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THE REALITY OF THE WESTWARD DRIFT OF THE GEOMAGNETIC FIELD ACCORDING TO ARCHAEO-MAGNETIC DATA

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In discussing the question of the dipole and non-dipole parts of the main geomagnetic field, three assumptions may be put forward: 1) The character of the convective motions of matter in the Earth' s core is such that the magnetic field generated by them is not (even in the first approximation) dipolar, i.e., on the Earth' s surface it differs sharply from a dipole field even with an ideally homogeneous structure of all layers of the crust and mantle. Under this assumption, the closeness of the present-day field at the Earth' s surface to a dipole field should be regarded as a chance phenomenon. 2) The deviation of the real field from a dipole field is the result of electromagnetic shielding by the crust (owing to horizontal inhomogeneity in the distribution of susceptibility) or by the mantle (owing to horizontal inhomogeneity in the distribution of conductivity). In this case the field at the surface of the core is assumed to be dipolar. 3) Inhomogeneities in the structure of the mantle layers directly adjoining the core, through mechanical or electromagnetic braking, distort the convective vortices, the consequence of which is the deviation of the magnetic field from a dipole field. In this case the basic character of the motions of matter in the core is assumed to correspond to a dipole field, but the real field both near the surface of the core and at the Earth' s surface has non-dipole components.

The first assumption is unlikely, since, according to paleomagnetic data, in the past the field was for the most part close to a dipole field. This indicates that the initial generated field is dipolar, and that deviations from dipolarity are of secondary character. In discussing the other two possibilities, the decisive question is that of westward drift. If westward drift, i.e., the displacement of the foci of secular variation toward the west, really exists, and if, in the formal mathematical subdivision of the magnetic field into dipole and non-dipole parts, it turns out that secular variation in general, and its westward drift in particular, are manifested considerably more strongly in the non-dipole part of the field, then this speaks in favor of the third assumption: shielding layers, whatever their character, cannot move inside the Earth, completing a full revolution in a time of the order of a thousand years, whereas a distortion in vortical motion

Fig. 1. Smoothed curves of secular variations of inclination, constructed from mean inclination values computed with allowance for the weight of each measurement. *a*—for Ukraine (Kiev, 50°.5 N, 30°.5 E), *b*—for Poland (Warsaw, 52°.2 N, 21° E).

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can be preserved by this motion and transported by it. As for the displacement of the core and the shell relative to one another, the associated displacement of isolines, with a homogeneous core—shell boundary, should appear considerably more strongly in the dipole part of the field.

Since the reality of westward drift, obtained by analyzing maps of magnetic isolines of different epochs, is disputed by some authors, it is of interest to study this phenomenon by another method—the method of archaeomagnetic investigations.

If one compares the archaeomagnetic curves of variations in inclination for two regions: Poland (Warsaw) and Ukraine (Kiev), situated approximately at the same latitude and 9.5° apart from one another, one can see—

that they are periodic curves shifted in phase relative to one another (Fig. 1), with the variation in Poland lagging behind the variation in Ukraine. This shift of the secular-variation curves corresponds to the phenomenon of westward drift.

From the mean displacement in time of the curves corresponding to different longitudes, the magnitude of the drift velocity can be calculated. If the drift is regarded as westward, then its mean velocity should be taken as 0.16 deg/year; if as eastward (a formal comparison of the two curves also permits this possibility), then the value of the velocity proves to be 0.02 deg/year. On the other hand, from the analysis of observatory observations the velocity of westward drift is on average 0.2 deg/year.

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Fig. 2. Curve of the change in inclination in the Caucasus over the last 8000 years. The points denote the results of measurements of samples from Bulgaria with a phase shift calculated taking into account a westward-drift velocity of 0.23 deg/year.

In terms of the questions raised above, the fundamentally important point is the very fact of the existence of a systematic one-sided drift in the latitudinal direction. The question of whether this drift is westward or eastward is of

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secondary importance. If the drift is considered a direct reflection of convective motions in the core, then the nature of these motions should be judged from changes in the magnetic field at the Earth' s surface, and not vice versa; if, however, the primary cause is taken to be displacement of the mantle relative to the core, then, when electromagnetic braking of the core predominates, the drift should be westward, and when tidal braking of the mantle predominates—eastward.

However, since an estimate of both phenomena ([1]) shows that the effect of electromagnetic braking substantially exceeds tidal braking, in what follows we shall discuss specifically westward drift.

In Fig. 2 the solid curve, constructed on the basis of archaeomagnetic measurements ([2]), represents the change in inclination in the Caucasus for the time interval from 4000 years B.C. to the present. On this curve, points indicate the values of inclination for various moments in time, determined from samples from Bulgaria and recalculated to the longitude of the Caucasus with allowance for westward drift at a velocity of 0.23 deg/year ([3]). Good-

A closer coincidence of the points with the Caucasus curve gives grounds to assume the existence of westward drift with a rate on the order of 0.2 deg/year.

If the phenomenon of westward drift is considered real, then the following regularity should be observed: the extreme values of the inclination should occur not synchronously over the entire surface of the Earth, but with a shift in time proportional to the longitude of the place. Fig. 3 illustrates the existence of such a regularity*. All points characterizing the position of the maximum inclination on the time axis for different geographical longitudes, within the error of determination, lie on a straight line. The tangent of the angle of inclination of this line to the abscissa axis characterizes the rate of westward drift. Taking into account the possible errors in determining the moments of time corresponding to $I_{\max}$, this quantity can be estimated as **0.23 ± 0.06 deg/year**.

Fig. 3. Dependence of the time of occurrence of the last maximum of inclination on longitude.
1 –London, λ 0°, φ 51°; 2 –Paris, λ 2°, φ 49°; 3 –Rome, λ 13°, φ 42°; 4 –Sicily, λ 14°, φ 37°; 5 –Hungary, λ 18°, φ 48°; 6 –Poland, λ 21°, φ 52°; 7 –Lvov, λ 24°, φ 50°; 8 –Kaunas, λ 24°, φ 55°; 9 –Vilnius, λ 25°, φ 54.5°; 10 –Ukraine (Kiev),

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λ 30.5°, φ 50.5°; 11 –Caucasus, λ 45°, φ 41°; 12 –Central Asia, λ 66°, φ 40°; 13 –China, λ 115°, φ 40°; 14 –Japan (Watanabe); 15 –Japan (Yokutake), λ 140°, φ 36°.

Thus, the phenomenon of westward drift, the existence of which could have been assumed on the basis of processing observatory observations over 180 years, is confirmed by the results of archaeomagnetic observations at least for the last 700 years for the territory lying between 0 and 140° E longitude and $43 \pm 4°$ N latitude. The estimate of the drift rate from archaeomagnetic data gives the same order of magnitude as that from observatory determinations.

Some scatter of the points relative to the mean line is explained not only by errors in archaeomagnetic determinations, but also by the fact that secular variations have regional and local features: the system of isopors moves westward while changing somewhat.

As further archaeomagnetic data on secular variations accumulate, a more accurate estimate of the magnitude of the westward drift rate can be made, and its latitudinal and longitudinal dependences can also be revealed.

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* The dependence on geomagnetic longitude has the same character.

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