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OCEANOGRAPHY AND GEOMAGNETISM

By

J. A. FLEMING

Carnegie Institution of Washington

Because of the large portion of the Earth that is covered by the oceans, the determination of accurate values of the geomagnetic elements at sea is a major objective in a world survey. It was not until 1905-1929 that realization of this objective was obtained through the systematic oceanic surveys sponsored by the Carnegie Institution of Washington through its Department of Terrestrial Magnetism. Earlier magnetic surveys at sea included those of the PARAMOUR (1698-1700), the EREBUS, the TERROR and the PAGODA (1840-45), the NOVARA (1857-60), the CHALLENGER (1872-76), and the GAZELLE (1874-76). Observations were also made by naval services of various countries and more lately by the DISCOVERY, the GAUSS, and by vessels of other Antarctic Expeditions.

All of the observations through 1900 were of varying degrees of accuracy determined by available instruments and by the disturbing factors inherent in the magnetic character of the vessels. The distribution of the observations, both as regards position and epoch, was inadequate to readily yield co-ordinated surface charts that applied to definite epochs, and the observations were frequently limited to but one or two elements. The CARNEGIE (1909-29) was a specially designed nonmagnetic vessel, equipped with newly designed instruments capable of yielding results of high accuracy under the difficult conditions inherent in work at sea. The CARNEGIE and her special equipment were developed following earlier experience (1905-08) on the brigantine GALILEE.

It has long been realized that irregularities in the surface distribution of the geomagnetic field over continental areas may bear definite relation to geologic features of the Earth's crust. In comparatively recent years geomagnetic data have been intensively utilized as an aid in the determination of the character of geologic substructure. A considerable part of the observed Earth's geomagnetic field may be ascribed to a uniformly magnetized sphere. The difference between this uniform or normal magnetization and the whole observed field, that is, the residual field, reflects those irregularities caused by geologic formations. The Earth's outer crust or shell is not homogeneous and is not uniform in its magnetic behavior. There are regions of local magnetic disturbance, many of which are caused by magnetic

ore-deposits, some of them so great as to give rise to local poles and other irregularities of intensity twofold or even threefold the normal value in those regions. The anomalies at Kursk, Russia, at Berggiesshübel, Germany, and in New South Wales are striking examples of magnetic irregularities or anomalies. The great anomaly in South Africa resulting from the huge Pilansberg system of Paleozoic volcanic dykes shows strong magnetization in a direction opposite to the present-day geomagnetic field.

The magnetic anomalies over continental areas must have counterparts in the great oceanic basins. Therefore, the study of the former must aid investigation of oceanic structure. Indeed, observations on isolated islands and island groups almost invariably indicate abnormal magnetic conditions, and the magnetic survey of the oceans by the Carnegie Institution of Washington since 1905 has revealed similar abnormal conditions at sea.

The application of surface magnetic-survey results to the investigation of crustal features of the ocean bottom depends, however, both on differences in substructural physical properties and upon the magnitude of these differences. The magnetic susceptibility of rocks, some of which are strongly magnetic (as iron-ores and igneous and metamorphic rocks) and others weakly magnetic (as most sedimentary rocks) are important factors. Thus, observed surface magnetic anomalies afford a general reconnaissance method that will indicate regions that might be subjected to more intensive geophysical studies. The magnetic approach lacks depth-control; geologic features must increase in proportion to depth if they are to be revealed by geomagnetic data. Unless the magnetic anomaly observed at sea is over shallow water (or, if over deep water, unless it is of enormous proportions), no immediate exact information regarding particular areas of bottom substructure may be obtained by study of only those charts showing surface isomagnetic contours.

The geomagnetic field undergoes changes with time, that is, secular variation; the investigation of this phenomenon offers large potential value in the study of the Earth's crust. Herein is the great need for a continuance of the accurate surface magnetic survey of the oceans to determine the character of such changes with epoch and to determine the accelerations of such changes at various places.

From the data of several centuries, investigators have noted the apparent regularity of secular variation when considering only a single station or a small part of the Earth's surface, such as western Europe—say one-hundredth of the Earth's surface. When the observational data over the whole Earth are taken into account, however, it is found that secular variation is not a phenomenon that may be

explained by periodic movements of the Earth's magnetic poles and the like; rather, it is a regional one connected with the large geological structure—oceans and continents—of the deeper layers of the Earth's crust. Techniques for the organization and interpretation of the data must be developed and experimental research must be conducted along lines which will supply information on basic physical problems related to this subject.

Surface secular-variation data are compiled from isomagnetic charts for various epochs. For succeeding epochs, shifts of the isomagnetics occur. Lines or contours joining points of equal annual change are called isopors. The foci of rapid isoporic changes raise questions of broad geophysical significance. Surface isopors for geomagnetic total intensity for the epoch 1942.5, based on the recently-published intensive analysis by the Carnegie Institution of Washington (data obtained during 1905–1945), are shown in Fig. 1. A large part of these changes may have origin in influences impressed by forces deep within the Earth. The rise and fall of the rate of secular change, and the slow expansion followed by the gradual contraction of the surface areas within which there have been excessive alterations in the magnetic elements, are significant of such changes. The distribution of isoporic foci is noteworthy. They are practically all in or near the great land-masses. Those foci found in the Pacific Ocean are generally of moderate intensity and not well defined, as shown in Fig. 2. These relations to the surface structure of the Earth indicate a causal relation with crustal or subcrustal movements and conditions.

Attention may be called to the apparent diminution of the intensity of the Earth's magnetic field which is marked over oceanic areas, especially in the western and southern hemispheres.

Observed earthquake-wave velocities and reflections for different regions and depths give some evidence that the crustal layer is thin under the Pacific Ocean. Under the Atlantic and Indian oceans the crustal layers are of appreciable depth. Under the Pacific Ocean different geological and geophysical properties from those found elsewhere may be expected. Thus, longitudinal distribution of surface isoporic foci agrees with that of land-areas as shown by the modest rates of annual change over the Pacific as compared with those over the Atlantic and adjoining continental areas. A definite control is necessary for a number of epochs to facilitate the investigation of causes producing and governing these surface progressive changes; accurate knowledge of the accelerations and of rates of annual distribution for different epochs is necessary.

Further data on the correlation between the surface-distribution of secular-change activity promise to give conclusions concerning both

the character of the layer and the secular-variation processes localized in the crustal layer. Continued magnetic surveys at sea should amalgamate seismic and magnetic, and possibly gravimetric, approaches to crustal adjustments.

There is an interesting possibility that information on secular-variation may be extended to times more remote than those for which observations exist. When lava cools and freezes following a volcanic outburst it takes up a permanent magnetization dependent upon the orientation of the geomagnetic field at that given time. This, because of small capacity for magnetization in the Earth's field after freezing, may remain practically constant; thus the direction of the originally acquired permanent magnetization can be determined by laboratory tests, provided orientation of the mass to be tested is carefully noted and marked when it is removed.

Just as lavas, cooling through the Curie-point in the presence of a magnetic field, become magnetized in the direction of the field, so sediments containing microscopic magnetic particles also assume the direction of the prevailing magnetic field. This is "fossil" magnetization for the magnetic field of the epoch of deposition maintained in the sediment. Whether this fossil magnetism remains as a connate property of the rock, or is destroyed by subsequent events, depends upon the postnatal experience of the sediment. In so far as it remains, it affords a record of geomagnetism and offers an important clue to the history of the rock.

The project to measure geomagnetism at great depths in the sea may now be consummated by magnetic examination of bottom core-samples. Special equipment, already designed and tested, permits detection of magnetic moment equivalent to that of a good steel magnet one millimeter long and one-hundredth millimeter in diameter.

Tests on cores show distinct differences in the direction and intensity of magnetization for succeeding sections of cores. By interrelating individual cores through similarities in their magnetism, it may be possible ultimately to determine more accurately than by surface observations the extent and character of the regional magnetic anomalies over the oceans.

The excess of gravity in the oceans and a sudden decrease at the continental borders, with resulting deviations of isostasy, arise not only from sources in the Earth's crust but from far within the plastic layers below, thus creating current-systems below the crust—possibly downward below the oceans and upward below the continents. The surface chart of isoporic foci and their motions with time certainly lend strength to the idea which indicates that the interior of the Earth is more mobile than the external layers, not only as a whole but

regionally. Interior currents may convey deep material with special magnetic properties, thus accounting for disturbances at the crust.

Therefore, it is important that improved knowledge of magnetic anomalies and of interrelations with gravimetric anomalies and seismic and tectonophytic conditions be obtained.

While more information on secular-variation changes in the Earth's magnetism is required for navigation, yet future geomagnetic data over the oceans are far more necessary to advance theoretical studies. It is of first importance to continue the work of the CARNEGIE, which was lost in 1929, because further surface surveys of like accuracy will enhance the theoretical value of the work already done. Investigation on diminution of the geomagnetic field—so pronounced in the southern and western hemispheres, as already stated—calls for more data over the oceans.

Theoretical investigations demanding continuation of oceanic geomagnetic surveys include, among others, the following:

(a) Determination of secular-variation of progressive changes of the geomagnetic field involving their accelerations, which the data accumulated so far indicate cannot be extrapolated reliably over periods as long as five years. A definite control is necessary for a number of epochs to facilitate the investigation of causes producing and governing these progressive changes.

(b) The study of regions of local disturbance, particularly of those indicated by earlier work over "deep-sea" areas, including accompanying determination of oceanic depths, of gravity and of the study of core-samples.

(c) The determination of additional distribution-data in a few large areas not already covered.

The question arises whether the theoretical requirements might not be met in a less expensive way than through construction and maintenance of nonmagnetic vessels. Study has indicated what might be done to control magnetic secular-variation data over the oceans between Lat. 60° N. and 60° S. through observations on land only. The maximum control which could be so effected on the surface would result from some 150 secular-variation stations along the coasts of the continents and on islands. Some 90 of the stations are readily accessible. The remainder include the more inaccessible islands which are subject, generally, to magnetic local disturbance. These islands introduce uncertainties both in the effects upon secular-variation changes and in the relation between the normal and the island value, even though the inaccessibility of stations insures exact reoccupations. The reduction to common epoch would be more difficult because of the length of intervals between reoccupations and

of the lack of the better distribution of data to be had from observations at sea.

Even if the complete scheme for control by observations on land could be attained, it appears that the areas lacking necessary data would be very large. These areas approximate nearly 15,000,000 square miles in the Pacific Ocean, over 3,000,000 in the Atlantic Ocean, and some 6,000,000 in the Indian Ocean—a grand total of 24,000,000 square miles in the oceanic areas between parallels 60° N. and 60° S. Local disturbances at many stations on islands, which would undoubtedly result in some data being unsuitable for discussion, actually would make for an even greater total area. These areas involve portions of the Earth's surface where there are at present the greatest irregularities in the progressive character of the secular variation in the Central and South Atlantic, Indian, North Pacific, East Central Pacific, and South Pacific oceans. Data of like kind over the remaining one-seventh of the Earth in the Polar areas may be expected through special expeditions on land and in the air.

Because of the great need for continuing the operations conducted for a quarter-century by the Carnegie Institution of Washington, and in view of this Institution's decision not to replace the *CARNEGIE*, the British Admiralty designed and completed the nonmagnetic vessel *RESEARCH*. Already there are marked uncertainties in present isomagnetic charts because of rapid isoporic changes in certain regions. Therefore, cruises by the *RESEARCH* are urgent.

The task of the geophysical surface survey of the oceans is so great that the hydrographic services of other nations should provide similar vessels with equipment and personnel to take an appropriate share in the execution and in the co-ordination of such service.

The present slow and costly methods of surface geomagnetic surveys, both on land and sea, may now be supplemented by new techniques and methods. The procedure of measuring the Earth's field at different times in different places in one region during one or more years, and in another at a different epoch, is inadequate for all the needs. What is required is a description of the geomagnetic field during a given year, based on measurements made during that year at an orderly set of points sufficiently close together and so spaced as to be nearly independent of topography of areas of land and sea, and of climate. That such measurements can be made from planes is now feasible instrumentally. No matter how accurately the magnetic elements are determined at a given surface point, information is still inadequate for surface isomagnetic maps in the absence of observations at intervening points. For a successful program an almost infinite number of stations is required.

This condition may now be remedied by magnetic observations with instruments airborne above the surface of the Earth, thus giving observations that are farther removed from magnetic anomalies which depreciate the accuracy of surface observations. By means of instruments carried at high speeds, continuous observations may be obtained over a large area in a single day, so that in a relatively short time a survey of the normal geomagnetic field can be made. The accuracy of such techniques can be kept at a standard that is more than adequate for both practical and theoretical purposes.

Thus, as a result of an effective airborne instrument (a) large areas may be covered quickly and continuously, (b) surface anomalies, which are of no significance in the preparation of charts of the normal field, may be eliminated (by flying at altitudes of, say 20,000 feet, smoothed values of the geomagnetic elements are obtained directly, without the necessity of mathematical treatment or judgment in processing the data) and (c) flights in two or more horizontal planes may define uniquely the magnetic field.

Perfection of a suitable airborne instrument will require considerable time and funds; nevertheless, the end results would justify large expenditures of both, particularly for observations over the oceans where the elimination of surface anomalies at high levels will make for better interpretation of surface irregularities over the normal field.

In conclusion, the facts of the geomagnetic research in the field and in the laboratory must contribute much to formulate a complete picture of the Earth's crust and particularly of that great portion which is covered by the oceans.