Isostatic reduction on the basis of the Airy–Heiskanen crustal model indicates that the Bouguer bowl is best explained by central thickening under the country of original thickness $T = 20$ km (Einarsson 1954). Bodvarsson & Walker (1964, Fig. 7) have made a new reduction, using seismically indicated crustal layers, and find that the facts can be explained by a thickening of a 6 km thick ‘D-layer’ to a 15–20 km thick ‘blister’. Both reductions thus give a similar overall picture.

Going further into details, a main aspect of the gravity field is the fact that the contours of the Bouguer bowl have essentially the same shape as the island—both are slightly oval with an E–W major axis. Moreover, deviations from a regular oval shape are often identical in both. This is for instance clear in the case of the Northwestern Peninsula (Figs. 1 and 2). This fact shows that there is a connection between the gravity anomaly and the present (and geologically late) extent and shape of the island. This is most significant in face of the geological knowledge that the present island is a fragment of an older, much more extensive land area.

Consider first the Northwestern Peninsula. It is built up of Tertiary basalts the total thickness of which is at least several kilometres. The flat-lying basalts are truncated along the coast, and the present peninsula cannot be but a small remnant of an original basalt plateau. Yet, the Bouguer anomaly and, hence, the deeper structure, is closely connected with the shape of this remnant. There is hardly any other explanation of this fact than the assumption that the peninsula was formed by faulting.

On the basis of geomorphologic studies it has been concluded (Einarsson 1963) that marine abrasion of the order of 10 km can be reconstructed on coastal sections in this area exposed to the open sea. Before this (differential) abrasion the coast was still more characterized by straight lines than now. On this basis, and the fact that older base levels for valley erosion have been uplifted to about 300 m above sea-level, it may be concluded that the peninsula was formed by faulting after formation of the basalt plateau and that the position of the main faultlines, bordering the peninsula, is approximately as shown in Fig. 2. The gravimetric and geological interpretations are, therefore, in good agreement with each other.
FIG. 1. Bouguer anomaly map of Iceland; figures in milligals.

FIG. 2. Bouguer anomaly map of northwestern Iceland; figures in milligals. Small circles indicate position of gravity stations. Main faults, inferred from geology, are indicated by straight lines around the peninsula.
For other parts of Iceland, formed by the older Tertiary basalts, the opinion is similarly substantiated that the present contours are in the main the result of faulting with subsequent differential marine abrasion up to about 10 km. The Bouguer bowl is thus related to a fragment of an extensive plateau, left over in a tectonic process. The facts are consistent with the assumption that the crustal structure determining the gravity anomaly, including the main blister under the country, originated in that tectonic process.

Bodvarsson & Walker (1964) suggest a single scheme for the Lower Tertiary, Upper Tertiary, Pleistocene, and Recent volcanism of Iceland: there was, according to their assumption, all the time a relatively narrow volcanic zone, such as the Recent one, while the early borders of the zone drifted gradually apart, all in all some 400 km, because of progressive intrusion of dykes in the axis of the zone. The central 'blister' in the 'D-layer' is supposed to be the expression of these intrusions.

This hypothesis does not well explain the gravity field, neither its details nor general outlines. According to the scheme, and clearly for geometrical reasons, crustal drift of 400 km, and corresponding dyke intrusions, would not have been limited to the present island (which is about 400 km broad) but would have extended many hundred kilometres to the S or SW and N or NE of the present country. If a major gravity anomaly was formed in this process it would have had a clear SW–NE orientation. But there is nothing to suggest that the Bouguer bowl is part of an original Bouguer trough with such orientation. Thus the scheme proposed by Bodvarsson & Walker (1964) seems to require that the axially oriented volcanism did not have a marked gravity effect.

The theory meets another difficulty in connection with seismic boundaries. Pálmason (1963) has summarized his results from thirty seismic profiles in northern and northeastern Iceland in the diagram shown in Fig. 3. The boundary between his layers I ($V = 4.2$ km/s) and II ($V = 5.1$ km/s) sinks under the well-known subsided zone east of Bardardalur but is otherwise horizontal. There are local depressions in the II–III boundary, i.e. they are not general N–S troughs.
The most striking fact about these boundaries is their horizontality and, hence, their independence of geological horizons in the tilted plateau basalts. This is perhaps most obvious in the east. Here the basalts dip 5–8° W, corresponding to the line L (which I have inserted in the diagram, using a dip of 6°). This demonstrates firstly, the difficulty of finding in the seismic boundaries a support for a theory of the deeper geological structure under Iceland.

The nature of the seismic boundaries is still uncertain. It seems to me a likely hypothesis that they are related to zeolite zones (or zones of higher-temperature infillings), such as Walker has demonstrated in Eastern Iceland, and in part to pressure. But whatever the nature of the boundaries, it seems very likely that they would be quite different in a permanently active volcanic zone from what they are outside that zone. The seismic profiles are still few but as far as they go they have revealed no such difference.

FIG. 4. Dips of the Tertiary plateau basalts; simplified. 0 means no dip. Length of fine arrows is proportional to the dip between 1 and 9°. Heavy arrows indicate dips of 10–30°. Hatching: post-glacial volcanic zones.

The geological part of the paper by Bodvarsson & Walker (1964) is largely founded on studies which the author (G. P. L. Walker) has done in eastern Iceland, and on a generalized picture of the rest of the country.

We shall first present a general picture of the plateau basalts (cf. Fig. 4). Along the east coast we have an arcuate strip (A), about 30° of arc, 200 km long and 50 km broad, or less than one-tenth of the area of Iceland. In this strip the dip is W–NW, or towards the neovolcanic zone. In middle western Iceland a strip (B), about $50 \times 100 \text{km}^2$, has SE dip and in northern Iceland a strip (C), about $25 \times 75 \text{km}^2$, has E dip. These strips, dipping towards the neovolcanic zone, have an area of less than 20% of the country and about 30% of the areas occupied by the plateau basalts. But they are prominent in the Icelandic scenery and thus led early observers to the generalization that the plateau basalts dip mainly towards and are symmetrically
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arranged about the neovolcanic zone. However, as revealed by a recent map (Einarsson 1960) shown simplified in Fig. 4, 70% of the basalts do not conform with this 'rule'. Instead, this majority forms a number of large and small blocks dipping in various directions and one can recognize such structures as flexures, anticlines and synclines. In this picture the dips have no genetic relationship to the formation of the basalts themselves but are clearly the result of later tectonic movement. In strip (B) the earliest lavas (thought to be Lower Tertiary) dip about 8° SE, and near the top of the basalts, in groups containing cold climate vestiges, the dip is 6° SE. Only at the top there are lavas of decidedly less dip, in part due to late faulting. This verifies that during building up of the majority of the plateau tilting was faint, the main movement occurring towards the end or after the outpouring of the basalts.

There is ample evidence of an extensive planation of the dipping basalt blocks before a new tectonic phase. In the latter vertical movement was the main manifestation while tilting is much less apparent.

For strip A, or really for its central part where mapping is most thorough, Walker gives a picture rather different from the general one I have given here, i.e. gradual tilting towards the neovolcanic zone concurrent with the building up of the plateau. From this he concludes that this zone existed from the earliest volcanic time as a main site of the volcanism. It is now unnecessary to state that this conclusion lacks support in the remaining 80–90% of the plateau basalts.

In strip A Walker has established the existence of practically horizontal zeolite zones. The horizontality suggests that the zeolites were formed after cessation of tilting, and a confirmation is found in the fact that layering of onyxes, infilling the dipping basalts, are always nearly horizontal. The near-horizontality of the onyxes is a general rule in all the basalt areas, as far as observations go. The onyxes, and probably also the zeolites, are then essentially a post-volcanic phenomenon. This may be understood in hydrological terms: deposition of infillings will require circulation of groundwater and hence (apart from local heat sources) variations in the height of the groundwater level.

Such variations will be found after tectonic movements but much less in the original plateau of nearly horizontal lavas. One may wonder why the onyxes formed only after near-cessation of tilting in strip A, if tilting was gradual during all the long volcanic history.

Summarizing geological and geophysical results one is led to the following picture. The plateau basalts do not generally show a symmetry about the recent volcanic zone across Iceland. Between the outpouring of the main bulk of the basalts and the recent volcanic activity there was a period of tilting, then a period of peneplanation, and, finally, a period of block faulting with vertical movements during which the deeper structure was affected in a way evidenced by the gravity anomalies. Against this background it seems difficult to support the hypothesis that the recent volcanic zone has been a permanent feature ranging as far back in time as the oldest plateau basalts of which the country is built up. In my view this zone which shows a clear relationship to the Mid Atlantic Ridge, cannot be traced farther back than to about the later period of block faulting.

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References


