Deep-Sea Research, 1966, Vol. 13, pp. 427 to 443. Pergamon Press Ltd. Printed in Great Britain.

Magnetic anomalies over the Reykjanes Ridge*

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(*Received* 12 *November* 1965)

Abstract—A detailed aeromagnetic survey has been made over a large portion of the Reykjanes Ridge. The magnetic pattern observed displays great linearity, parallel to the topographic trend of the ridge and has the topographic crest as an axis of symmetry. The identification of two main magnetic provinces, noted in previous studies of the mid-ocean ridges, is confirmed. Possible relations between the structures of the Icelandic Plateau and the Reykjanes Ridge were investigated.

INTRODUCTION

EWING, HEEZEN and HIRSHMAN (1957) first suggested that a distinct magnetic anomaly, which had been observed on a few widely separated crossings of the mid-ocean ridge crest might be characteristic of the entire length of the ridge crest. Within recent years the cumulative number of magnetic profiles across the crest, at various latitudes and in various oceans, has shown that the ridge does have characteristic anomalies and has permitted a much more accurate description of these anomalies (HEIRTZLER and LE PICHON, 1965; MATTHEWS, 1965; VACQUIER and VON HERZEN, 1964).

An extensive magnetic survey off the west coast of North America (MASON, 1958; MASON and RAFF, 1961; RAFF and MASON, 1961), an extensive but much less systematic survey off the east coast of North America (DRAKE, HEIRTZLER and HIRSHMAN, 1963) and more recent surveys of several smaller areas (for example, HEIRTZLER, 1965; PETER and STEWART, 1965) have shown that magnetic anomalies may have great linearity over distances of hundreds to thousands of kilometers. Since the mid-ocean ridge crest was known to have a major magnetic anomaly and there were indications that it had a linear character a survey of the ridge was planned in 1961. It was anticipated that the ridge survey would help to elucidate the origin of the linearity of the magnetic features which might possibly be related to ridge formation.

Many of the smaller wave-lengths of magnetic profiles across the ridge are approximately 10 km in width and any detailed survey of the ridge should have a track spacing of no more than this distance. To survey a reasonably large area with this track spacing requires the utilization of electronic navigational methods. A portion of the Mid-Atlantic Ridge southeast of Iceland, known as the Reykjanes Ridge, was selected for a detailed magnetic survey because (a) it was known to have one of the largest magnetic anomalies of the mid-ocean ridge system, (b) it had adequate LORAN A coverage, (c) there was a magnetic observatory nearby and records were available for the removal of time variations of field strength and (d) there was an operating base for an aeromagnetic survey aircraft at Keflavik (Fig. 1). This survey was undertaken

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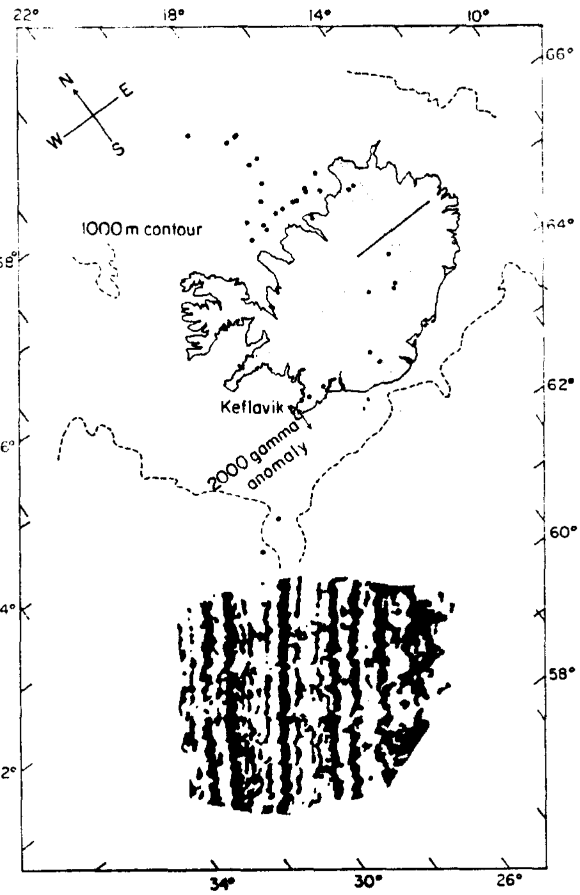


Fig. 1. The magnetic survey area southwest of Iceland. Positive anomalies are shown in solid black. The belts of Quarternary volcanics in Iceland are shaded (after BODVARSSON and WALKER, 1964). Epicenters north of the survey area are represented by solid dots (after SYKES, 1965). The line in eastern Iceland locates the geologic section used in Fig. 11.

as a Lamont Geological Observatory–U.S. Naval Oceanographic Office co-operative project during October and November of 1963.

For the first time, this study reveals in detail the magnetic pattern over a large area of the mid-ocean ridge, in a place where its identification as a mid-ocean ridge is beyond doubt. Previous studies, however, had provided several important results. It is now recognized that there is a distinct anomaly (called the axial anomaly) associated with the topographic crest of the ridge. The axial anomaly appears, everywhere, to be caused by a strongly magnetized body of about 10 km width, 6–10 km thickness with its top at the sea floor and extending along the ridge crest. This anomaly is apparently small or absent near and within the fracture zones. While very accurate magnetic surveys in the open ocean have not been possible (because of navigational problems) there were clear indications that other ridge anomalies paralleled the axial anomaly for some distance out on the flanks. Aside from the axial anomaly, an axial zone of anomalies has been recognized. Anomalies of this zone are characterized by a shorter wave-length than the flank anomalies, and this characteristic cannot be accounted for by the difference in water depth between crest and flanks. The bodies responsible for the anomalies of the axial zone appear to be entirely within the basaltic upper layer of the crust (" basement " or " layer 2 "). It has been noticed that the regional value of the magnetic field strength, when averaged over the axial zone anomalies, may be reduced by several hundred gammas (10^{-5} oersteds = 1 gamma) from the adjacent regional value. This depressed region, localized around the axial anomaly, corresponds to a region of high average heat flow where a comparison has been possible. The deficit of magnetic material which causes this lowering of regional field strength could be caused by an elevation of the Curie isotherm.

The mid-ocean ridge system has long been known to be the seat of seismic activity. Only recently have seismic recording, reporting and analysis techniques allowed very accurate epicenter determinations. These very accurate locations indicate that many epicenters are situated at fracture zones or lateral offsets of the ridge axis. While some epicenters are found where there is no known fracture zone, it has never been clear whether or not small fracture zones occurred at those epicenter locations along the ridge axis. Since interruptions in the magnetic anomaly pattern are a sensitive indicator of the presence of fracture zones, the comparison of accurately located epicenters and the magnetic pattern over the Reykjanes Ridge offers an opportunity to see if all epicenters on the ridge are along small fracture zones. Many bathymetric profiles have been run over the crest of the Reykjanes Ridge. Thus it is possible to compare the locations of the ridge axis as defined by the topographic axis, the epicenter axis and the magnetic axis.

SURVEY OPERATIONS AND DATA REDUCTION

The area surveyed measures about 350 by 350 km with the northern edge of the survey area about 350 km southwest of Keflavik, Iceland (Fig. 1). Flight lines were approximately NW–SE along those LORAN hyperbolas which most nearly crossed the ridge perpendicularly. A U.S. Naval Oceanographic Office Project MAGNET survey aircraft was flown at 1500 ft (0·46 km) altitude with a track spacing of 5–10 km. 58 lines were flown in the NW–SE direction (Fig. 2) and 12 cross lines were flown in the NE–SW direction. The maximum navigational uncertainty is believed to be 3 km in the northwestern section and 6 km in the southwestern section.

Total geomagnetic field intensity measurements were obtained with a vector airborne magnetometer (Schonsted and Irons, 1955) of the orienting fluxgate type. The aircraft had been magnetically compensated by flights over Fredericksburg Magnetic Observatory and instrumentation drift was determined during each flight by comparison with a standard voltage source kept at the operation base. The average drift error during the survey period was $\pm 22\ \gamma$.

All flights were made during daylight hours. Magnetograms from the Leirvogur Magnetic Observatory (64° 11'N, 21° 41'W) showed no time variations in excess of 30 γ during the time of the survey measurements. Because the time variations and the instrumental drift were small relative to the amplitude of most of the magnetic anomalies observed the data were not corrected for these effects.

Although magnetic readings were taken on a strip chart recorder these readings and the navigation data were subsequently digitized and the data processed by digital

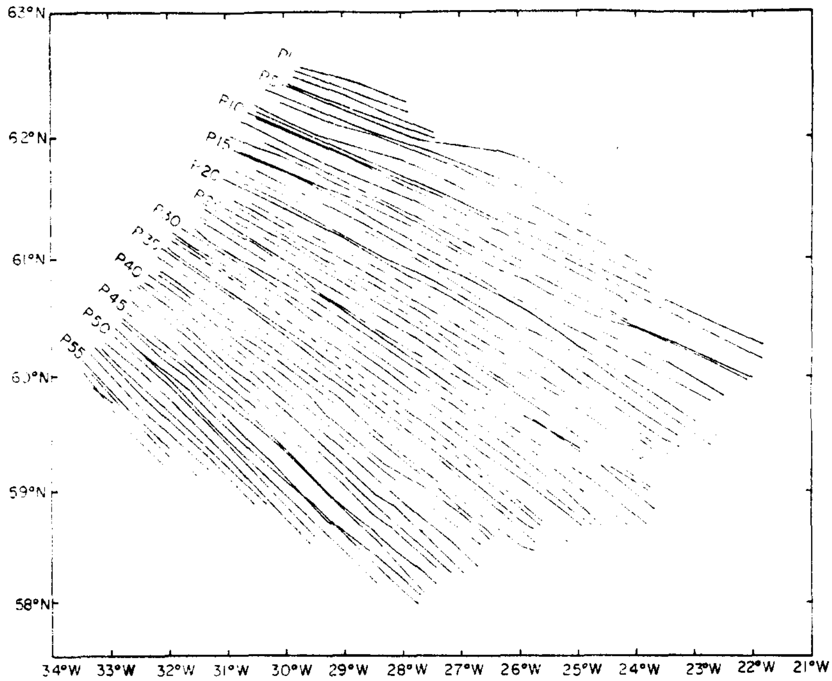


Fig. 2. NW–SE flight lines. Magnetic profiles shown in other figures are identified by the letter " P." Dashed line indicate no magnetic data.

methods. From the magnetic record time, to the nearest 5 seconds, instrument reading and dial setting were read and digitized. Readings were taken at least every 30 seconds and more often in the most disturbed areas. The distance between readings was never greater than 4 km and very frequently less than 2 km. The total number of readings was approximately 13,000. The magnetometer data and navigation data were used as inputs to a computer program that incorporated the calibration table for the magnetometer. The output of this program gave date-time, latitude, longitude, cumulative track distance and total intensity in gammas for each magnetic reading.

An inspection of the total intensity profiles indicated an axial anomaly of nearly 3000 γ in peak-to-peak amplitude and a regional field that varied by about the same amount across the area. Consequently, it was deemed sufficient to remove a regional field that was a linear function of latitude and longitude. A linear function of geographic north latitude (θ) and geographic west longitude (λ) was fitted by least squares to the magnetic total intensity (F) values. Data from the 50 longest NW–SE profiles (about 12,000 points) were used as input to the least-squares program. The corresponding regional field was given by the formula.

$$F(\text{gammas}) = 48{,}633{\cdot}14 + 184{\cdot}4\,(\theta - 50) + 121{\cdot}9\,(\lambda - 20)$$

The magnetic anomaly was then determined by subtracting each calculated regional value from each total intensity observation.

The data, thus processed, permitted several forms of graphic presentation with an on-line digital plotter. Track charts on Mercator scale, profiles of the total intensity and anomaly values against distance and longitude, and contours of total intensity and anomalies on Mercator scale were made by the computer.

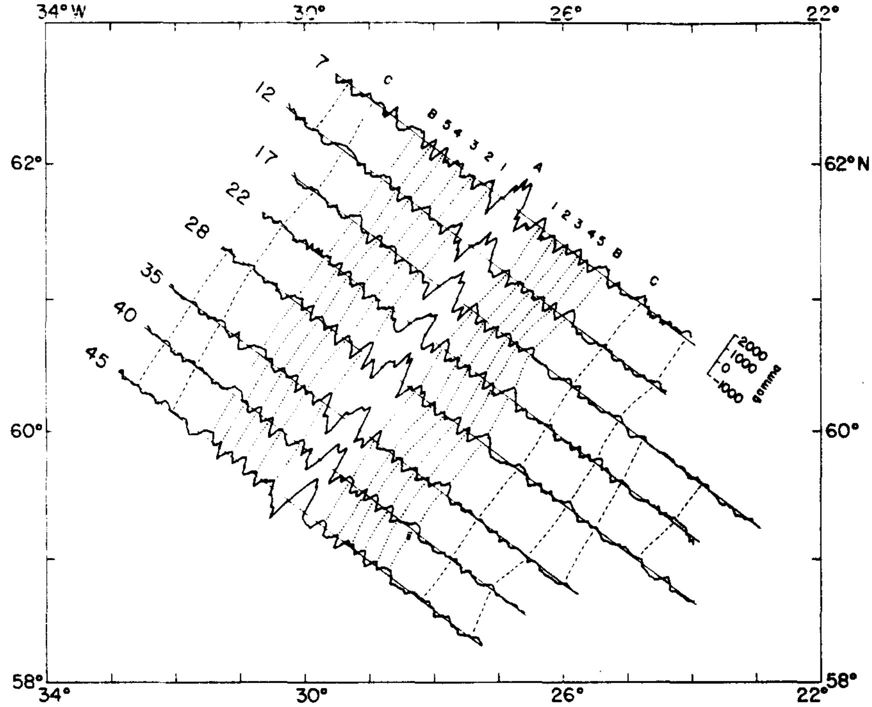


Fig. 3. Eight anomaly profiles projected on lines perpendicular to the structural trends. Profile numbers are at the west end of the lines. Letters and numbers over the anomalies identify particular magnetic features.

Figure 3 shows, in detail, 8 profiles projected along a line perpendicular to the strike of the ridge. Figure 4 shows two profiles close to a bathymetric profile. Figures 5a and 5b

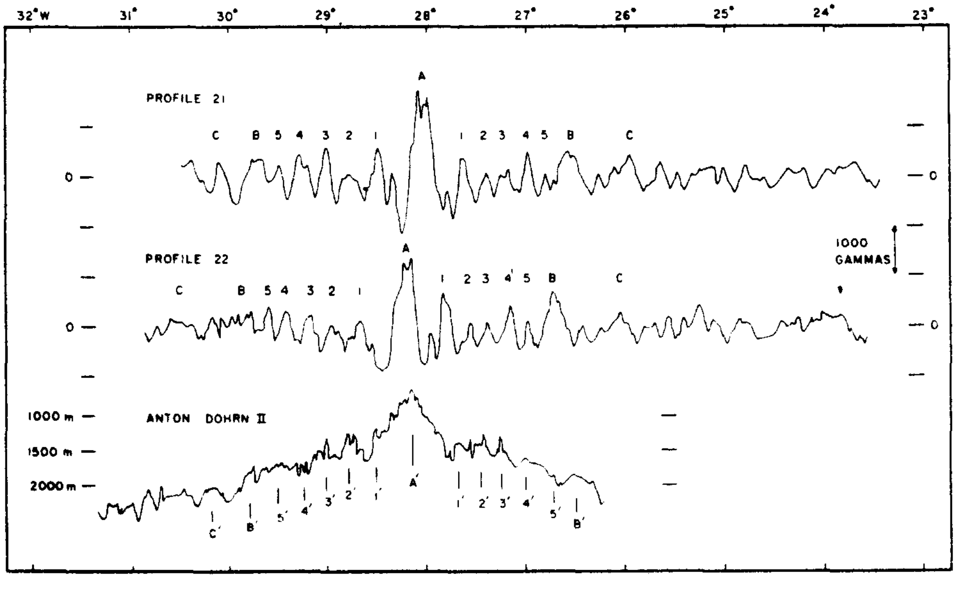


Fig. 4. Magnetic anomaly and bathymetric profiles, plotted as a function of longitude.

show the contours of anomaly values. Similar contour maps of the total intensity field were also made but are not shown here. These maps as well as NW–SE anomaly profiles are shown in an informal manuscript report of the U.S. Naval Oceanographic Office. The general purpose contouring program used was written by R. B. Murray of Control Data Corporation for randomly spaced input data points. Because of the large number of points the contouring was done for two slightly overlapping areas, one north of about 60·2°N and the other south of about 60·4°N. The initial operation of this program is the generation of new data points at orderly spaced grid points by interpolations and extrapolations from the input data. The total number of grid points was about one-half the number of input data. The contouring procedure thus smooths the data to an extent. The amount of smoothing is evident when one of the magnetic profiles (Figs. 3 or 4) is compared with the amplitude of the contoured anomalies (Figs. 5a or b).

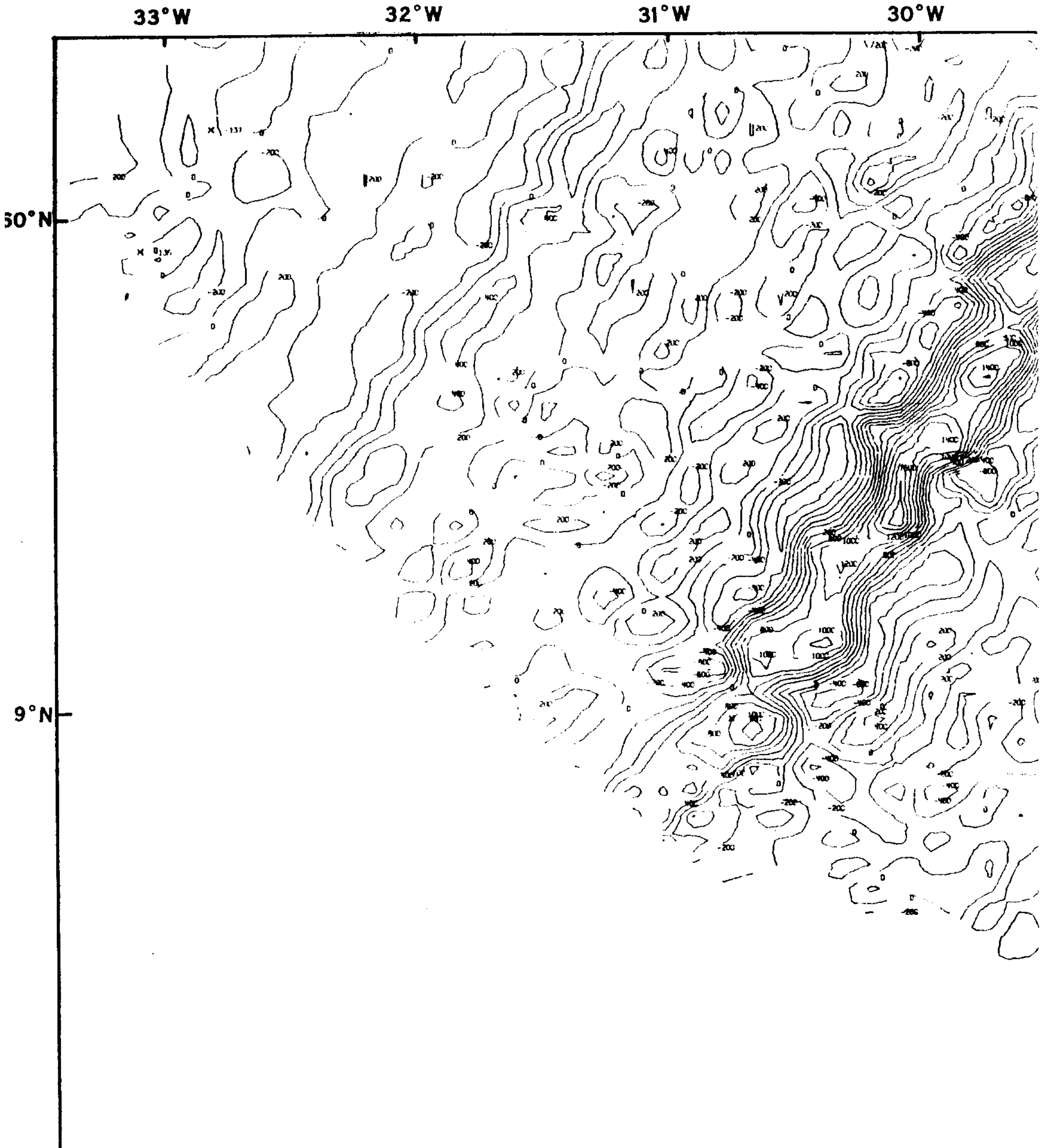
The methods used for calculating a regional field and for contouring the data are not optimum for bringing out the extreme linearity of the magnetic anomalies. These methods were employed because of their objectivity. Clearly a more adequate regional could have been determined and that regional could have included the depressed field strength near the axial anomaly. Also the results of this paper show that it would have been justified to use a contour program which, in the calculation of precontour grid points, weights the calculated values in favor of data points lying NE–SW.

BATHYMETRY AND MAGNETIC ANOMALIES

A bathymetric study of the area was made by the V.F.S. *Gauss* in 1957 and the F.F.S. *Anton Dohrn* in 1958 (ULRICH 1960, 1962). Fifty profiles, 100–200 km long, with an average spacing of about 10 km, were run over the crestal area of the ridge perpendicular to its trend between the Reykjanes Peninsula and 60°N. Four longer profiles, about 400 km long were made with a spacing of about 200 km. Thus the bathymetry of the crest in the northern half of the survey area is well known, whereas the bathymetry of the flanks on each side of the crest is poorly known. The Deutsche Hydrographische Institut Chart No. 256 (redrafted for Fig. 6) should be judged on this basis.

From these data, it is clear that the Reykjanes Ridge is a continuous straight feature running SW–NE from 55°N to the Reykjanes Peninsula where it joins the Quaternary belt of volcanics running also SW–NE in southern Iceland. While the continuity of the crest is evident, no rift valley has been recognized and the small morphological features do not seem to be linear. The four long profiles are not adequate to prove or disprove the linearity of larger scale morphological features over the flanks. In the northerly parts of the survey area the crest region is isolated by abrupt increases in water depth at about 30 km on either side of the axis. This abrupt increase in depth is gradually less noticeable in more southerly profiles until, at 60°N, it has disappeared and the water depths increase more regularly with distance from the ridge axis.

The location of the positive part of the axial anomaly is shown as a shaded area on Fig. 6. Excluding the local westerly offset in the ridge crest at about 60·5°N, which is probably due to a navigational error in the bathymetric profiles, it is seen that the magnetic anomaly is over the topographic crest, but that its axis is apparently


33°W
32°W
31°W
30°W
9°N

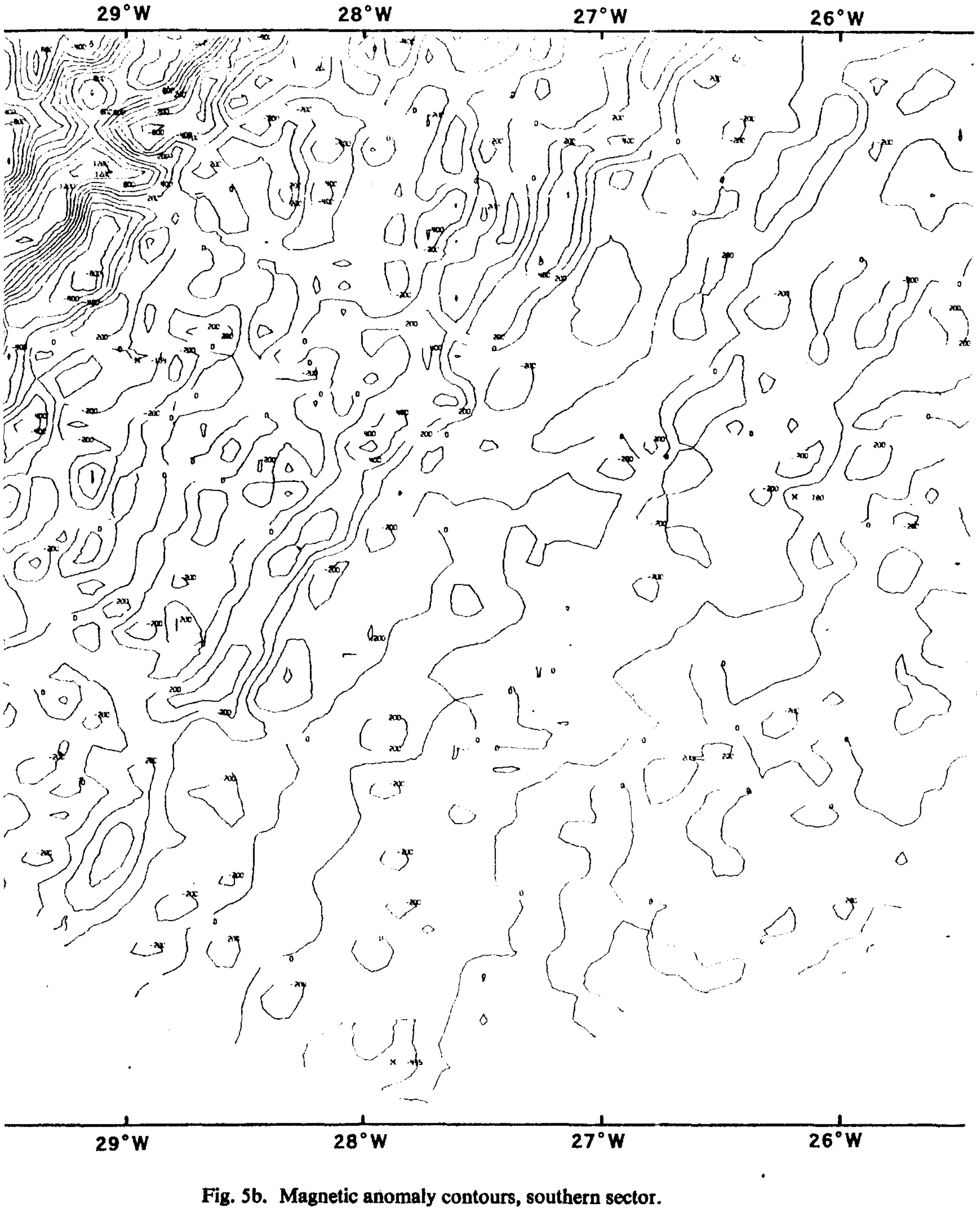
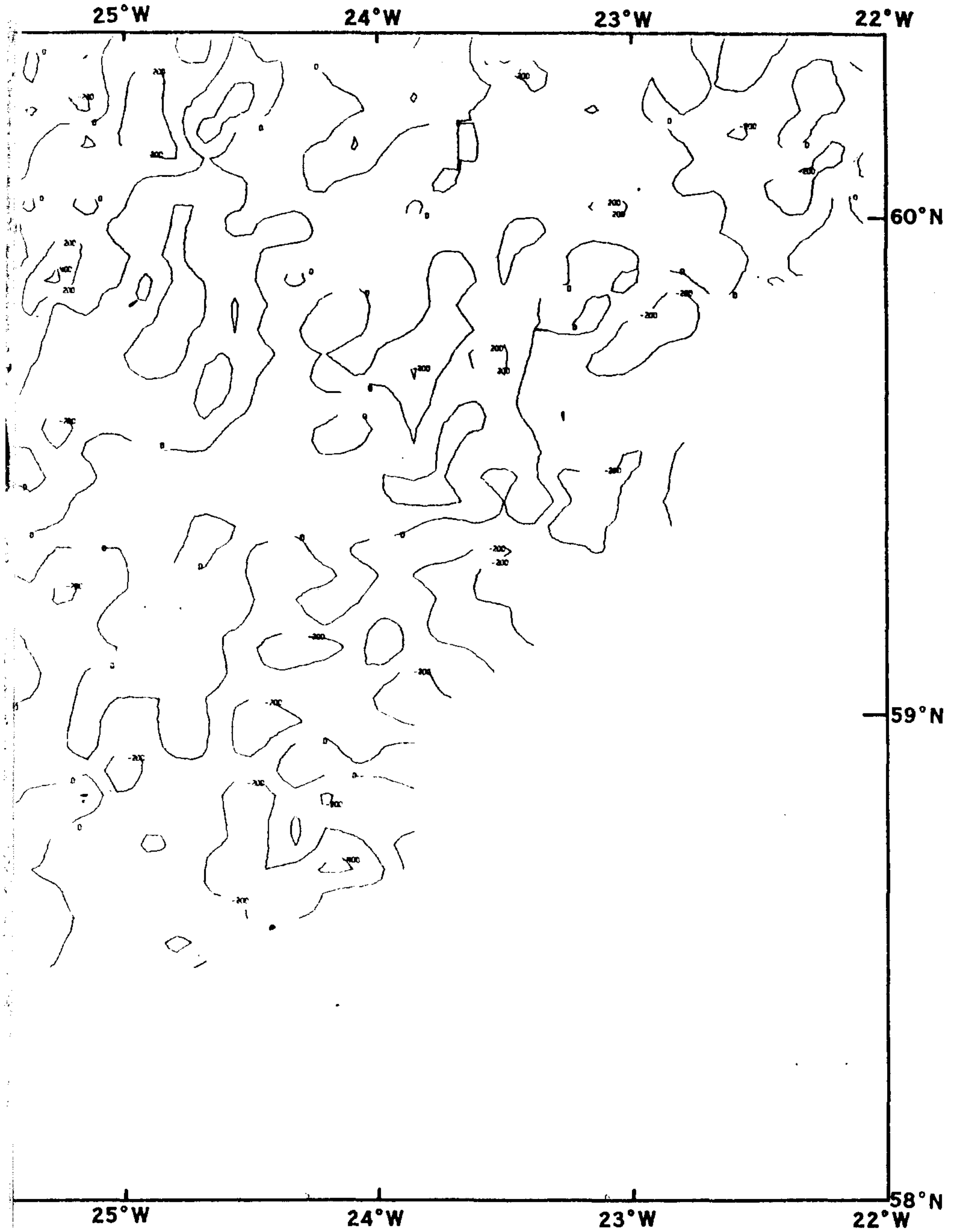


Fig. 5b. Magnetic anomaly contours, southern sector.


25°W
24°W
23°W
22°W
60°N
59°N
58°N

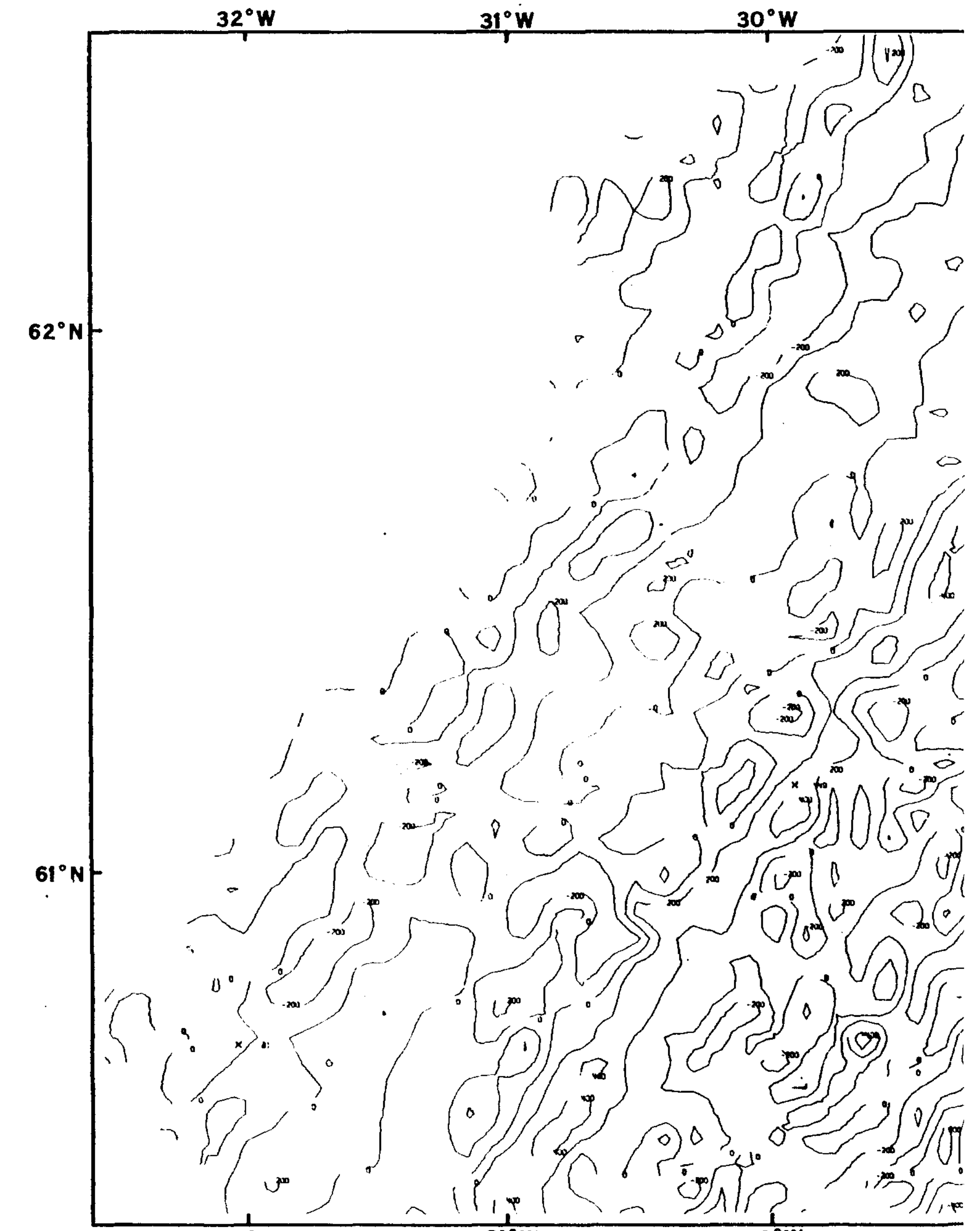
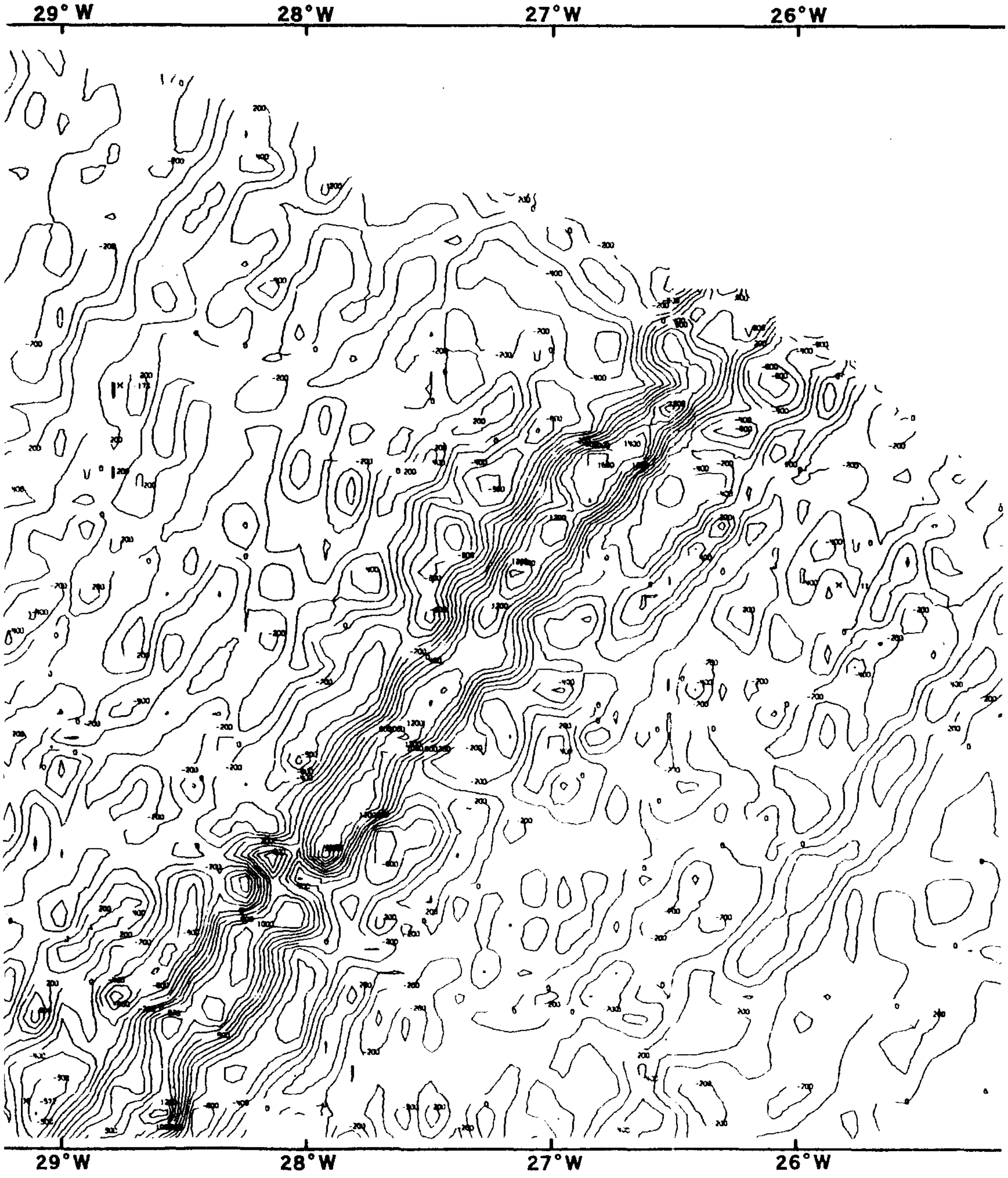
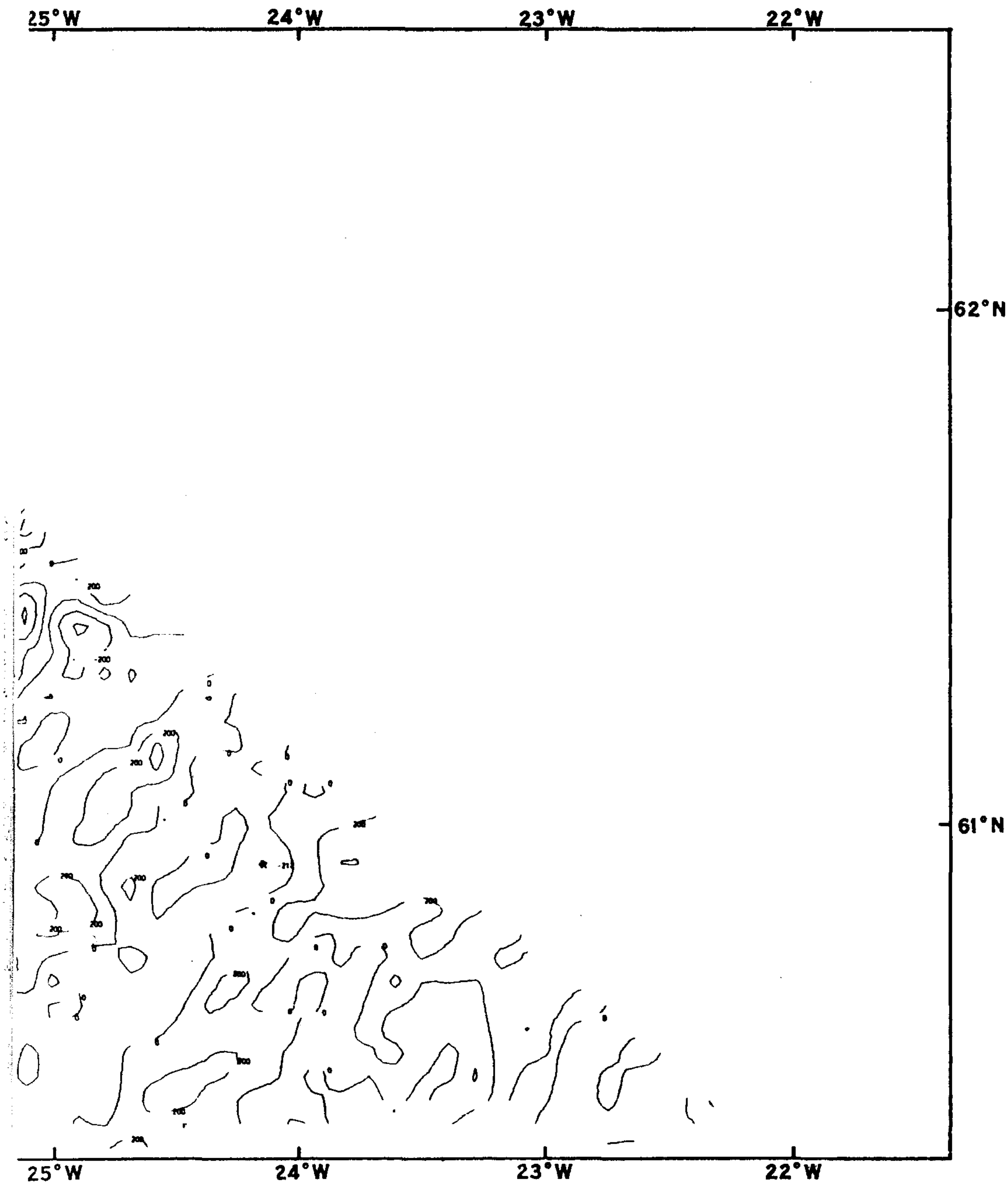


Fig. 5a. Magnetic anomaly contours, northern sector.



Numbers at or near the break in the contours identify the contour, in gammas. An " X " with adjacent numt



ɪer identifies spotted data points. A 200-γ contour interval was used.

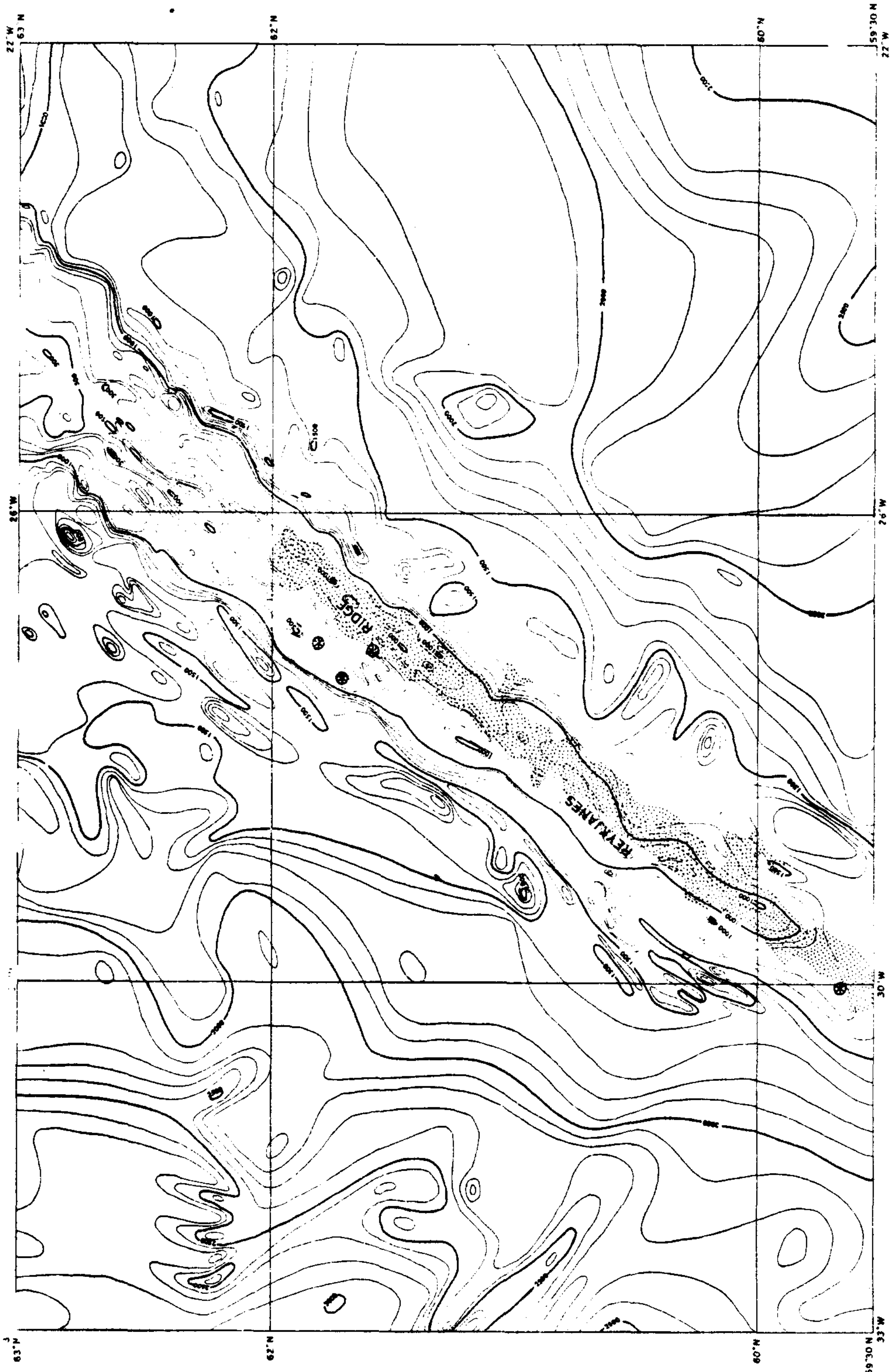


Fig. 6. Bathymetric contours of Reykjanes Ridge area (after Deutsche Hydrographische Institut Chart No. 256). Contour interval is 100 meters. Epicenters (after SYKES, 1965) are shown as circles. The area covered by the large positive magnetic anomaly is shown shaded.

slightly to the east of the topographic axis. Model studies, discussed later, indicate that the body causing the anomaly is about as wide as the shaded area. Thus the topographic crest generally coincides with the location of the body causing the axial magnetic anomaly.

Figure 4 shows the long *Anton Dohrn* profile II with two adjacent magnetic profiles. The bathymetric profile is made along a slightly different course than the aeromagnetic profiles so that it crosses the axis of the crest just south of the two magnetic profiles. There is a slight suggestion that the topography over the flanks consists of inclined topographic blocks, with the scarp generally facing the axis of the ridge. This is somewhat supported by the similarity between the widths of these blocks and the wavelengths of the magnetic anomalies. This suggests that these topographic blocks might be the surface expressions of the bodies responsible for the magnetic anomalies. Letters and numbers on Fig. 4 indicate a possible correlation between magnetic anomalies and topographic features. If the linearity of these topographic features and their correlation with the magnetic anomalies are substantiated by later work, it would indicate that the magnetic pattern is controlled primarily by the tectonic history of the ridge and not by reversals of the earth's magnetic field.

MAGNETIC ANOMALY PATTERN

The main features of the magnetic anomaly pattern can be recognized by an examination of Figs. 3, 4, 5, 7 and 10. Figure 3 was obtained by projecting the profiles along a perpendicular to the trend of the ridge, which intersects the actual tracks over the positive axis of the anomaly A. The zero anomaly line corresponds to the projected track and the average spacing between profiles is about 40 km. The maximum distance between the ends of the projected profiles and the ends of the actual tracks is about 30 km for profile 7 and diminishes towards the south. This figure displays well the magnetic pattern and provides the basis of the following discussion.

The axial anomaly A over the crest is the outstanding feature. It has generally a width of 40 km and an amplitude of 3000 γ peak-to-peak. It has steep gradients on each side of a broad maximum on which three smaller features can be followed over most of the profiles. The maximum is clearly larger than the minimum indicating that this anomaly is produced by a mass of normally magnetized material. On each side, six anomalies of smaller wavelength and amplitude, about 15 km and 500–1000 γ respectively (joined by dotted lines in Fig. 3), can be correlated over the whole 350 km of the survey. The symmetry of these anomalies on each side of the axis is remarkable, even for smaller details.

These thirteen anomalies occupy an area about 200 km wide, between lines BB of Figs. 3 and 7. This axial area closely corresponds to a region of depressed magnetic field. On each side of the axial area, the pattern of the anomalies changes abruptly. Irregularly spaced longer wavelength anomalies having an amplitude of about 300 γ are present together with shorter wavelength 100–200 γ anomalies. The larger wavelength anomalies can be correlated from profile to profile for long distances (dashed lines in Fig. 3, see also Fig. 7).

Heirtzler and Le Pichon (1965) have recognized two main patterns of the magnetic anomalies over the axial zone of the Mid-Atlantic Ridge. North of 30°S, a large axial anomaly is present in a zone of otherwise small, short wave-length

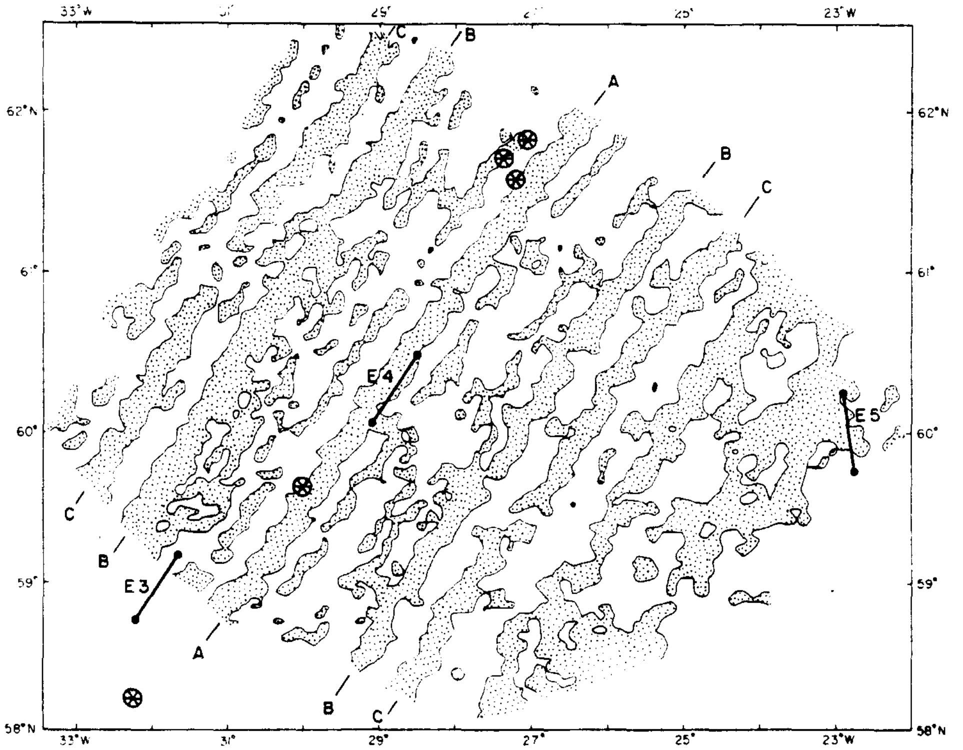


Fig. 7. The magnetic pattern over the area surveyed. Areas of positive anomalies from Fig. 5a and b are shaded. Short line segments are locations of seismic refraction sections shown in Fig. 8. Circles represent earthquake epicenters.

anomalies. South of 30°S, the anomalies have the same wave length but increase progressively in amplitude towards the axis. Over the lower flanks of the ridge, the " flank anomalies " present a different character, having longer wave-length and less regularity in spacing. TALWANI *et al.* (1965) have presented evidence that suggests that the southern pattern is characteristic of the East Pacific Rise and displays great linearity parallel to the rise. The profiles in the lower part of Fig. 10 are obtained by continuing the magnetic field upward to a height of 2·0 km above sea level (TALWANI, 1964). These profiles can then be compared with other profiles over the mid-ocean ridges, where the water depth over the crestal area is about 3 km. The axial anomaly is still very large, compared to the adjacent ones, as in the North Atlantic pattern. On the other hand, the six still large and very linear anomalies on each side are more suggestive of the southern pattern. Thus, the magnetic pattern over the Reykjanes Ridge seems to be intermediate between these two types.

In any case, Fig. 10 clearly shows the differences between the two main magnetic provinces over the Reykjanes Ridge. The 200-km wide axial magnetic zone consists of large amplitude, short wave-length, linear anomalies, presenting great symmetry on each side of the very large axial anomaly. The " flank province " consists of longer wave-length, smaller amplitude, irregularly spaced anomalies, on which is superimposed small wave-length " magnetic noise," making it more difficult to recognize the main linear pattern. However, it should be noticed that the widths of these provinces are much smaller than further south over the Mid-Atlantic Ridge, probably corresponding to the small width of the Reykjanes Ridge itself.

While the linearity of the magnetic anomaly pattern is evident in Fig. 3, it is also demonstrated in Fig. 7 where positive anomalies are shaded. The large central positive anomaly is identified by line AA. It is interesting to note that the causative body is as wide as the positive part of the axial anomaly, but displaced about 4 km to the west. The other dominant trends are identified by lines BB (limits of the axial zone) and CC on both sides of AA. The lines BB are separated from AA by about 100 km and the lines CC are about 135 km from AA. Notice that a Mercator projection was used so that the same east–west distance seems to be longer by about one tenth at the top of the figure than it is at the bottom. As the regional was obtained by fitting a plane to the magnetic field over the whole area of the survey and as there is a general depression of the field between lines BB, the maximums of the anomalies numbered 2, 3, 4 and 5 (Fig. 3) often do not even reach the zero level and for this reason are not properly shown in Fig. 7. If the field were not depressed between lines BB, five striking linear trends would appear between AA and BB. The remarkable axial symmetry of this magnetic pattern is clear evidence that it is genetically related to the ridge. In the eastern part of the survey area, the spacing between tracks is somewhat larger and the magnetic anomalies are not much greater than the contour interval of 200 γ. To study adequately the anomaly trends in this part of the area, one should have smaller track spacing, better navigational accuracy and adjustments should be made for time variations and instrumentation drifts. However, as mentioned earlier, once the short wave length magnetic " noise " is filtered out, as it would be if the water depth were 5 km (Fig. 10), it appears that small amplitude, large wave length and irregularly spaced anomalies which can be correlated for long distances are characteristic of this magnetic province.

The bathymetric survey of the crest, north of 60°N., had already indicated that the ridge was not offset along any small fracture zone. Figs. 3 and 7 present definite evidence of the absence of any offset of the linear trend of the Reykjanes Ridge in this area. There are actually several places where discontinuities in the contours occur. Where such discontinuities are parallel to flight lines, their reality is questionable. For example, the eastward spur from the AA anomaly at 60°N. 29°W. and the breaks in the contours just north of this feature are probably due to the absence of data along profiles 33 and 34 in this locality. Several other interruptions seem real, as near 61°N., 31°W.

GUTENBERG and RICHTER (1954) did not indicate any epicenters over the Reykjanes Ridge. However, SYKES (1965) located five epicenters (Fig. 7) over this ridge in the survey area with an accuracy of about 10 km. The group of epicenters in the northern part consists of a main shock and two aftershocks. Of these, the best located is the farthest west (108 readings). The epicenters do not appear to be related to any unique features of the magnetic pattern. While it is not clear whether any significance can be attached to the location of the earthquakes west of the main anomaly, the good coincidence of the topographic, magnetic and seismic axes is evident. This fact is specially interesting as it has been demonstrated that rift valley and fracture zones are absent in this area. It can then be concluded that while earthquakes do occur along the topographic axis of the ridge, even where there are no rift valley or fracture zones, they are much less frequent than in other parts of the ridge where these topographic features are present.

CAUSES OF THE ANOMALIES

While a detailed magnetic survey gives accurate information about the structural trends of the region studied, it provides much less information about the materials causing the anomalies. However, one can obtain some indication of the maximum depth and vertical extent of the causative bodies and an estimate can be made of the minimum magnetization of these bodies. Model computations actually gave results identical to the ones obtained in a previous investigation of the ridge magnetic anomalies (HEIRTZLER and LE PICHON, 1965).

The axial anomaly (A of Fig. 3) is caused by a body magnetized along the present direction of the earth field. The slopes of the anomaly and its shape indicate that the causative body has its top surface within one kilometer of the sea floor. The sharpness of the minimum precludes a depth larger than 10 km for the lower end of the body. If the vertical extent is less than 5 km, the magnetization required becomes unreasonably high. On the other hand, along the axis, the heat flow is probably large, as in Iceland further north (BODVARSSON and WALKER, 1964) and in the Mid-Atlantic Ridge further south. The lower end of the axial body cannot be deeper than the Curie isotherm depth, which, for a heat flow of 5 μcal/cm^2 per sec would be approximately 6 km. Such a body, extending from the sea-floor to a depth of 6 km, would have a width of 20 km and a magnetization contrast of 0·008 e.m.u. This high value of magnetization suggests that there is an important remanent component of the magnetization in the direction of the present field. If the model is assumed to be within a reversely magnetized medium, then the magnetization has to be only one half of this value. The sharpness of the other anomalies of the axial zone (between lines BB, Fig. 4) also indicates that the upper surfaces of the causative bodies are close to the ocean floor. Their width is about half that of the axial body and, if they have a rectangular cross-section, their vertical extent is not more than 2 km. Fig. 10 clearly shows that the important difference between the axial anomaly and the adjacent ones rapidly increases with height over the seafloor.

Three seismic refraction lines have been shot in this area (EWING and EWING, 1959). The position of these lines is shown in Fig. 7 and the seismic structure illustrated in Fig. 8. Stations E3 and E4 are probably the best made over the Mid-Atlantic Ridge and should be quite reliable. The structure there consists of 3–4 km of a high velocity basement, interpreted as volcanic, over a 7·2 to 7·6 km/sec material, which most probably represents altered mantle. There were no arrivals from the assumed layer of 300 m of sediments, and it is possible that there are instead about 500 m of low-velocity volcanics. In any case, the structure is not different than further south over the Mid-Atlantic Ridge and essentially consists of a bulge of altered mantle covered by 2–4 km of volcanics. The analysis of the magnetic anomalies strongly suggests that they originate entirely or for the greatest part in this upper volcanic layer. While the accuracy of the locations of the seismic stations may not be as precise as the magnetic anomalies, there does not seem to be any significant differences in the seismic properties of the basement under the magnetic highs and lows.

It has been mentioned earlier that the magnetic field is depressed over the 200 km-

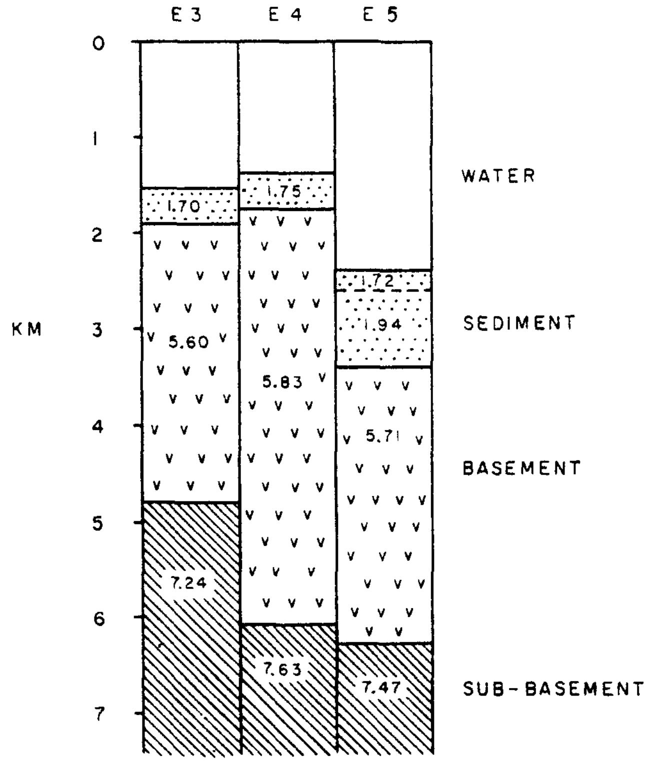


Fig. 8. Seismic refraction sections from EWING and EWING (1959). Velocities are in km/sec.

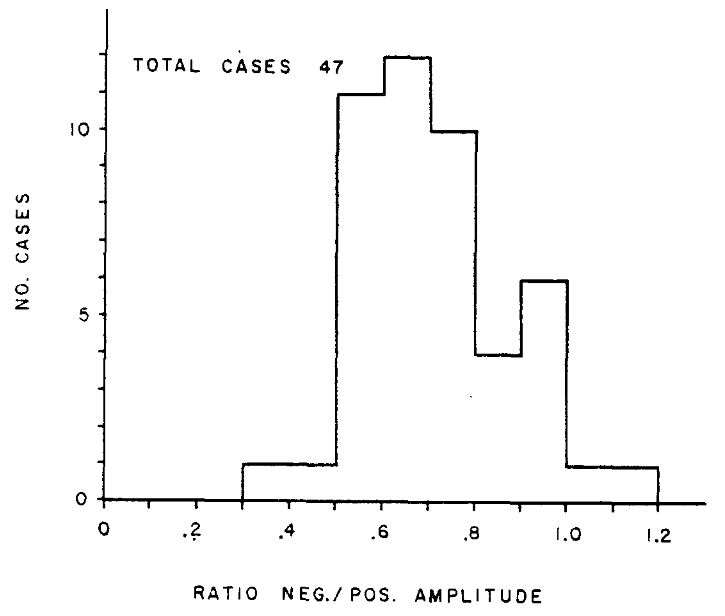


Fig. 9. Histogram of ratio of negative amplitude to positive amplitude of the axial anomaly AA. The distribution shows that the amplitude of the negative part of the anomaly is commonly 0·6–0·8 of the amplitude of the positive part of the anomaly. If the zero level is raised by 400 γ, the ratio becomes about 0·45 which is characteristic of the model fitted to this axial anomaly. This figure is then evidence for a depressed regional field over the axial zone.

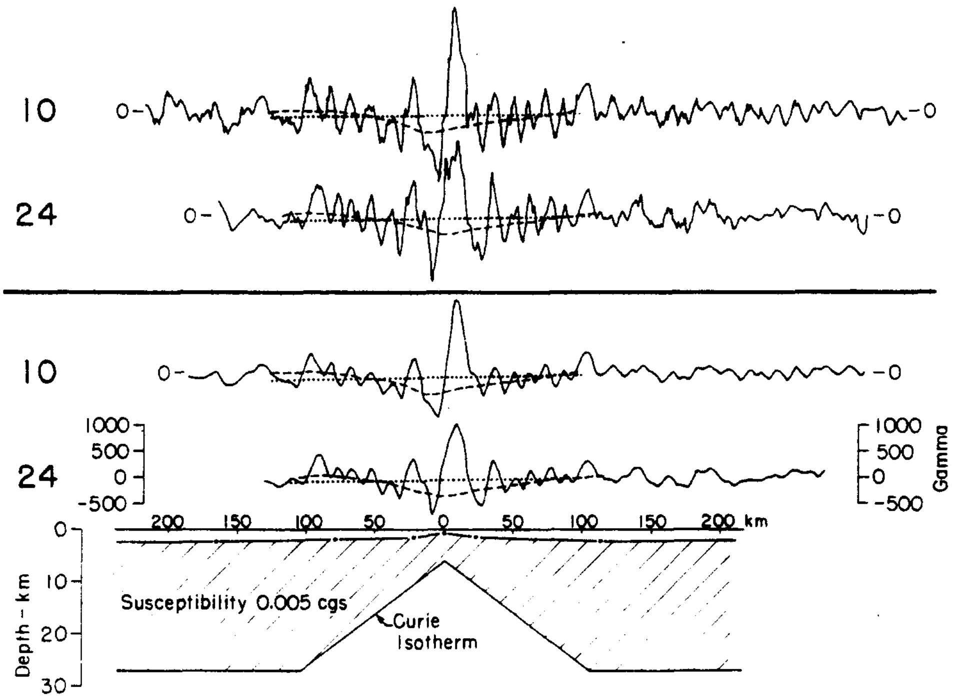


Fig. 10. The anomaly caused by an elevated Curie isotherm in the crustal region. The two upper profiles show observed anomalies (0·06 km above sea level, 1 km above crest, or 3 km above basins). The two lower profiles represent the two upper profiles as they would be observed 2·0 km above the flight level (2·5 km above sea level, 3 km above crest, or 5 km above basins). The dashed line shows the anomaly produced by the variation in the assumed depth of the Curie isotherm. The dotted line is the zero anomaly level of the calculated anomaly.

wide axial zone (Fig. 9). A body of rectangular cross-section, 5 km in vertical extent, magnetized along the present direction of the earth field should produce a magnetic anomaly having a ratio of negative to positive maximum amplitude of about 0·45. A body having a larger vertical extent should have an even smaller ratio. However, Fig. 9 shows that the most frequent negative to positive ratio for the axial anomaly AA is 0·6 to 0·8, indicating a depression of the regional field of more than 400 γ. This point is illustrated in Fig. 10 where the upward continuation better displays the configuration of this regional low. The cause of this broad minimum has to be a progressive deficit of magnetization, reaching a maximum under the axis. While a much larger proportion of reversed material in the axial zone would produce such a low, a simpler and more probable cause is a rise in the Curie isotherm (Heirtzler and Le Pichon, 1965). If the heat flow has a value of 1 μcal/cm^2 per sec over the flank, and reaches 5 under the axis, with a thermal conductivity of 5×10^{-3} cal/°C. cm. sec, the Curie isotherm (500°C) would rise from a depth of 27 km under the flanks to a depth of 6 km under the axis. Such a configuration of the Curie isotherm would produce the regional anomaly observed with a large minimum over the axis and a smaller maximum on the west side. It is interesting to note that this rise in the Curie isotherm has to be continuous from about 100 km on each side toward the axis in order to match the shape of this regional anomaly.

It can then be concluded that the bodies causing the magnetic anomalies in the axial zone are probably entirely within the 2–4-km thick upper volcanic layer except for the body causing the large axial anomaly which is about twice as wide as the other bodies and may be several times thicker, its lower end corresponding to the Curie isotherm. This whole 200-km wide axial zone seems to have a distribution of temperature such that the Curie isotherm progressively rises to a minimum depth under the axis.

GEOLOGIC HYPOTHESES

While limits can be put on the configuration and magnetization of these bodies, the origin advocated for this general structural pattern depends on the geologic hypothesis adopted. The location of the axial body under the floor of the rift valley in the Mid-Atlantic Ridge suggests that it consists of volcanic material filling a tensional crack. The existence of progressively smaller anomalies on the sides was attributed by HEIRTZLER and LE PICHON, (1965) to a pattern of subsidiary fractures. VINE and MATTHEWS (1963) on the other hand, following DIETZ (1961), suggested that this pattern was due to a spreading ocean floor, originating at the ridge axis, and alternately normally and reversely magnetized. However, this hypothesis in its present form does not explain the characteristic change in magnetic pattern from the axial zone to the flanks and the difference between the axial anomaly and the adjacent ones. More recently, MATTHEWS (1965) has assumed a process similar to the one by which BODVARSSON and WALKER (1964) explained the structure of Iceland. Crustal drift, in this case, is produced by crustal extension through injection of dykes in a central rift. It is consequently important to investigate whether the magnetic pattern found over the Reykjanes Ridge continues into Iceland and whether a structure similar to the geologic structure adopted for Iceland can produce such a pattern.

While this survey stopped short of the Icelandic shelf (Fig. 1), flights from Keflavik, in the Reykjanes Peninsula, to the survey area indicate that there is a large 2000 γ anomaly, about 20 km wide, over the Reykjanes Peninsula. It is apparently produced by the belt of Quarternary volcanics which, if the values of magnetization are the same as further north (see later) must have a depth extent of at least 3 km. This anomaly is similar but somewhat smaller than the anomaly characteristic of the crest of the Reykjanes Ridge. The existence of this anomaly probably indicates that the magnetic axis, as the epicenter belt, continues into Iceland in the SW–NE quaternary band of volcanics which is presently active. On the other hand, these flights suggest that, while the large axial anomaly does continue into Iceland, the magnetic pattern detected over the survey area breaks down before the edge of the Icelandic shelf. This fact is not surprising as geologic and seismic results indicate that Iceland is a large plateau basalt with a thickness of volcanics of more than 10 km, whereas the Reykjanes Ridge is a narrow ridge in which the anomalous mantle is capped by a small thickness of basalt.

There are thus important structural differences between the ridge and Iceland and the magnetic pattern characteristic of the ridge seems to break down over the Icelandic slope. However, it is still possible that a process somewhat similar to the one at the origin of the Icelandic plateau basalt is responsible for the magnetic pattern observed over the ridge. To test this possibility, we used a simplified geologic section (Fig. 11), extending from the western end of the main graben of Iceland toward the east (Fig. 1). This section was prepared by H. WENSINK on the basis of surface geology investigations using paleomagnetic mapping techniques (WENSINK, 1964). The eastern part of the section, from 110 km to the eastern end, is arbitrary and was used to avoid an edge effect in the computation of the magnetic anomalies. The magnetization assumed (0·006 c.g.s.) was the average of magnetization measured on rock samples. The section consists essentially of a wide block of recent, normally magnetized lava with, on each side, flows of alternately reversed and normal magnetization dipping toward the graben. This dip progressively increases from about 4° to 8° toward the east. The section was arbitrarily terminated at a depth of 2 km which corresponds approximately to the average thickness of flow basalts (TRYGGVASON and BÅTH, 1961). The corresponding magnetic anomalies were computed at a height of 1 and 2·5 km over sea level, corresponding to a height of 0·5 to 2 km over the eastern plateau. The 60-km wide central anomaly over the graben is about twice as wide

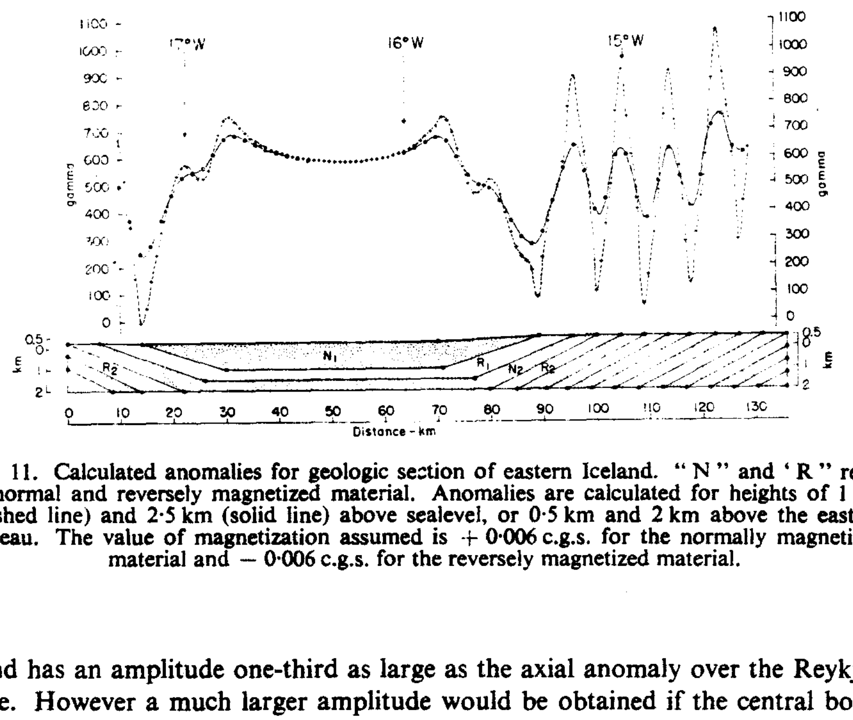


Fig. 11. Calculated anomalies for geologic section of eastern Iceland. " N " and ' R " refer to normal and reversely magnetized material. Anomalies are calculated for heights of 1 km (dashed line) and 2·5 km (solid line) above sealevel, or 0·5 km and 2 km above the eastern plateau. The value of magnetization assumed is + 0·006 c.g.s. for the normally magnetized material and − 0·006 c.g.s. for the reversely magnetized material.

as and has an amplitude one-third as large as the axial anomaly over the Reykjanes Ridge. However a much larger amplitude would be obtained if the central body is assumed to extend several km deeper and still have a large magnetization contrast. This is probable, as a large number of feeder dykes would produce this effect. Over the eastern plateau, due to the smaller wavelength of the anomalies, their amplitude decreases somewhat faster with altitude than they decrease over the ridge. Otherwise, the similarity is very good. The interesting point is that these anomalies are not produced by vertical blocks of dykes, but by flows of lava. This fits well with the results of model studies, namely that the bodies have a much larger horizontal than vertical extent. Notice also that the maximum does not occur over the exposed part of the normally magnetized material, but over the western end of the outcrop.

It is thus clear that such a model requires relatively small changes to give an anomaly pattern similar to the one observed over the Reykjanes Ridge. The central body would have to be one-half as wide and three times thicker and flows on each side should be either twice as thick or with a smaller dip. In other words, the possibility, that such a geologic process is at the origin of the anomalies of the axial zone over the Reykjanes Ridge, cannot be denied on the basis of the analysis of magnetic data. The arguments for or against this origin have to come from other geological or geophysical considerations. Even so, the problem of the origin of the flank anomalies would still remain unsolved.

SUMMARY AND CONCLUSION

1. The magnetic pattern over the Reykjanes Ridge consists of extremely linear anomalies, parallel to the trend of the ridge and displaying great axial symmetry. The pattern is genetically related to the ridge.
2. The outstanding feature is a 3000-γ anomaly, caused by a normally magnetized body, 20 km wide, probably extending from the sea floor to the Curie isotherm, and which coincides with the topographic crest and the seismic belt.
3. On each side, six shorter wavelength one thousand gamma anomalies form, together with the large axial anomaly, an axial zone 200 km wide. These anomalies are caused by bodies entirely within the upper volcanic layer which overlies the anomalous upper mantle.
4. The axial area corresponds to a zone where the field is depressed by several hundred gammas, probably indicating an important and continuous rise in the Curie isotherm toward the axis.
5. On each side of the axial zone, the flank anomalies have longer wavelength, smaller amplitude and more irregular spacing. Their linearity is less evident, because of the small wavelength magnetic " noise " superimposed on them.
6. If one accepts their much smaller widths, these magnetic provinces have the same general characteristics as those described over the Mid-Atlantic Ridge by HEIRTZLER and LE PICHON (1965) and over the East Pacific Rise off western North America by TALWANI *et al.*, (1965).
7. The large axial anomaly apparently continues within the belt of Quaternary volcanics which extends over the Reykjanes Peninsula. However the magnetic pattern seems to breakdown over the Icelandic slope.
8. The geologic structure of Iceland is such that a similar magnetic pattern, centered over the main graben, is probably developed there. While such a geologic structure could explain the axial magnetic pattern observed over the ridge, the differences between the Icelandic plateau and the Reykjanes Ridge are so large that it is not clear to us how their geologic structures can be similar.

Acknowledgements—We would like to thank Professor T. SIGURGEIRSSON of the University of Iceland for supplying magnetograms, Mr. G. LORENTZEN for assistance and guidance in the execution of the survey, Dr. E. ZURFLUEH for assistance in planning in the early phases of this project, Mr. V. GOLDSMITH as the Lamont Field representative, Miss L. HADLEY for writing the computer program to determine the regional field, Dr. H. WENSINK for valuable discussions on the magnetic properties of Icelandic structures, Dr. M. EWING for reviewing the manuscript and Dr. M. TALWANI for numerous discussions and valuable suggestions.

This work was supported by the Department of the Navy, Office of Naval Research under Contract Nonr 266 (48).

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