MAGNETIC ANOMALIES OVER OCEANIC RIDGES

By F. J. VINE and Dr. D. H. MATTHEWS
Department of Geodesy and Geophysics, University of Cambridge

TYPICAL profiles showing bathymetry and the associated total magnetic field anomaly observed on crossing the North Atlantic and North-West Indian Oceans are shown in Fig. 1. They illustrate the essential features of magnetic anomalies over the oceanic ridges: (1) long-period anomalies over the exposed or buried foothills of the ridge; (2) shorter-period anomalies over the rugged flanks of the ridge; (3) a pronounced central anomaly associated with the median valley. This pattern has now been observed in the North Atlantic[1,2], the Antarctic[3], and the Indian Oceans[4,5]. In this article we describe an attempt to account for it.

The general increase in wave-length of the anomalies away from the crest of the ridge is almost certainly associated with the increase in depth to the magnetic crustal material[1]. Local anomalies of short-period may often be correlated with bathymetry, and explained in terms of reasonable susceptibility contrasts and crustal configurations; but the long-period anomalies of category (1) are not so readily explained. The central anomaly can be reproduced if it is assumed that a block of material very strongly magnetized in the present direction of the Earth's field underlies the median valley and produces a positive susceptibility contrast with the adjacent crust. It is not clear, however, why this considerable susceptibility contrast should exist beneath the median valley but not elsewhere under the ridge. Recent work in this Department has suggested a new mechanism.

In November 1962, H.M.S. *Owen* made a detailed magnetic survey over a central part of the Carlsberg Ridge as part of the International Indian Ocean Expedition. The area (50 × 40 nautical miles; centred on 5° 25′ N., 61° 45′ E.) is predominantly mountainous, depths ranging from 900 to 2,200 fathoms, and the topographic features are generally elongated parallel to the trend of the Ridge. This elongation is more marked on the total magnetic field anomaly map where a trough of negative anomalies, flanked by steep gradients, separates two areas of positive anomalies. The trough of negative anomalies corresponds to a general depression in the bottom topography which represents the median valley of the Ridge. The positive anomalies correspond to mountains on either side of the valley.

In this low magnetic latitude (inclination −6°) the effect of a body magnetized in the present direction of the Earth's field is to reduce the strength of the field above it, producing a negative anomaly over the body and a slight positive anomaly to the north. Here, over the centre of the Ridge, the bottom topography indicates the relief of basic extrusives such as volcanoes and fissure eruptives, and there is little sediment fill. The bathymetry, therefore, defines the upper surface of magnetic material having a considerable intensity of magnetization, potentially as high as any known igneous rock type[6], and probably higher, because it is extrusive, than the main crustal layer beneath. That the topographic features *are* capable of producing anomalies is immediately apparent on comparing the bathymetric and the anomaly charts; several have well-defined anomalies associated with them.

Two comparatively isolated volcano-like features were singled out and considered in detail. One has an associated negative anomaly as one would expect for normal magnetization, the other, completely the reverse anomaly pattern, that is, a pronounced positive anomaly suggesting reversed magnetization. Data on the topography of each feature and its associated anomaly were fed into a computer and an intensity and direction of magnetization for each obtained. Fig. 2 shows the directions of the resulting vectors plotted on a stereographic projection. Having computed the magnetic vector by a 'best fit' process, the computer recalculated the anomaly over the body, assuming this vector, thus giving an indication of the accuracy of fit. The fit was good for the case of reversed magnetization but poor for that of approximately normal magnetization. The discrepancy is scarcely surprising since we have ignored the effects of adjacent topography, and the interference of other anomalies in the vicinity. In addition, the example of normal magnetization is near a corner of the area where the control of contouring is less precise. The other example is central where the control is good. In both cases the intensity of magnetization deduced was about 0·005 e.m.u.; this is equivalent to an

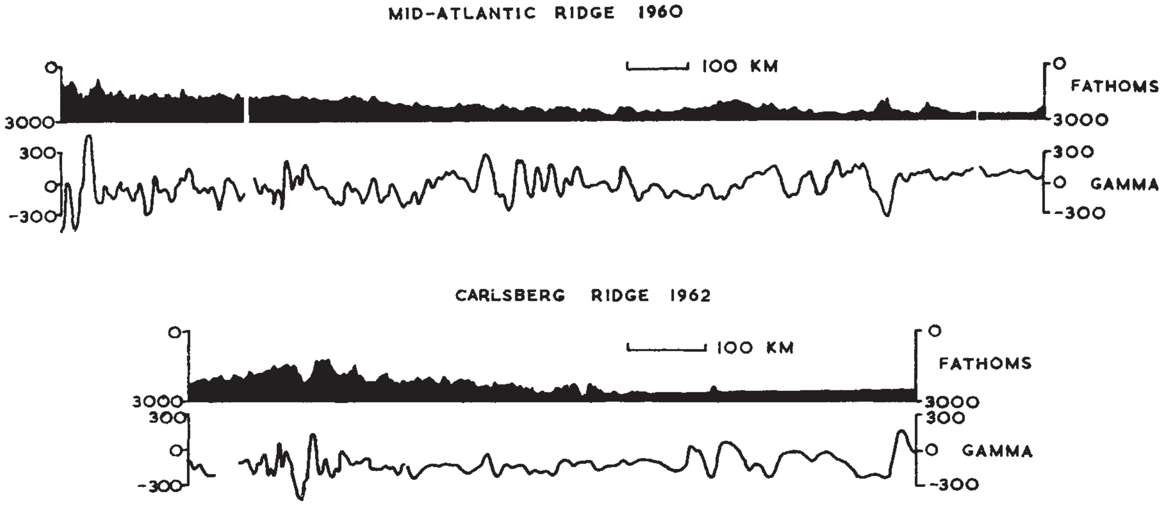

Fig. 1. Profiles showing bathymetry and the associated total magnetic field anomaly observed on crossing the North Atlantic and the north-west Indian Oceans. Upper profile from 45° 17′ N. 28° 27′ W. to 45° 19′ N. 11° 29′ W. Lower profile from 30° 5′ N. 61° 57′ E. to 10° 10′ N. 66° 27′ E.

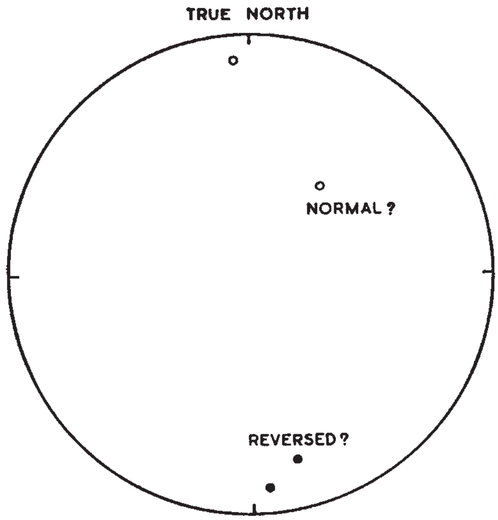

Fig. 2. Directions of the magnetic vectors obtained by the computer programme plotted on a stereographic projection, together with the present field vector and its reverse. Bearings and inclinations: present field vector 356°; −6° (up); computed vectors 038°; −40° (up); 166° 30′; +13° (down)

effective susceptibility of ± 0·0133: (effective susceptibility = total intensity of magnetization (remanent + induced)/present total magnetic field intensity : mean value for basalts of the order of 0·01).

In addition, three profiles, perpendicular to the trend of the Ridge, have been considered. Computed profiles along these, assuming infinite lateral extent of the bathymetric profile, and uniform normal magnetization, bear little resemblance to the observed profiles (Fig. 3). These results suggested that whole blocks of the survey area might be reversely magnetized. The dotted curve in Fig. 3 *B* was computed for a model in which the main crustal layer and overlying volcanic terrain were divided into blocks about 20 km wide, alternately normally and reversely magnetized. The blocks were given the effective susceptibility values shown in the caption to Fig. 4 (3).

Work on this survey led us to suggest that some 50 per cent of the oceanic crust might be reversely magnetized and this in turn has suggested a new model to account for the pattern of magnetic anomalies over the ridges.

The theory is consistent with, in fact virtually a corollary of, current ideas on ocean floor spreading[7] and periodic reversals in the Earth's magnetic field[8]. If the main crustal layer (seismic layer 3) of the oceanic crust is formed over a convective up-current in the mantle at the centre of an oceanic ridge, it will be magnetized in the current direction of the Earth's field. Assuming impermanence of the ocean floor, the whole of the oceanic crust is comparatively young, probably not older than 150 million years, and the thermo-remanent component of its magnetization is therefore either essentially normal, or reversed with respect to the present field of the Earth. Thus, if spreading of the ocean floor occurs, blocks of alternately normal and reversely magnetized material would drift away from the centre of the ridge and parallel to the crest of it.

This configuration of magnetic material could explain the lineation or 'grain' of magnetic anomalies observed over the Eastern Pacific to the west of North America[6]

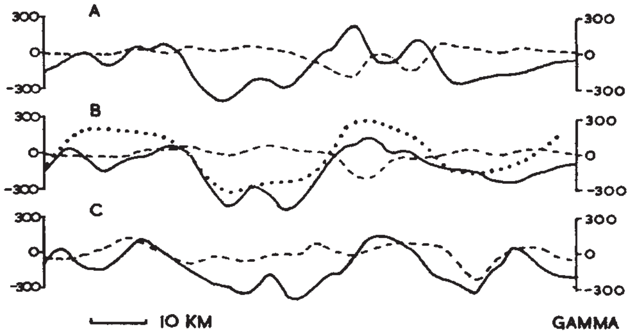

Fig. 3. Observed and computed profiles across the crest of the Carlsberg Ridge. Solid lines, observed anomaly; broken lines, computed profile assuming uniform normal magnetization and an effective susceptibility of 0·0133; dotted line, assuming reversals—see text. The computed profiles were obtained assuming infinite lateral extent of the bathymetric profiles

(probably equivalent to the long-period anomalies of category (1)). Here north–south highs and lows of varying width, usually of the order of 20 km, are bounded by steep gradients. The amplitude and form of these anomalies have been reproduced by Mason[9,10], but the most plausible of the models used involved very severe restrictions on the distribution of lava flows in crustal layer 2. They are readily explained in terms of reversals assuming the model shown in Fig. 4 (1). It can be shown that this type of anomaly pattern will be produced for virtually all orientations and magnetic latitudes, the amplitude decreasing as the trend of the ridge approaches north–south or the profile approaches the magnetic equator. The pronounced central anomaly over the ridges is also readily

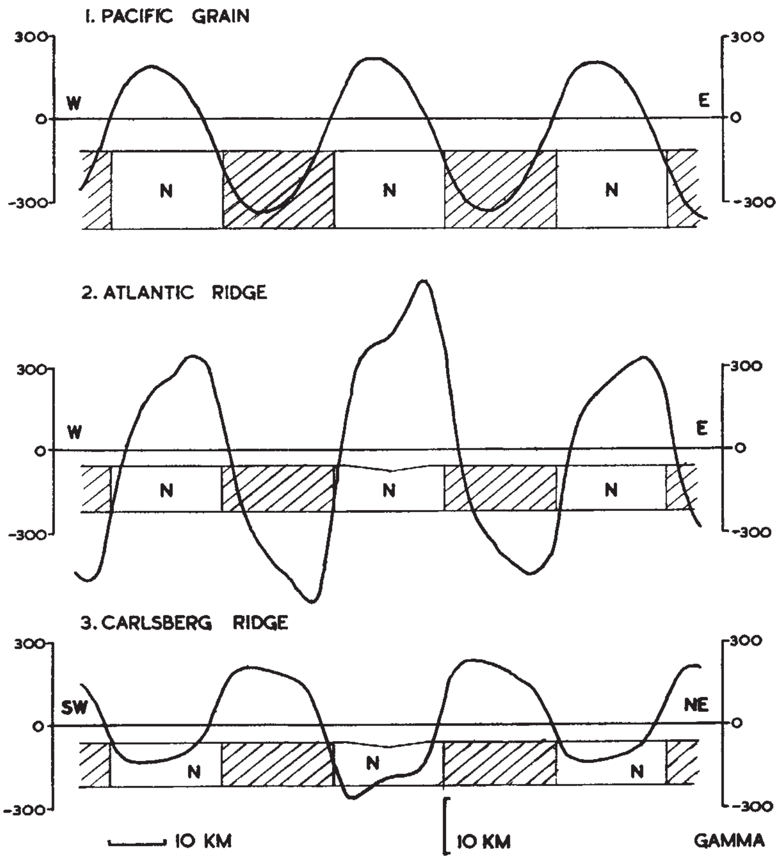

Fig. 4. Magnetic profiles computed for various crustal models. Crustal blocks marked *N*, normally magnetized; diagonally shaded blocks, reversely magnetized. Effective susceptibility of blocks, 0·0027, except for the block under the median valley in profiles 2 and 3, 0·0053

(1) Pacific Grain. Total field strength, T = 0·5 œrsted; inclination, I = 60°; magnetic bearing of profile, θ = 073°. (2) Mid-Atlantic Ridge, T = 0·48 œrsted; I = 65°; θ = 120°. (3) Carlsberg Ridge, T = 0·376 œrsted; I = −6°; θ = 044°

explained in terms of reversals. The central block, being most recent, is the only one which has a uniformly directed magnetic vector. This is comparable to the area of normally magnetized late Quaternary basics in Central Iceland[11,12] on the line of the Mid-Atlantic Ridge. Adjacent and all other blocks have doubtless been subjected to subsequent vulcanism in the form of volcanoes, fissure eruptions, and lava flows, often oppositely magnetized and hence reducing the effective susceptibility of the block, whether initially normal or reversed. The effect of assuming a reduced effective susceptibility for the adjacent blocks is illustrated for the North Atlantic and Carlsberg Ridges in Fig. 4 (2, 3).

In Fig. 4, no attempt has been made to reproduce observed profiles in detail, the computations simply show that the essential form of the anomalies is readily achieved. The whole of the magnetic material of the oceanic crust is probably of basic igneous composition; however, variations in its intensity of magnetization and in the topography and direction of magnetization of surface extrusives could account for the complexity of the observed profiles. The results from the preliminary Mohole drilling[13,14] are considered to substantiate this conception. The drill penetrated 40 ft. into a basalt lava flow at the bottom of the hole, and this proved to be reversely magnetized[13]. Since the only reasonable explanation of the magnetic anomalies mapped near the site of the drilling is that the area is underlain by a block of normally magnetized crustal material[14], it appears that the drill penetrated a layer of reversely magnetized lava overlying a normally magnetized block.

In Fig. 4 it will also be noticed that the effective susceptibilities assumed are two to five times less than that derived for the isolated features in the survey area described. Although no great significance can be attached to this derived intensity it is suggested that the fine-grained extrusives (basalts) of surface features are more highly magnetized than the intrusive material of the main crustal layer which, in the absence of evidence to the contrary, we assume to be of analogous chemical composition (that is, gabbros). This would appear to be consistent with recent investigations of the magnetic properties of basic rocks[6].

The vertical extent of the magnetic crust is defined by the depth to the curie-point isotherm. In the models this has been assumed to be at 20 km below sea-level over the deep ocean but at a depth of 11 km beneath the centre of the ridges where the heat flow and presumably the thermal gradient are higher. These assumptions are questionable but not critical because the amplitude of the simulated anomaly depends on both the thickness of the block and its effective susceptibility, and, although the thickness is in doubt by a factor of two, the susceptibility is in doubt by a factor of ten. Present magnetic declination has been assumed throughout the calculations: it would probably have been better to have ignored this, as in palæomagnetism, assuming that true north approximates to the mean of secular variations; but this is unimportant and in no way affects the essential features of the computations.

In order to explain the steep gradients and large amplitudes of magnetic anomalies observed over oceanic ridges all authors have been compelled to assume vertical boundaries and high-susceptibility contrasts between adjacent crustal blocks. It is appreciated that magnetic contrasts within the oceanic crust can be explained without postulating reversals of the Earth's magnetic field; for example, the crust might contain blocks of very strongly magnetized material adjacent to blocks of material weakly magnetized in the same direction. However, the model suggested in this article seems to be more plausible because high susceptibility contrasts between adjacent blocks can be explained without recourse to major inhomogeneities of rock type within the main crustal layer or to unusually strongly magnetized rocks.

We thank Dr. R. G. Mason and K. Kunaratnam of the Imperial College of Science and Technology, London, for details of the three-dimensional programme used in this work. The programme was originally devised by K. Kunaratnam for a Ferranti *Mercury* Computer. It has been rewritten for use on *Edsac* 2. We also thank the Director of the Cambridge University Mathematical Laboratory for permission to use *Edsac* 2, and Sir Edward Bullard for his advice and encouragement throughout.

This work was partly supported by a grant from the U.S. Office of Naval Research (Contract No. *N*62558–3542).

1 Heezen, B. C., Ewing, M., and Miller, E. T., *Deep Sea Res.*, **1**, 25 (1953).
2 Keen, M. J., *Nature*, **197**, 888 (1963).
3 Adams, R. D., and Christoffel, D. A., *J. Geophys. Res.*, **67**, 805 (1962).
4 Heirtzler, J. R., *Tech. Rep. No.* 2, *Lamont Geol. Obs., New York* (1961).
5 Matthews, D. H., *et al.*, *Admiralty Marine Sci. Pub. No.* 4 (in the press).
6 Bullard, E. C., and Mason, R. G., *The Sea*, **3**, edit. by Hill, M. N. (in the press).
7 Dietz, R. S., *Nature*, **190**, 854 (1961).
8 Cox, A., Doell, R. R., and Dalrymple, G. B., *Nature*, **198**, 1049 (1963).
9 Mason, R. G., *Geophys. J.*, **1**, 320 (1958).
10 Mason, R. G., and Raff, A. D., *Bull. Geol. Soc. Amer.*, **72**, 1259 (1961).
11 Hospers, J., *Geol. Mag.*, **91**, 352 (1954).
12 Thorarinsson, S., Einarsson, T., and Kjartansson, G., *Intern. Geog. Cong. (Norden)*, Excursion E.I.1 (1960).
13 Cox, A., and Doell, R. R., *J. Geophys. Res.*, **67**, 3997 (1962).
14 Raff, A. D., *J. Geophys. Res.*, **68**, 955 (1963).

FORMATION OF STABLE SHELLS FROM PROTEIN SUB-UNITS AS A MODE OF VIRUS SYNTHESIS

By Prof. G. BELYAVIN and Dr. ELIZABETH ROWATT

Department of Bacteriology, University College Hospital Medical School, London, W.C.1

THE structure of virus particles is at present interpreted in terms of the generalized model originally proposed by Crick and Watson[1]. The basis of this model is an outer shell or 'capsid' of individual protein sub-units or 'capsomeres', arranged in a symmetrical manner and surrounding a core of nucleoprotein.

In electron micrographs, virus particles have been found to be either rod-shaped or approximately spherical. The spherical forms in some cases approximate very closely to polyhedra with regularly orientated faces. Given a sub-unit basis for the shell, the solution of virus particle structure depends on the determination of those symmetrical arrangements of individual units which will generate surfaces of spherical, polyhedral or cylindrical form.

The original model postulated by Crick and Watson insisted on a regular arrangement of sub-units in the shell, so that every unit position in the surface is geometrically equivalent. It follows that the forces exerted on each sub-unit by its neighbours are equal throughout, leading to a stable complete shell. The original proposal suggested that these forces might be physical or chemical but made no specific predictions about them. Crick and Watson[1] pointed out that spherical or near spherical shells