Marine Geomagnetic Anomalies*

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Abstract

The criterion for separating the earth's main field from magnetic anomalies of crustal origin is reviewed. A concise resume of the nature of magnetic anomalies over the Mid-Atlantic Ridge, the anomalies caused by great elongated but unidentified bodies and the magnetic anomalies over seamounts is presented.

1. Introduction

To most persons studying marine magnetic data it seems that marine magnetic anomalies are a great deal simpler than magnetic anomalies on land. This situation may be due to simpler geology or may be simply the result of the fact that the measuring instrument is separated by sea water a great distance from any magnetic material, with the consequent attenuation of small wavelength anomalies, or it may be due to the fact that marine magnetic profiles are usually very long, cover diverse types of geologic structure, and offer more of an opportunity to categorize anomalies.

The basis for separating anomalies due to crustal features from higher order pole effects of the earth's main field was established by Alldredge, Van Voorhis and Davis (1963). Those authors showed that the wavelengths observed on long profiles fall into two distinct wavelength groups. Wavelengths shorter than about 200 miles can be assumed due to variations in crustal magnetization while wavelengths longer than about 2000 miles are probably due to core or deep mantle effects. That paper further demonstrated that the earth's main field should be quite adequately described by a spherical harmonic expansion of degree and order 10. Figure 1 shows 5 long marine total intensity profiles from which the earth's main field has been removed by calculating the spherical harmonic field using the 48 term Jensen and Cain coefficients for 1960. The small scale residual anomalies of crustal origin are evident. The trend of the curves away from the zero gamma line is due to secular variation (very small near the equator) and the limited accuracy of the coefficients (especially in high southern latitudes). If more recent values of coefficients had been used there would have been less trend away from the zero line.

While crustal anomalies may be of the order of 200 miles in wavelength the combination of spectral distribution, navigational uncertainties, and instrumentation sensitivity favors the study of anomalies of 10 to 60 miles in half-width.

There are a number of geophysical characteristics that distinguish the earth's crust under the oceans from that under the continents. These include the crustal transition

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Fig. 1 Five long total magnetic intensity profiles with the earth's main field strength for 1960 removed. The field strength, in gammas, is plotted as a function of longitude. The latitude of the end points is indicated at the ends of each profile.

at the continental boundary, the thinness of the crust in the oceans, the occasionally high heat flow values and the existence of the mid-ocean ridge system. There are three particular types of magnetic anomalies that have occupied that attention of marine geomagneticians studying crustal structure. These are the anomalies associated with the mid-ocean ridge system, magnetic anomalies of great linearity and continuity that may occur anywhere in the oceans, and the magnetic anomalies associated with seamounts.

2. Magnetic Anomalies Associated with the Mid-Ocean Ridge System

There is a singular elevation or ridge that unites most the oceans of the world. Only rarely, as in Africa, does this ridge cross the continents. A great deal of speculation about the origin of the earth has been centered on the unique geophysical features of this ridge. The geomagnetic field is very disturbed over the mid-ocean ridge and sea level anomalies of the total intensity reach an amplitude in excess of 3000 gammas over parts of it. Such amplitudes are sometimes found over seamounts but nowhere else in the deep oceans.

There are other less extensive ridges in the oceans. Some of these have strong magnetic effects, others do not.

Probably the Mid-Atlantic Ridge has been crossed with more magnetic profiles than any other part of the ridge system. Each and every crossing has displayed a magnetic disturbance. Figures 2 and 3 show the location of the anomaly on all published profiles and some unpublished profiles of Lamont Geological Observatory. (Figures 2, 3, 4 and the subsequent discussion on the Atlantic Ridge are extracted from a paper by Heirtzler and Le Pichon, 1964). In the North Atlantic the ridge anomaly is large and relatively isolated. South of 30°S the anomaly is more diffuse but the magnetic axis is still defined. Figure 4 shows profiles across this transition. It has been shown that the amplitude of the central anomaly can be largely accounted for by the inclination of the geomagnetic field vector and the water depth for the various latitudes. Calculated anomalies over a two dimensional model show that the body causing the central anomaly has a width of

Fig. 2 Points mark the positions where a large magnetic anomaly is observed over the North Atlantic portion of the Mid-Atlantic Ridge. The symbols opposite the points identify the vessel making the observation. Irregular lines through selected points are ship's tracks for which profiles are shown in Figure 4. After Heirtzler and Le Pichon, 1964.

Fig. 3 A continuation of Figure 2 for the South Atlantic. After Heirtzler and Le Pichon, 1964.

about 10 km, upper surface at the sea floor and the lower surface 6 to 10 km below the sea floor. Anomalies immediately adjacent to the central one are caused by bodies whose lower surface is appreciably shallower. The anomalies can be accounted for entirely by induced magnetization although the susceptibility assumed must be large (about 0.01 cgs.).

The extreme linearity, or two-dimensionality, of the Mid-Atlantic Ridge and adjacent anomalies has been made more evident by preliminary results of a detailed Lamont Geological Observatory-U.S. Naval Oceanographic Office aeromagnetic survey over the Reykjanes Ridge south of Iceland with a 3 to 5 mile grid spacing. It now seems that the central magnetic anomaly better defines a continuous axis of the Mid-Atlantic Ridge than does the axis of the earthquake epicenter belt or the central rift valley.

3. Anomalies with Great Linearity

The existence of more-or-less continuous anomalies with lengths of hundreds to thousands of kilometers has been known for a number of years. The interesting *pattern* of the linear trends was first made evident from a study of the anomalies of the Northeast Pacific by Vacquier, Raff, Warren and Mason, (Vacquier, et al., 1961; Mason and Raff, 1961; Raff and Mason, 1961) (see Figure 5). A similar but less detailed study was made of anomalies off the east coast of North America by Drake, Heirtzler and Hirsh-

Fig. 4 Residual magnetic profiles, as a function of east-west distance from the Ridge magnetic axis, and topography for five selected crossings of the Mid-Atlantic Ridge. The approximate latitude of the magnetic axis is given for each profile. Between 31°S and 39°S the central magnetic anomaly changes from an isolated to a diffuse type. After Heirtzler and Le Pichon, 1964.

man (1963). Figure 6 shows the trends found in that study together with trends found in the Gulf of Mexico by Burckle, Heirtzler, and Peter (1964), trends north of Hispaniola by Geddes and Dennis (1963) and other trends reported in USNOO report TR-160 and trends in the Laborador Sea by Hood and Godby (1964). This figure also shows a line that separates different types of magnetic relief, an extension of the line originally drawn by King, Zietz and Dempsey (1961). One of the unique aspects of the trends off the east coast is the continuity of anomalies across the continental shelf and coastal land areas.

Figure 7 displays the trends of magnetic anomalies around the intersection of two island arcs: the Kurile-Kamchatka Island Arc and the Aleutian Arc. It utilized the results of a Japanese survey (Uyeda and Rikitake, 1964) and a survey by the U.S.S.R. (Solov'yev and Gainanor, 1963) and clearly shows trends following major structural features. It now seems that many, if not most, ocean areas have great linear magnetic anomalies. Hope (1964) has called these features "macranomalies"

Fig. 5 Crustal magnetic anomalies in the Northeast Pacific. The shaded stripes represent positive anomalies. From Menard, *Marine Geology of the Pacific*, copyright © 1964 by McGraw-Hill, Inc. used by permission.

Clearly, the material causing these extensive linear anomalies is of paramount importance to geophysics. Certain conclusions about the nature of this material are now suggested:

In the abyssal plains: As first suggested from a statistical analysis of marine aeromagnetic profiles by Serson and Hannaford (1957) the top of the body lies from one to two kilometers below the ocean floor. It seems to lie in the upper part of the "basement" reached by the seismic profiling technique.

Over the continental shelf: Although the upper surface of the body may be at the same depth below sea level as in the abyssal plains it is deeper below the ocean bottom than has been defined by seismic refraction techniques. Off eastern North America the body appears to be nearly conformal with but deeper than the refraction basement.

Fig. 6 Crustal magnetic anomalies off the east coast of North America. The lines represent the axes of magnetic highs.

Fig. 7 The trends of magnetic anomalies in the vicinity of the Kurile-Kamchatka and Aleutian Island Arcs.

Over the Mid-Atlantic Ridge: The upper surface of the body appears to be at or very close to the ocean floor. The central anomaly has a lower face that is 6-10 km below the upper face but the flank anomalies on the Ridge, as well as those in the abyssal plains may have a thickness of only 1 to 2 km. A detailed magnetic study of Iceland and other islands where the mid-ocean ridge rises above sea level is very desirable. Several countries are planning magnetic surveys of the Iceland area.

The magnetic susceptibilities required in model calculations are, if remanent magnetization is excluded, quite high even for volcanic-type materials.

4. Magnetic Studies of Seamounts

Seamounts have been studied recently because they are objects of the marine environment whose geometry is reasonably well defined and can sometimes be dated by other geophysical evidence.

The procedure in these studies is to assume various uniform magnetizations until a best-fit is obtained to the observed magnetic anomaly contours. From the best-fit magnetization and a separate calculation of induced magnetization one can, by vector subtraction, reach an estimate of remanent magnetization. From the relatively few seamounts that have been so studied it is evident that remanent magnetization is very

Fig. 8 Magnetic anomaly (solid line) and bathymetric (dashed line) contours of four seamounts. Values in gammas and fathoms. Upper left after USNOO Report TR-137, 1962; upper right after Van Vooris and Walezak, 1963; lower left after Bullard and Mason, 1963; lower right after Talwani, 1964.

important. Figure 8 shows the bathymetric and magnetic total intensity contours over four seamounts (Van Voorhis and Walezak, 1963; Talwani, 1964; USNOO Report TR-137, 1962; Bullard and Mason, 1963). If these seamounts were magnetized simply by induction there would be a magnetic high toward the magnetic equator and a magnetic low on the opposite side. It is clear that this is not the case and that remanent magnetization exists. While such analyses (and the magnetic study of oriented samples from the ocean floor) are of considerable interest not enough studies have been made to determine the confident limits on any individual analysis. Such procedural question as how much of the seamount is volcanic, how much of the adjacent bottom structure is also magnetic and what constitutes a best-fit, at present, limit the utility of the results.

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