Gravity, Aero-Magnetism and Earthquakes in SW-Iceland

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ABSTRACT

Gravity, magnetic and earthquake data from an area in SW-Iceland containing a constructive rifting zone are processed, compared and analyzed.

After a predominant bowl-like regional trend has been removed, the residual gravity data are characterized by a negative anomaly of 6-10 milligals that follows the axis of the rifting zone. It is suggested that this anomaly is caused by Pleistocene volcanics buried in the crust and possibly a zone of partial melt at subcrustal depths. Also revealed in the analysis is a clustering of earthquakes in the South Iceland seismic zone around a positive gravity anomaly.

The magnetic signature of the rifting zone is enhanced by directional filtering of the aeromagnetic data. This processing delineates two distinct areas of crustal accretion during the Brunhes epoch, one coinciding with the presently most active part of the plate boundary, the other some 20 kilometers east of it. This is interpreted as a westward shift of the axis of maximum activity in the rifting zone during the last several hundred thousand years.

Directional filtering of the gravity and magnetic data also reveals linear anomalies trending transversely to the rifting zone, but at a 30-40° angle to the estimated direction of plate motion. It is suggested that these cross-grain structures may be the result of magmatism related to contraction cracks developing within the cooling plates as they move away from the plate boundary.

INTRODUCTION

Gravity and airborne magnetic data from the southwest corner of Iceland have been processed and analyzed by newly developed techniques and computer software, partly as a test for these methods. Using these processing techniques, it is possible to isolate and emphasize lineaments in the data. Due to the tectonic origin of the lineaments, the available earthquake data were an ideal supplement to the gravity and magnetic data, as shown by the synergism in their joint interpretation.

The location of the test area is shown in Figure 1. The size of the area was set somewhat arbitrarily at 126x126 km^2, corresponding to a grid of 64x64 points. This covers most of the active volcanic zone in SW-Iceland, henceforth called the western volcanic or rifting zone, with the exclusion of the western part of the Reykjanes peninsula.

THE GRAVITY DATA

The acquisition of the gravity data under discussion was started in the late sixties. Most of it was collected in the early seventies but some dates from

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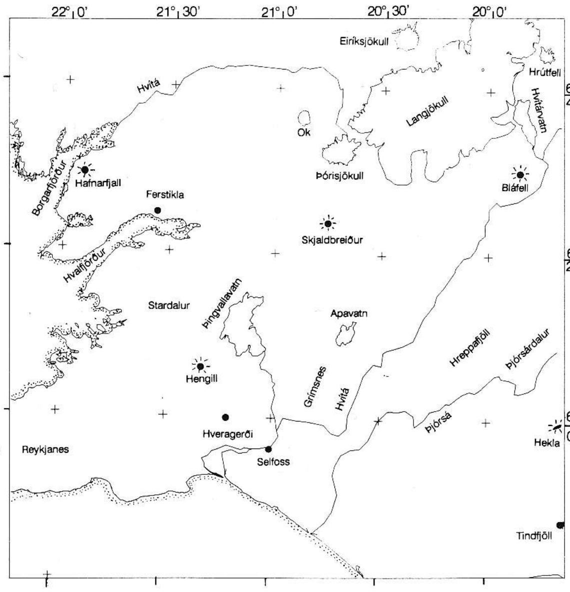

Fig. 1. The location of the research area in southwestern Iceland and the localities mentioned in the article. The size of the research area is 126x126 km^2.

Mynd 1. Staðsetning rannsóknarsvæðisins á Suðvesturlandi og staðanöfn sem koma fyrir í greininni. Stærð svæðisins er 126x126 km^2.

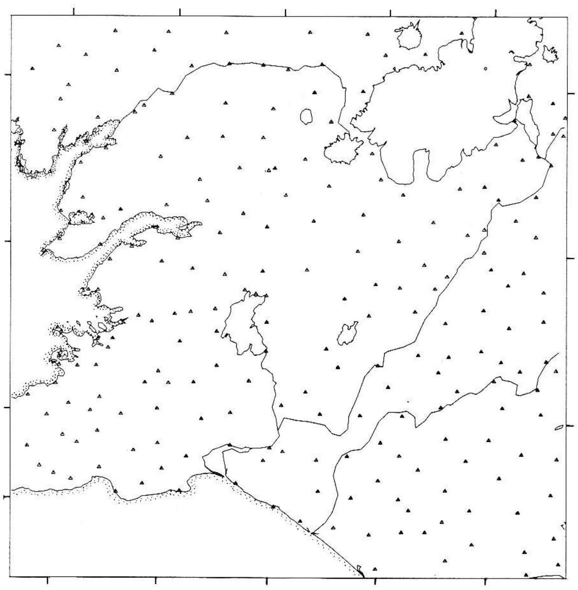

Fig. 2. The gravity stations.

Mynd 2. Þyngdarmælistöðvarnar.

the early eighties. Figure 2 shows the location of the gravity stations.

A Bouguer correction was applied to the data assuming an average rock density of 2500 kg/m^3. In reality, the density varies greatly and any single value for it can do no better than minimize some statistical parameter of the data. The value chosen minimizes the roughness of the Bouguer anomaly surface, as measured by its fractal dimension (Þórarinsson and Magnusson, in press). The resulting map is shown in Figure 3. Its main feature is a steep inland gradient in the gravity; a part of the bowl-like trend noted by Einarsson (1954) to characterize the gravity map of Iceland.

To enhance geologically interesting anomalies and bring out details in the map, the regional trend is removed by finding a suitable field to subtract from the Bouguer gravity data. For this purpose, a succession of two-dimensional polynomials were fitted to the data and analysis of variance (ANOVA) applied to the residual anomaly to test whether a significant reduction had occurred (e.g. Davis, 1973). Table I sums up the ANOVA results and shows quite conclusively that a second order polynomial should be used for the regional trend. Figure 4 shows the second order trend which obviously is a part of the bowl-like gravity low noted before (Einarsson, 1954). Figure 5 shows the residual Bouguer anomaly map after the trend in Figure 4 has been subtracted from the Bouguer anomaly map in Figure 3. Figure 5 will henceforth be referred to as the gravity map.

INTERPRETATION OF THE GRAVITY MAP

The largest anomaly on the gravity map in Figure 5 is the gravity low that stretches from the Reykjanes peninsula in the southwest to the Langjökull glacier in the northeast. This low corresponds to the active western volcanic zone.

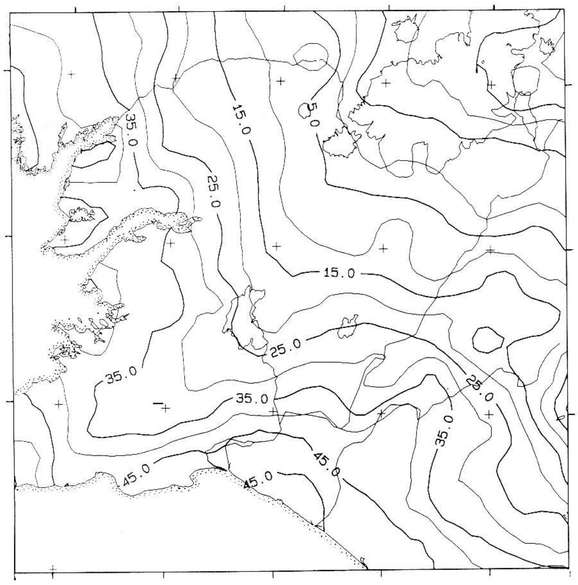

Fig. 3. The Bouguer anomaly map calculated with a Bouguer density of 2500 kg/m^3. Contour lines are 5 milligals apart.

Mynd 3. Bouguer þyngdarkort, reiknað með Bouguer eðlisþyngdinni 2500 kg/m^3. *Milli jafngildislína eru 5 milligal.*

The source of this anomaly could lie both in the crust and the mantle. Volcanic products erupted during the Pleistocene are likely to contain a high proportion of hyaloclastites with lower density than the surrounding basalts erupted in ice-free environment. The surface formations then subside as they are buried by younger volcanics and are carried sideways out of the volcanic zone by plate movements. The crust formed in this way during the Pleistocene is of lower average density than the crust formed by dense lava flows or intrusions, which gives rise to negative gravity anomalies. Another possible source is the layer of partially molten material thought to underlie most of Iceland (Gebrande and others, 1980; Beblo and Björnsson, 1978). This layer is at shallower depth beneath the volcanic zone than under the older Tertiary and Quarternary areas. A thinner crust and a higher degree of melt at the crust-mantle interface beneath the volcanic zone may produce a gravity low (Hersir and others, 1984; Björnsson, 1985). We note that a zone of no reflections was identified by Zverev and others (1980) on a seismic reflection profile that crosses the volcanic zone in SW-Iceland. This zone, interpreted to be a volume of high degree of partial melt, was located at about 8 km depth directly beneath Skjaldbreiður.

TABLE I. ANOVA for polynomials fitted to the gravity data.

TAFLA I. ANOVA reikningar fyrir bakgrunnssvið þyngdarmælinganna.

order of polynom.	goodness of fit	degrees of freedom	F value	F test, $\alpha = 0.95$
1	82.2%	2, 288	667.23	3.00
2	89.5%	5, 285	65.23	2.21
3	89.5%	9, 281	0.08	1.88

Goodness of fit is measured by the coefficient of determination and shows how much the variance in the data is reduced by the polynomial. *Degrees of freedom* are shown for the polynomial and the residual data. The *F value* indicates the improvement in goodness of fit over the increase in variables in the polynomial. We state, with $\alpha = 95\%$ confidence, that the added parameters significantly improve the fit if the F value exceeds the F test statistic listed in the last column.

At Langjökull in the north, the gravity low appears to turn to the east, but no data are available from the glacier. In the south, near Hengill, it turns WSW but does not seem to continue out to the tip of the peninsula as might be expected from the earthquake distribution (Klein and others, 1977; Halldórsson and others, 1984).

There are three main local minima in the gravity low. Counting from the south, the first one is in the tuffaceous mountain complex on the peninsula southwest of Hengill. This low may at least partly be a spurious creation of the Bouguer correction. The second occurs just east of the lake Þingvallavatn, which is in a topographic low in the rifting zone. The third is at Skjaldbreiður, discussed above. Smaller minima appear at the western and eastern

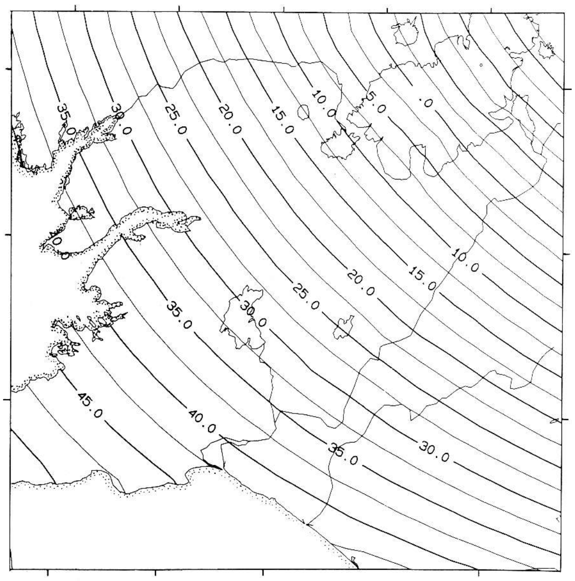

Fig. 4. The second order polynomial trend which is subtracted from the Bouguer anomaly as regional background. This trend is a part of the bowl-like regional trend observed in the gravity map of Iceland. Contour lines are 2.5 milligals apart.

Mynd 4. Bakgrunnssvið þyngdarmælinganna. Frá Bouguer gildunum er dregið bakgrunnssvið sem er fundið með annarrar gráðu fjölliðu. Bakgrunnssviðið er hluti af þeirri skálarlaga þyngdarlægð sem einkennir Bouguer þyngdarkortið af öllu Íslandi. Milli jafngildislína eru 2.5 milligal.

edges of the Langjökull glacier, but no data are available from the glacier so their existence is not well documented.

An alternative view of the particulars of the gravity low has been offered by Sæmundsson (pers. comm.). Rather than focusing on the minima, he points out that they are separated by central volcanic complexes or areas of maximum volcanic production, which might be expected to give rise to positive gravity anomalies. Sæmundsson (in press) has also suggested the existence of two separate rows of volcanic complexes transverse to the rifting zone, which would encompass these local gravity highs.

The second largest gravity anomaly in Figure 5 is a gravity high in the Southern lowlands. This anomaly is separated from a somewhat lesser high in the vicinity of Þjórsárdalur by a NW trending gravity valley. The two highs could either be interpreted as a plateau of high values between the western and eastern volcanic zones in South Iceland, or as two local highs related to extinct central volcanoes. The first interpretation requires an explanation of the gravity low that runs NW from Hekla to the Hreppafjöll mountains and possibly across the rifting zone. The second interpretation requires an explanation of the expansive gravity high in the Southern lowlands, which seems far too large to be produced by a single volcano.

East of this we see a small corner of a deep gravity low, presumably associated with the eastern volcanic zone. The minimum of this low is located at Hekla.

The northwest corner of the map is characterized by relatively high gravity values, reflecting higher density values in geologically older provinces. Superimposed on this are a couple of roughly circular positive anomalies, at Ferstikla by Hvalfjörður and at Hafnarfjall by Borgarfjörður. These are both related to extinct central volcanoes (Franzson, 1978). South of the Ferstikla anomaly there is a lesser gravity high at Stardalur (Friðleifsson and Kristjánsson, 1972), and southwest of it a part of an anomaly with an offshore center. Both anomalies are thought to reflect eroded volcanic centers.

DIRECTIONAL ANALYSIS OF THE GRAVITY MAP

The directionality of the gravity map is analyzed by calculating its two-dimensional power spectrum, shown in Figure 6[1]. The data are first windowed in

1. The gravity map consists of 64x64 grid points based on 290 gravity stations, which means it is heavily overgridded. The spectrum shown in Figure 6, however, is limited to the lower half of the frequency range (32x32 values). The wavelength at the edge of the spectral plot is approximately 8 kilometers. Thus, the contour lines drawn in Figure 6 generally correspond to wavelengths exceeding the distance between stations.

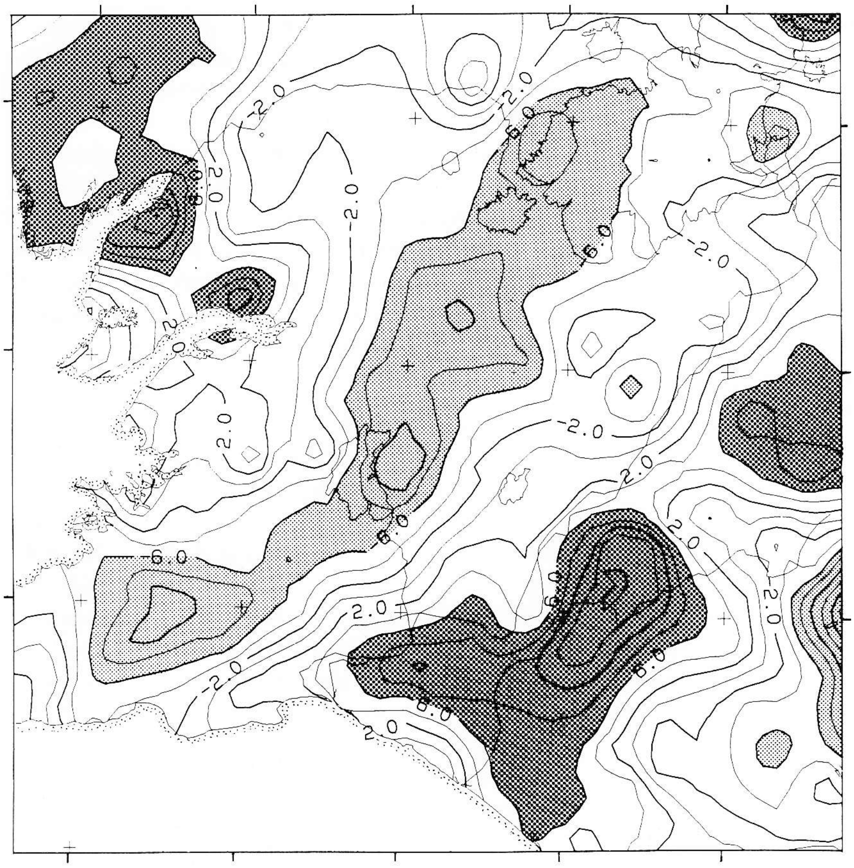

Fig. 5. The gravity map after a regional trend has been subtracted from the Bouguer anomaly. The lighter shade marks areas of gravity less than -6 milligals, while the heavier shade shows areas where gravity values are above 6 milligals. Contour lines are 2 milligals apart.

Mynd 5. Þyngdarkortið eftir að bakgrunnssvið hefur verið dregið frá Bouguer þyngdarkortinu. Á ljósgráu svæðunum eru þyngdargildi lægri en -6 milligal, en á dökkgráu svæðunum eru þau hærri en +6 milligal.

the space domain with a circular Hanning window to reduce leakage, or edge effects, and a periodogram is then calculated from the Fourier transform of the data. The periodogram, without any smoothing in the frequency domain, constitutes our estimate of the power spectrum.

For a map with random values the spectrum consists of concentric circles but for a surface influenced in some particular direction there appear radial peaks in the spectrum indicating the preferred direction of lineaments in the map (Þórarinsson and others, 1988). This allows us to put a quantitative estimate on the lineation in a mapped surface by studying its two-dimensional power spectrum.

Three fairly strong peaks appear in the spectrum depicted in Figure 6[2]. The direction of the largest peak is 30-40° (clockwise from the horizontal), reflecting the rifting zone from Hengill to Langjökull. The second strongest peak points 70-80° and reflects the Hengill-Reykjanes part of the rifting zone. These two peaks merge at lower frequencies (closer to the center of the spectrum) and together they constitute the signal from the gravity low.

The third peak in the power spectrum points 130-140° and represents lineation perpendicular to the general trend of the rifting zone. This peak is noticeably weak at lower frequencies but quite prominent at higher frequencies, indicating a fairly shallow origin. Its main sources are the alignment of the gravity highs in the northeast (Hafnarfjall and Ferstikla) and the Hekla-Hreppafjöll gravity low.

2. A fourth peak appears at high frequencies pointing straight north and south, but this is probably a spurious signal due to edge effects in the Fourier Transform.

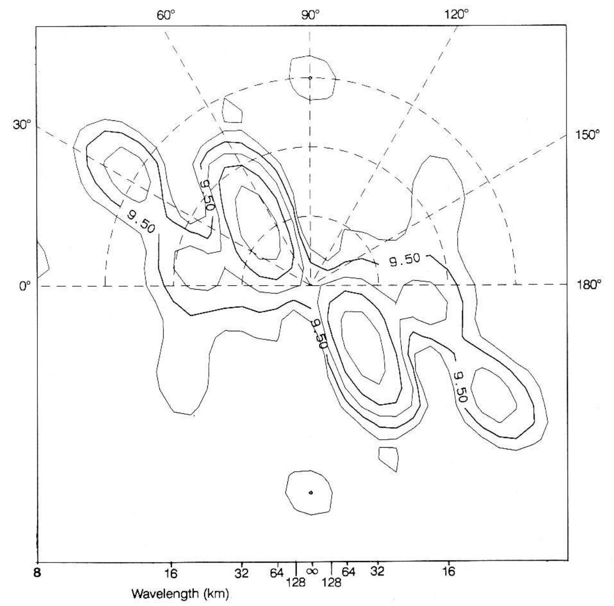

Fig. 6. The power spectrum of the gravity map. The spectrum is symmetric about the origin. A protractor is superimposed on the upper half of the spectrum to help in its inspection. Frequencies are lowest (longest wavelengths) at the center and increase radially outwards to the Nyquist frequency at the edges. Spectral anomalies are perpendicular to the space domain lineaments they represent; hence, lineaments running north-south in the space domain result in horizontal anomalies while east-west lineaments create vertical anomalies in the spectrum.

At low frequencies the energy in the gravity spectrum is located in the upper-left and lower-right quadrants, corresponding to a broad gravity anomaly of a general NE-SW direction, but at higher frequencies this separates into two major peaks. A third high frequency peak appears in the lower-left and upper-right quadrants, corresponding to narrower anomalies running NW-SE in the gravity map.

Mynd 6. Afróf þyngdarkortsins er samhverft um miðjuna. Yfir efri helminginn er lagður gráðubogi svo auðveldara sé að lesa úr aflrófinu. Tíðni er lægst í miðjunni og vex síðan í Nyquist tíðni á brúnunum. Frávik jafngildislína í aflrófinu frá sammiðja hringjum standa hornrétt á þær meginlínur í kortinu sem valda þeim. Þannig veldur norður-suður stefna á kortinu láréttu fráviki í aflrófinu og lóðrétt frávik í aflrófi svarar til austur-vestur stefnu meginlína á kortinu.

Í aflrófinu er lágtíðniorkan einkum í efri fjórðungi til vinstri og neðri fjórðungi til hægri, sem svarar til breiðs þyngdarfráviks með stefnu NA-SV, en við hærri tíðni klofnar þetta í tvo toppa. Þriðji hátíðnitoppurinn í aflrófinu er í neðri fjórðungi til vinstri og efri fjórðungi til hægri, en það svarar til mjórra þyngdarfráviks með stefnu NV-SA.

As mentioned earlier, Sæmundsson (in press) suggests two rows of volcanic complexes which would stretch across the gravity map in Figure 5. Most of the complexes are accompanied by positive gravity anomalies. The first row starts at Kollafjörður in the west[3], crosses the rifting zone at Hengill and extends across the gravity high in the southern lowlands to Hekla (a gravity low). The second row starts at Hafnarfjall and Ferstikla in the NW corner of the map, crosses the rifting zone at the relatively high gravity values between Þingvellir and Skjaldbreiður and reaches east to the positive anomaly at Þjórsárdalur.

The proposed rows of volcanic complexes follow the direction of relative plate motion, N280-285°E, as calculated from the plate rotation pole of Minster and Jordan (1978), and might be interpreted as trails created by foci of high volcanic productivity in the rifting zone. It must be noted, however, that an indication of lineation with this direction is conspicuously missing from the power spectrum in Figure 6.

THE MAGNETIC DATA

The aeromagnetic data were mostly acquired in 1968-1980 with several lines added in 1985-1986. The magnetic field values in the latter have been corrected for secular variation to make them compatible with the earlier data. The flight altitude was

3. The Kollafjörður and Stardalur central volcanoes, which belong to this group, are discussed in the following chapter on interpretation of the magnetic anomalies.

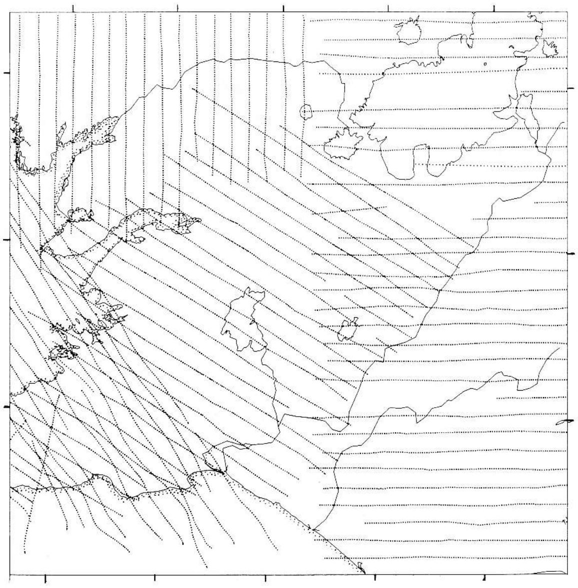

Fig. 7. The flight lines in the aeromagnetic survey.

Mynd 7. Fluglínur segulmælinganna.

900-1200 meters above sea level. Figure 7 shows the aeromagnetic survey lines. Figure 8 shows the residual aeromagnetic field in SW-Iceland after the removal of a linear trend, henceforth referred to as the magnetic map.

Further enhancement of geologically interesting magnetic anomalies depends on defining suitable criteria for the anomaly separation. Inspection of the map shows it to be dominated by NE-SW trending lineaments and the geological significance of this linearity is quite clear since it is known to be the strike of the active rifting zone.

The directionality of the map is more rigorously analyzed by calculating its two-dimensional power spectrum, shown in Figure 9[4]. If no lineation occurred in the map the spectrum should consist of concentric circles, but the strong NE-SW lineation produces an elongation of the spectrum perpendicular to that direction. The NE-SW trend can be separated from the rest of the magnetic field by directional filtering (Þórarinsson and others, 1988), and this turns out to be an effective enhancement technique. The filtering is accomplished by cutting out a pie slice from the spectrum containing only the dominant trend and transforming it back to a regular space domain map, leaving out the rest of the magnetic field (Þórarinsson and others, 1988). The positive magnetic anomalies[5] thus separated out of the magnetic map are shown in Figure 10, henceforth referred to as the magnetic anomaly map.

In addition to the main trend discussed above, the magnetic spectrum also contains a high-frequency peak representing NW-SE striking lineaments. The main source of this signal is a negative magnetic anomaly which coincides with the Hafnarfjall-Ferstikla gravity high. These cross-grain anomalies, oriented perpendicular to the rifting zone, are discussed in more detail below.

INTERPRETATION OF THE POSITIVE MAGNETIC ANOMALIES

The magnetic anomaly map in Figure 10 is dominated by two large anomalies. The first one starts at the coast, encompasses the Hengill area and runs up to the gravity low east of Þingvellir discussed earlier. North of Þingvellir it appears to continue as a much narrower anomaly up to Skjaldbreiður, but this could be a filtering effect. The second anomaly starts in Grímsnes, an area that was volcanically active up until a few thousand years ago, runs to the northeast and terminates near the gravity minimum on the eastern edge of the Langjökull glacier discussed earlier. Taken together, the two anomalies

4. The spectrum shown in Figure 9 includes 32x32 values and the wavelength at the edge of the spectral plot is approximately 8 kilometers. The average distance between flight lines is about 4 km and the sampling distance along the lines is about an order of magnitude less. The contour lines plotted thus correspond to wavelengths longer than the distance between data points.

5. The directionally filtered map contains both positive and negative anomalies parallel to the Hengill-Langjökull rifting zone, but the strongest signal is due to the positive anomalies which reflect volcanism in the Brunhes epoch. This signal is further emphasized in Figure 10 by applying a threshold filter of +250 nanotesla to the directionally filtered map.

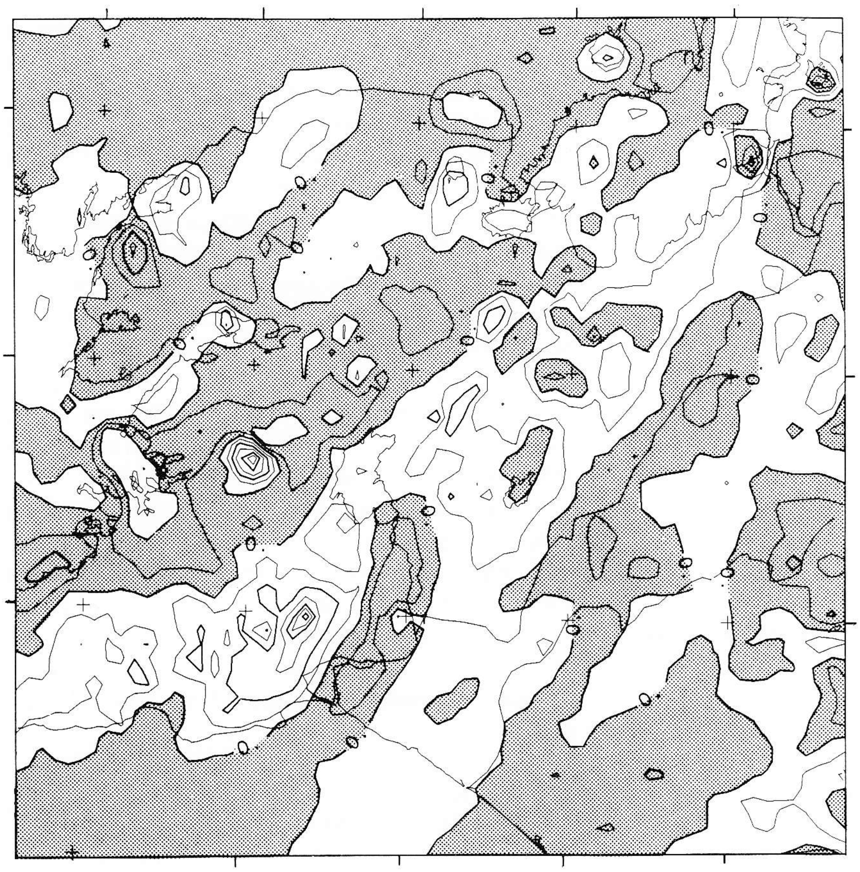

Fig. 8. The magnetic map. Contour lines are 500 nanotesla apart (1 nanotesla = 1 gamma). Shaded areas indicate negative values.

Mynd 8. Flugsegulkortið. Milli jafngildislínanna eru 500 nanótesla. Skyggð svæði sýna lágan segulsviðsstyrk.

form what might be referred to as the Brunhes magnetic lineation (Jónsson and others, in press).

A host of smaller anomalies is also present in the map, some due to geological phenomena and some due to topography. The fact that they are elongated NE-SW is for some of them an artifact of the directional filtering. To properly study those anomalies, a magnetic map should be gridded on a smaller scale and the appropriate anomaly separation techniques applied to each case individually. The filtered map should be studied with this in mind.

Several anomalies are present on the Reykjanes peninsula west of the Hengill area. They reflect the en echelon distribution of volcanically active fissure swarms on the Reykjanes peninsula (Jakobsson and others, 1978; Jónsson and others, in press).

South of Hvalfjörður, an anomaly occurs over the eroded Stardalur volcanic center (Friðleifsson and Kristjánsson, 1972; Kristjánsson, 1987), accompanied by a localized high in the gravity map (Fig. 5). West of that, an anomaly is seen at the mouth of Hvalfjörður, presumably a signal from the so-called Kollafjörður central volcano[6]. Further north there are anomalies associated with the Hafnarfjall and Ferstikla central volcanoes and magnetic lineations caused by the tilted Pliocene lava pile.

In the northeast quarter of the map are several notable anomalies. The first occurs over the shield volcano Ok, the second is over the southwest corner of Langjökull, the third is over the center of the

6. Both these magnetic anomalies, at the Stardalur and Kollafjörður central volcanoes, actually seem elongated NW-SE on an unfiltered map. It might also be noted that both anomalies were observed to correspond to rather large localized highs (≈10 milligals) on the gravity map of Einarsson (1954).

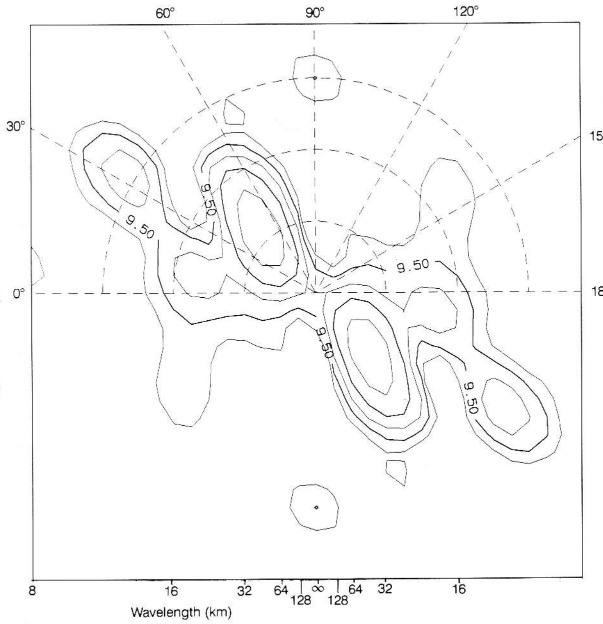

Fig. 9. The power spectrum of the magnetic map. For a general explanation of the spectrum see Figure 6. The NE-SW lineation apparent in the magnetic map dominates the spectrum, but turns out to be composed of two directional components, 45° at low frequencies (near the center of the spectrum) and 30° at higher frequencies. This reflects the en echelon pattern exhibited by the magnetic anomalies in Figure 10. A high frequency peak is also seen in the spectrum at 135°. This corresponds to the magnetic anomalies depicted in Figure 11.

Mynd 9. Aflróf segulkortsins. Skýringar varðandi aflróf eru gefnar með mynd 6. NA-SV stefna gosbeltisins er ríkjandi í aflrófinu, en reynist samsett úr tveimur þáttum. Lága tíðnin (nær miðju aflrófsins) stefnir 45°, en hærri tíðnin stefnir 30°. Þetta endurspeglar skástíga legu segulfrávikanna á mynd 10. Auk þessa er í aflrófinu hátíðnitoppur sem stefnir 135° og svarar til segulfrávikanna á mynd 11.

glacier, and the fourth over the glacier Eiríksjökull. The second anomaly is geologically most interesting. It coincides with an apparent gravity minimum (inadequately defined over the glacier) and intensive seismic activity in a volcanically productive area.

East of the rifting zone there is an anomaly over Hreppafjöll as well as several anomalies on the eastern edge of the map. Two of them are associated with the volcanoes Tindfjöll and Hekla while the others appear to be topographically induced.

CROSS-GRAIN STRUCTURES

As mentioned earlier, the gravity and magnetic spectra both contain a high frequency energy peak transverse to the main trend along the rifting zone. Separating these features out of the respective maps reveals a positive gravity lineament (Hafnarfjall-Ferstikla) and a suite of negative magnetic lineaments (Figure 11). The most prominent magnetic anomaly extends from the rift zone near the southern part of Þingvallavatn northwest across Hvalfjörður and Borgarfjörður where it coincides with the positive gravity anomaly. A similar linear anomaly in seismic velocities was noted by Pálmason (1971) and interpreted as reduced depth down to layer 3. The lineament cannot be regarded as seismically active. Figure 11 shows the seismic anomaly superimposed on the positive gravity and negative magnetic anomalies which have been passed through a narrow NW-SE oriented directional filter.

Certain portions of these lineaments seem to have their origin in recognized volcanic complexes such as Stardalur, Kollafjörður and Ferstikla, but their apparent organization into lineaments transverse to the rifting zone requires an explanation. The NW-SE direction differs from both the relative plate motion (N280-285°E) and the plate motion with respect to a fixed hot-spot reference frame (N277E° and N282E°) as estimated from the plate motion models of Minster and Jordan (1978). This suggests that the lineaments cannot be just trails of volcanic centers, emanating from active spots in the volcanic zone or embedded in the mantle below.

One possibility is that the lineaments correspond to contraction cracks within the cooling plate as it moves away from the plate boundary. The component of contraction perpendicular to the boundary is simply added to the drift velocity while the component parallel to the boundary leads to contraction cracks that are perpendicular to trajectories of equal

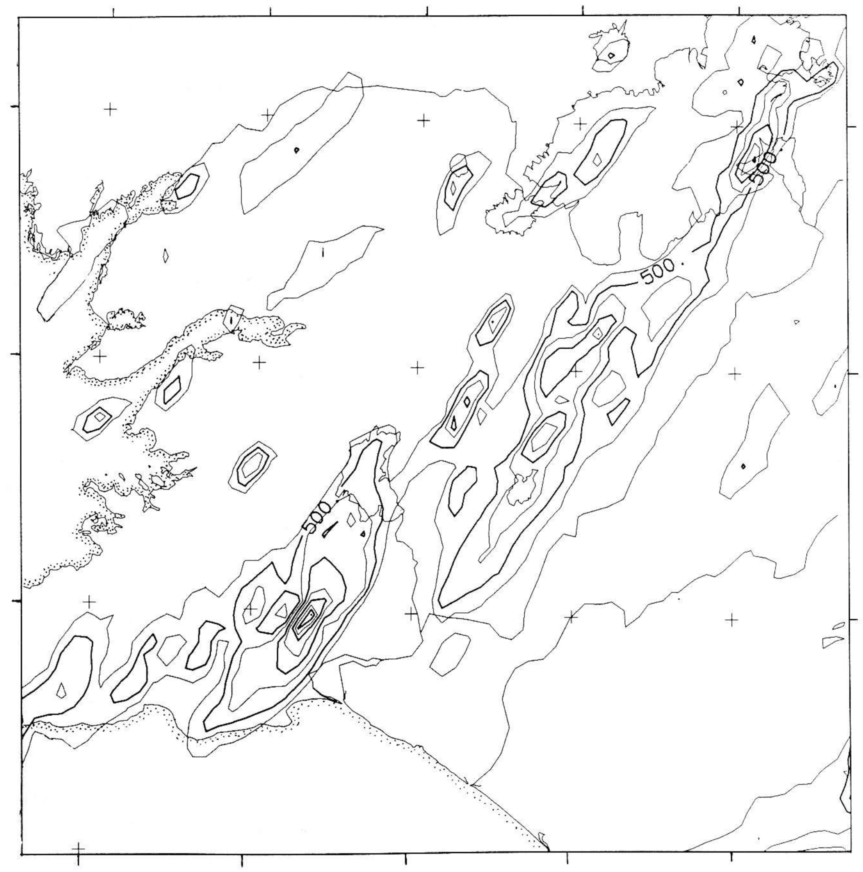

Fig. 10. The magnetic anomaly map, showing the positive anomalies in the magnetic map after directional filtering along the axis of the Hengill-Langjökull rifting zone. The filter direction is 40° and its width is 80° (out of 180°). The contour lines start at 250 nanotesla and are 250 nanotesla apart.

Mynd 10. Segulkort sem sýnir jákvæð segulfrávik stefnusíuð eftir ás gliðnunarbeltisins Hengill-Langjökull. Stefna síunnar er 40° og breiddin er 80° (af 180°). Jafngildislínur byrja í 250 nanótesla og milli þeirra eru 250 nanótesla.

temperature, i.e. perpendicular to the constructive plate boundary. In an oblique rift zone the direction of such cracks would not be the same as the direction of plate motion. These cracks are likely to be preferred locations for off-rift magmatism (Pálmason, 1981), leading to anomalous magnetization and linear magnetic and gravitational anomalies.

THE EARTHQUAKE DATA AND THE GRAVITY MAP

Figure 12 shows epicenters of earthquakes superimposed on the gravity map. The earthquakes are in the magnitude range 1.5-5.8 and occurred during the time interval 1974-1987. Parts or all of these data have been published previously (Einarsson and others, 1981; Einarsson and Sæmundsson, 1987; Foulger, 1988a; Einarsson, 1989). The data are obtained from a permanent network of short period seismographs, which has a station spacing of 10-45 km in this area (Einarsson and Björnsson, 1987). Most epicenters are located with standard errors smaller than 2 km, as calculated with the location program HYPOINVERSE (Klein, 1978).

The epicenters follow the plate boundaries quite faithfully, i.e. the active volcanic zones and the South Iceland seismic zone that stretches across the southern lowlands near 64° N latitude. The seismicity is not evenly distributed along these zones, however. It shows a persistent clustered pattern. The two westernmost clusters are related to geothermal areas, the Krísuvík and Hengill areas. The seismic activity here is quite persistent from year to year, and in the case of Hengill it has been shown to be related to the process of heat extraction from the crust (Foulger, 1988b). Both areas seem to be unrelated to any particular features in the gravity map.

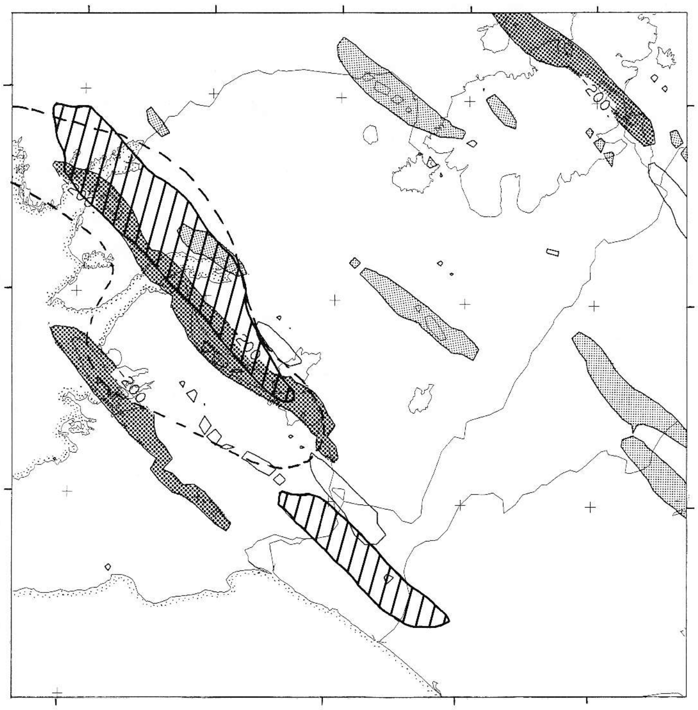

Fig. 11. The cross-grain structures. The hatched areas show filtered gravity anomalies exceeding 4 milligals while the shaded areas show filtered negative magnetic anomalies below -200 nanotesla. Both data sets were passed through a narrow directional filter oriented 135° with a bandwidth of 40°. Also shown by a heavy broken line is the contour line drawn by Pálmason (1971) encompassing an area with depth less than 2.5 kilometers down to seismic layer 3.

Mynd 11. Meginlínur þvert á gliðnunarbeltið. Strikuðu svæðin sýna síuð þyngdarfrávik yfir 4 milligal en gráu svæðin sýna síuð segulfrávik undir -200 nanótesla. Bæði þyngdar- og segulkortið voru síuð með þröngri stefnusíu sem sneri 135° og var 40° breið. Brotna línan umlykur svæði þar sem dýpi á hljóðhraðalag 3 er minna er 2,5 kílómetrar (Guðmundur Pálmason 1971).

Two clusters coincide with gravity lows in the western volcanic zone. Both are characterized by swarm activity. The southernmost one, at the shield volcano Skjaldbreiður, had substantial swarms in 1984 with the largest event reaching magnitude 4.5. The northernmost cluster, near Langjökull, is to a large degree due to a swarm in 1985, with the strongest earthquakes exceeding magnitude 4.

In contrast to the volcanic zone, the E-W transform zone in South Iceland does not show any obvious correlation with lineaments in the gravity map. The South Iceland seismic zone cuts across a positive gravity anomaly, the highest one in the map. A pronounced epicentral cluster occurs near the apex of the anomaly. This cluster is a persistent feature of the seismicity, and may represent an area of stress concentration around an asperity in the crust. The gravity anomaly indicates irregularity in the crustal structure, possibly the source of the stress concentration.

The easternmost earthquake cluster all belongs to a single sequence of events in May 1987. The sequence was a typical foreshock-mainshock-aftershock sequence, with a mainshock of magnitude 5.8. The event was associated with right-lateral strike-slip on a vertical, N-S striking fault (Bjarnason and Einarsson, in press). The mode of faulting is thus similar to that of previous large earthquakes in the transform zone as interpreted from surface features (Einarsson and Eiríksson, 1982).

ANOMALIES IN THE VOLCANIC ZONE

Figure 13 shows a composite map of the earthquakes and the gravity low and magnetic high observed in the volcanic zone. The gravity anomaly presumably is generally deep-seated, with roots extending at least 5-10 kilometers downward. One must bear in mind, however, that a part of the anomaly may be a fictitious creation of the Bouguer correction, due to unsuitable density values. Most of the magnetic anomaly has a much shallower origin, probably no more than 2 kilometers. The earthquakes plotted here all have their origin at depths less than 10-15 kilometers.

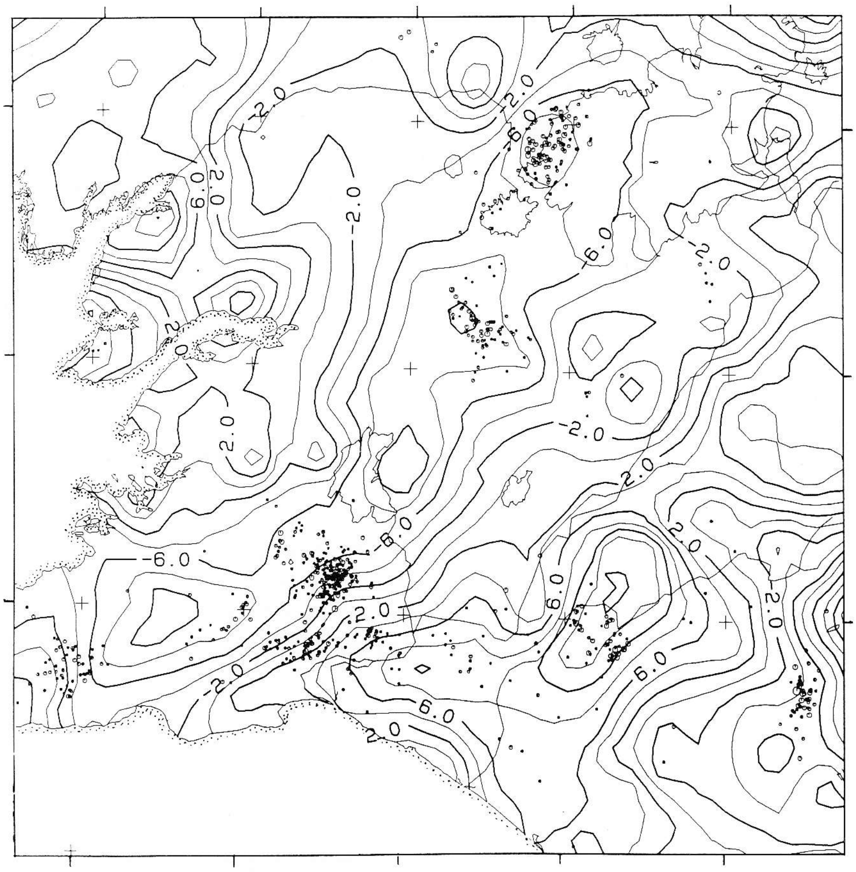

Fig. 12. Locations of earthquakes from 1974 to 1987 superimposed on the gravity map. Gravity contours are 2 milligals apart.

Mynd 12. Staðsetning jarðskjálfta frá árunum 1974 til 1987 merkt á þyngdarkortið. Milli jafngildislínanna eru 2 milligal.

It is evident from the map that the earthquakes can be separated into two groups: those that occur in the volcanic areas and those that occur in the South Iceland seismic zone.

The two prominent magnetic anomalies presumably show where magmatism has been most active during the Brunhes magnetic epoch (the last 0.7 million years). The southern anomaly is aligned with the gravity low and seismically very active. The anomaly and its continuation to the northeast through the gravity low, as well as the earthquake swarms at Skjaldbreiður and the glacier Langjökull, trace the presently active rifting zone (Sæmundsson, 1979). The northern anomaly is located some 20 kilometers east of the center of the rift and is only moderately seismically active. The last volcanic episode in that area was probably the one that produced the Grímsnes lavas 5-6000 years ago (Jakobsson, 1966).

The arrangement of the two magnetic anomalies relative to the presently active rifting zone shows a westward shift in the activity of the plate boundary on a time scale of hundreds of thousands of years. A gradual westward movement of activity has also been demonstrated in the geological mapping of the Hengill volcanic system by Kristján Sæmundsson (e.g. Björnsson and others, 1974; Árnason and others, 1986). This pattern of westward movement has also been noted by Þórarinsson and others (1988) and Foulger (1988a).

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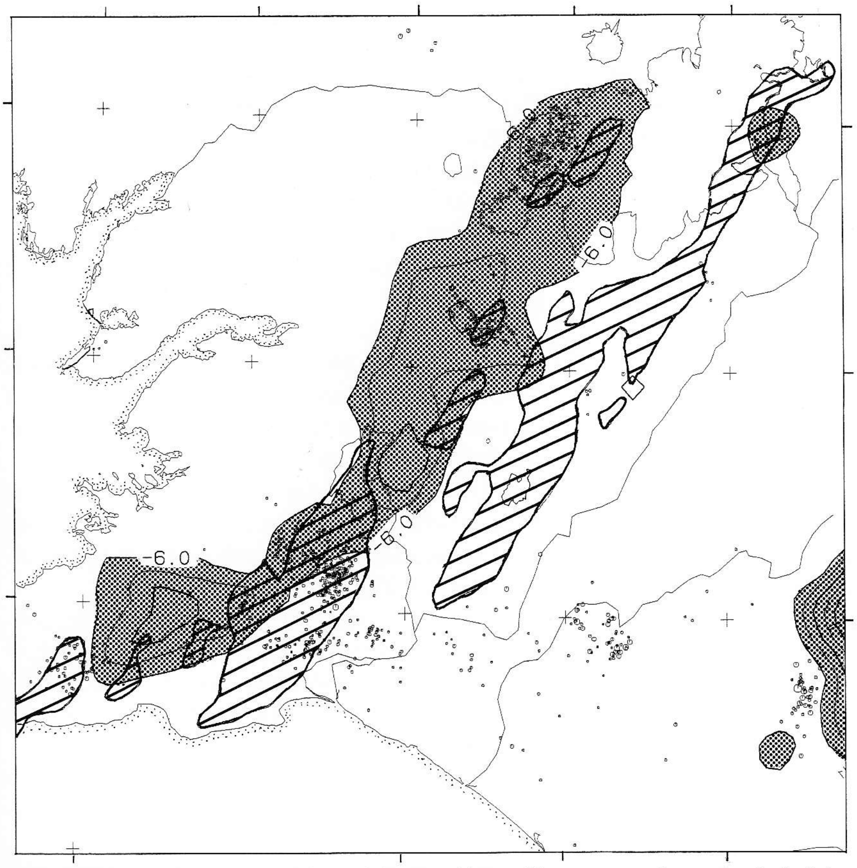

Fig. 13. The seismically and volcanically active areas are depicted by the gravity low (shaded), the directionally filtered magnetic high (hatched) and recent earthquakes (1974-1987).

Mynd 13. Skjálftavirk og eldvirk svæði endurspeglast í þyngdarlægð (gráskyggð), stefnusíuðum segulhæðum (strikaðar) og jarðskjálftum undanfarinna ára (1974-1987).

aeromagnetic data were collected by Þorbjörn Sigurgeirsson at the University of Iceland Science Institute in 1968-1980. Leó Kristjánsson and others (1989) reprocessed these measurements and added several lines flown in 1985-86. The seismic data were compiled at the University of Iceland Science Institute by Páll Einarsson.

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Ágrip

ÞYNGDARMÆLINGAR, SEGULMÆLINGAR OG JARÐSKJÁLFTAR Á SUÐVESTURLANDI

Þyngdarmælingar og flugsegulmælingar frá suðvesturhorni Íslands voru túlkaðar með nýjum aðferðum og bornar saman við jarðskjálftamælingar. Mynd 1 sýnir rannsóknarsvæðið.

Staðsetning þyngdarmælistöðva er sýnd á mynd 2 og Bouguer-leiðrétt þyngdarsvið á mynd 3. Notuð var Bouguer eðlisþyngdin 2500 kg/m^3 sem gefur sléttastan flöt á leiðréttu þyngdarsviði. Megineinkenni Bouguer-sviðsins er að því hallar inn til landsins. Til þess að draga fram smærri drætti í kortinu er bakgrunnssvið dregið frá Bouguer-gildunum með fjölliðu, sem valin er með tölfræðilegum aðferðum. Mynd 4 sýnir hið reiknaða bakgrunnssvið og mynd 5 sýnir þyngdarkortið eftir þessa reikninga.

Stærsta frávikið á mynd 5 er þyngdarlægð sem fylgir nokkurn veginn gliðnunarbeltinu frá Reykjanesskaga til Langjökuls. Ekki er ljóst hvort hún stafar fremur af lágri eðlisþyngd móbergsmyndana í skorpunni eða hlutbráðins lags á meira dýpi. Í þyngdarlægðinni eru grynningar á Hengilssvæðinu og milli Þingvallavatns og Skjaldbreiðs, þar sem upphleðsla af völdum eldvirkni hefur verið mest.

Næststærsta frávikið er þyngdarhæð á Suðurlandsundirlendi. Norðaustan hennar er þyngdarhæð við Þjórsárdal og eru þær aðskildar af dal í þyngdarsviðinu sem gengur frá Heklu norðvestur yfir Hreppafjöll og jafnvel yfir gosbeltið. Þyngdarhæðirnar má að hluta skýra sem áhrif frá rofnum megineldstöðvum.

Í norðvesturhorni kortsins eru almennt há þyngdargildi sem endurspegla hærri eðlisþyngd í eldra bergi. Við það bætast þyngdarhæðir við Hafnarfjall og Ferstiklu og aðrar minni við Stardal og Kollafjörð. Allar eru þær taldar tengjast fornum megineldstöðvum.

Mynd 6 sýnir tvívítt aflróf þyngdarkortsins. Með því má stefnugreina kortið, þ.e. leggja tölulegt mat á það hvaða strikstefnur móta lögun þyngdarsviðsins. (Athugið að toppar í stefnurós aflrófsins eru hornréttir á þau frávik í kortinu sem þeir svara til.) Þrjár aðalstefnur koma í ljós: 30-40°, 70-80° og 130-140°. Tvær þær fyrri svara til þyngdarlægðarinnar sem áður var lýst, en sú þriðja, sem snýr þvert á gosbeltið, stafar frá Hafnarfjalls-Ferstiklu þyngdarhæðunum og frá þyngdardalnum sem aðskilur þyngdarhæðirnar á Suðurlandi.

Fluglínur segulmælinganna eru sýndar á mynd 7 og segulkortið (að frádregnum sléttum fleti fyrir bakgrunnssvið) er sýnt á mynd 8. Meginfrávikin í þessu korti snúa öll NA-SV, sem er stefna gosbeltisins. Mynd 9 sýnir aflróf segulkortsins. Þar sést að NA- SV stefnan er samsett úr tveimur þáttum, lágtíðni sem stefnir 45° og hátíðni sem stefnir 30°, og ennfremur kemur í ljós hátíðnistefna þvert á gosbeltið, NV-SA.

Til þess að skoða betur þann þátt segulsviðsins sem svarar til gosbeltisins er segulkortið stefnusíað með breiðri síu NA-SV. Þar sem aðalfrávikið er segulhæð eftir gosbeltinu eru á mynd 10 aðeins sýndar jafngildislínur segulsviðs yfir ákveðnu lágmarksgildi, 250 nanótesla. Þar kemur í ljós að segulhæð gosbeltisins skiptist í tvennt. Syðri hæðin nær frá Þingvallavatni yfir Hengilinn og suðvestur í sjó, en sú nyrðri frá Grímsnesi norðaustur undir Langjökul. Auk þessara tveggja meginhæða eru svo smærri frávik í kortinu, einkum tengd megineldstöðvum.

Til þess að draga fram þau línulegu fyrirbæri í þyngdar- og segulkortunum, sem fram koma í stefnugreiningunni þvert á gosbeltið, eru kortin stefnusíuð með þröngri síu NV-SA. Þær þyngdarhæðir og segullægðir sem þá koma fram eru sýndar á mynd 11 ásamt upplýsingum um dýpi á hljóðhraðalag 3. Stungið er upp á að þverstefnan í kortunum geti stafað af eldvirkni utan gliðnunarbeltisins í samdráttarsprungum sem myndist þvert á plötuskilin þegar plöturnar rekur burt og þær kólna.

Á mynd 12 er staðsetning jarðskjálfta á árunum 1974-1987 borin við þyngdarkortið. Meirihluti skjálftanna liggur í eða við þyngdarlægðina sem fylgir gosbeltinu frá Reykjanesi að Langjökli. Auk þess verða skjálftar á Suðurlandsskjálftabeltinu, einkum í kring um þyngdarhæðina á Suðurlandi. Austast er svo þyrping skjálfta sem tilheyra einni hrinu frá 1987.

Á mynd 13 eru sýnd helstu frávik sem tengjast gosbeltinu, nefnilega þyngdarlægðin, segulhæðirnar og jarðskjálftarnir. Syðri segulhæðin fellur saman við þyngdarlægðina á Hengilssvæðinu og þar er mikil skjálftavirkni. Skjálftar og þyngdarlægð fylgja síðan virka gliðnunarbeltinu til norðausturs upp í Langjökul. Nyrðri segulhæðin er hins vegar rúmlega 20 kílómetra austan við gliðnunarbeltið og þar er lítil skjálftavirkni. Virkni í nyrðri hluta gosbeltisins hefur því greinilega færst vestur á bóginn á Brunhes-segulskeiðinu (síðustu 0,7 milljónir ára) og er það í samræmi við þá tilfærslu á virkni sem hefur orðið innan Hengils- kerfisins á sama tíma.