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`![Fig. 1](image)`

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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

GEOPHYSICS

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SOME FEATURES OF SECULAR VARIATIONS OF THE MAGNETIC FIELD OVER THE OCEAN

Secular variations of the Earth's magnetic field are clearly traceable in materials concerning magnetic declination: this element of the field has long been studied not only by researchers at observatories, but also by practicing seamen during numerous long voyages. Figure 1 presents the results of measurements of magnetic declination in cities where they were begun in the sixteenth century: in London (*1*), in Paris (*2*) and in Rome (*3*). Even without resorting to harmonic analysis of these curves, it is easy to see that they are almost regular sinusoids with the addition of a weakly expressed second harmonic. It is clearly seen that in all three cities the harmonic oscillation was superposed on a constant component, which is equal to −6.6° in London, −6.0° in Paris, and −2.8° in Rome.

Fig. 1

Under the conditions of ocean voyages, understandably, it was not possible to carry out over the course of four centuries the same careful measurements as at coastal observatories. Nevertheless, I. Fleming succeeded in collecting very extensive material of measurements in the Atlantic and Indian Oceans, partly on the continents of Europe, Africa, Asia, and America (beginning with the data of van Bemmelen for the epoch 1500), and in constructing a diagram of the distribution of magnetic declination at latitudes 40° N, 0, and 40° S ([1]).

Relying on this diagram, we constructed curves of magnetic-declination variations at various points, every 15° of longitude, on the equator and on two parallels 40° distant from it (see Fig. 2).

The curves of the series for 40° N, although not as smooth as in Fig. 1, nevertheless very much resemble them. In particular, they are all superposed on constant components, indicated by dotted lines; moreover, the magnitude of the constant component at first increases, passes through a maximum, and then decreases toward the eastern edge of the series. The curves of the series for 0°

Fig. 2

Figure 2: Fig. 2

(equatorial) and the series for 40° S, as a rule, do not permit one to judge the extreme values of declination. Here one can note only the limiting values of the western and eastern

declination from 1600 to 1937, and its mean values over this long interval of time.

The collection of curves—motley at first glance—acquires a definite and important meaning after all the obtained data are transferred to a schematic map (Fig. 3). The Mercator projection makes it possible to use the parallels as axes of abscissas, plotting the ordinate values in the direction of the meridians. On the basis of the series of curves for 40° N in Fig. 2, a curve was constructed with the abscissa axis along the parallel 40° N. The values of the constant component (negative—western) are plotted downward from the abscissa axis. The area between the resulting curve and the abscissa axis is shaded. As we see, the constant component is very small over the continents of Europe, Asia, and America, but it increases sharply over the Atlantic Ocean, reaching approximately −16° on the meridian 45° W.

Fig. 2

For the points of the equator and of the parallel 40° S, using the corresponding abscissa axes, continuous bold curves have been constructed which describe the changes in the mean value of declination at different longitudes. Although not as sharply as on the parallel 40° N, here too the difference between the continental field and the oceanic field is evident: the decrease of the mean declination near the "continental" meridian 32° E appeared not only on the equator, directly over Africa, but even slightly on the parallel 40° S, south of the continent. A secondary maximum of the mean declination is clearly expressed on the meridian 60° E in the Indian Ocean.

In Fig. 3, three curves are drawn with dotted lines; they show how the amplitudes of declination oscillations change at different longitudes. The amplitudes are also small over the continents and increase sharply in the Atlantic Ocean; they have a secondary maximum in the Indian Ocean. To avoid misunderstandings, the maxima and minima of all the dotted curves are tied by dash-dotted segments to the corresponding abscissa axes.

Thus, over the ocean, not only the values of the constant component of magnetic declination (or the mean values) are large, but also the magnitudes of the amplitudes of secular variations. Our hypothesis of the decisive role of the world ocean in the formation of the Earth' s magnetic field is again supported ([2–4]). After measurements and recordings of telluric currents in the ocean ([5,6]), there appeared grounds for ascribing to them the creation of the horizontal

Fig. 3

Figure 3: Fig. 3

component of the intensity of the geomagnetic field.

In 1959, direct measurements of magnetic declination at depths of about 2000 m in the Atlantic Ocean ([7]) allowed us to consider that no less than 1/3 of the latitudinal component of the geomagnetic field at the equator, midway between the shores of Africa and South America, owes its origin to telluric currents directed along the meridian, from north to south.

Until now, not only the origin of the remaining 2/3 of the latitudinal component has been unknown, but also the nature of the telluric currents themselves in the ocean, which form a kind of vortices around the continents ([3]). It is possible that the answer to both the first and the second question lies in the interactions between the Earth' s magnetic field, whose axis describes a cone around the geographical-

of the Earth' s axis, and the plasma surrounding the planet. There are also grounds to expect that this fundamental problem of geophysics will be solved after E. Bullard carries out the calculations connected with his hypothesis on the origin of the main geomagnetic field ([8]). According to this author' s supposition, as well as to the earlier hypotheses expressed by Ya. I. Frenkel ([9]), beneath the Earth' s solid crust there occurs powerful convection in a thick

Fig. 3

layer of molten material. It is caused by heating from within under the action of decaying radioactive elements. The presence of Coriolis forces leads to the angular velocity of rotation of the molten masses about the Earth' s axis increasing with distance from the crust toward the central solid core of the Earth. As a result, in the molten material, which possesses considerable electrical conductivity, an effect arises of a kind of self-exciting dynamo machine, and thus the Earth' s magnetic field is created.

Bullard carries out a qualitative study of the electromagnetic fields by excluding from Maxwell' s system of equations (for a moving medium) the electric-field intensity vector **E**, thereby obtaining a single equation in vector form

$$\nabla^2 \mathbf{H} = 4\pi\sigma \left(\frac{\partial \mathbf{H}}{\partial t} - \mathrm{rot}[\mathbf{v} \times \mathbf{H}] \right).$$

Here **H** is the magnetic-field intensity; σ is the electrical conductivity, measured in electromagnetic units; **v** is the linear velocity of motion of the molten material.

Since the Earth' s solid crust possesses a certain (insignificant) electrical conductivity, the electromagnetic field of the convective cells creates in it a weak current and thereby slightly retards the motion of the boundaryarsuup of molten masses around the Earth' s axis; their drift from east to west arises. It is precisely this drift that causes secular changes in magnetic declination of the type shown in Fig. 1, and an analogous drift of vortices from east to west, whose angular velocity, as is known, reaches 0.3° per year.

In his works Bullard regards the displacement of the Earth' s magnetic axis relative to its axis of rotation as simply given and not requiring explanation; this is the weak point of his interesting constructions. Indeed, paleomagnetologists, who consider the position of the magnetic axis in the most ancient epochs to have been sharply variable, naturally now arrive at the idea that, over the course of the Earth' s ancient history, the gyroscopic effect ordered the vortical motions in the molten substance beneath the crust, bringing it to its present state. But it must be admitted that in this case the Earth' s magnetic axis should have coincided with the planet' s axis of rotation. In fact, no coincidence of the axes occurred, and over the last three centuries the angle between the axes has even increased.

Meanwhile, the documentary materials that served for the construction of our Figs. 1–3 make it possible to combine Bullard' s concept of drifting convection cells with the concept of a natural main geomagnetic field whose axis coincides with the geographic axis of the Earth. Such a combination is not only possible but also extremely effective: it casts new light on the special role of the World Ocean.

This is indicated by quite simple considerations:

1. If the electromagnetic field of Bullard' s "vortices" interacts with the weakly conducting solid shell of the Earth, causing a drift of convection cells, then one should all the more expect interaction of this electromagnetic field with the well-conducting medium of ocean waters.

2. When the cells pass beneath the ocean, they cause intensified oscillations of the latitudinal component of the field strength and oscillations of magnetic declination that are substantially sharper than when the same cells pass beneath continents. This is convincingly evidenced by the dashed curves on the map in Fig. 3. They indirectly confirm the presence of interactions between the electromagnetic field of the cells and the conducting water medium. The three curves in Fig. 1 are also in complete agreement with Fig. 3: the closer an observatory is located to the ocean, the larger the measured constant component of magnetic declination and the amplitude of its oscillations over the centuries.

3. The principal result of such interactions is also visible in Fig. 3, especially at latitude 40°: it is the constant component of magnetic declination, which is small on the continents and large over the oceans.

4. As a result, it must be acknowledged that Bullard' s convection cells can create the main magnetic field of the Earth, whose axis coincides with the planet' s axis of rotation.

5. The interactions of the electromagnetic field of the cells with the well-conducting waters of the ocean create "vortices" of telluric currents in the ocean around the continents ([3]), and the associated pattern of magnetic declination.
6. It is possible that the interaction of the electromagnetic field of the cells with the waters of individual seas creates in them a constant component of current, upon which are superimposed the eddy currents induced in the sea during magnetic storms ([10]).

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CITED LITERATURE

1. I. Fleming, *Terrestrial Magnetism and Electricity*, 1949, p. 15.
2. V. V. Shuleikin, DAN, 76, No. 1, 57 (1951).
3. L. A. Korneva, DAN, 76, No. 1, 49 (1951); Tr. Morsk. gidrofiz. inst. AN SSSR, 7, 32 (1956); DAN, 107, 679 (1956).
4. V. V. Shuleikin, *A Short Course in the Physics of the Sea*, Ch. 8, 1959.
5. Yu. G. Ryzhkov, DAN, 113, No. 4, 787 (1957).
6. V. V. Shuleikin, DAN, 119, No. 2, 257 (1958).
7. V. V. Shuleikin, DAN, 130, No. 5, 1015 (1960).
8. E. G. Bullard, H. Gellman, *Phil. Trans. Roy. Soc. London*, A. 247, 213 (1954); Ed. Bullard, *Nature*, No. 12 (1960).
9. Ya. I. Frenkel, DAN, 49, No. 1, 98 (1945).
10. V. V. Shuleikin, DAN, 134, No. 6, 1343 (1960).

Note: Figure translations are in progress. See original paper for figures.