An Interpretation of the Archeomagnetic Field Intensity

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Abstract

Available data of the ancient geomagnetic field intensity determined by the archeomagnetic measurement are compared with theoretically calculated curves of secular variation in the geomagnetic total force at three mutually remote sites. It is particularly remarkable that the anomalous archeomagnetic results from equatorial America (Peru, Bolivia and Mexico) can be accounted for by the model including the westerly drifting components of non-dipole field superposed on the standing non-dipole and the oscillating dipole fields. The good agreement of the archeomagnetic date and the calculated curves may imply that the drifting non-dipole field given in Yukutake's model has been persistent over the past 4,000 years.

1. Introduction

Ancient geomagnetic field intensities of historical and archeological periods have recently been determined at several localities over the world with the archeomagnetic techniques. Most of the data were summarized in catalogues and a review article (Smith, 1967a, b, c; 1968). A few more sets of results have been added since then. Among these data, Bucha's study of samples from Czechoslovakia (4,400 B.C. up to the present time) and from Turkey (6,500 B.C. to 5,400 B.C.) indicates an almost periodical character of the field intensity (Bucha, 1967). Kitazawa obtained a comprehensive result for the past 10,000 years in the northeastern Japan (1969). Both of their results seem to be best fitted to a sinusoidal curve with the period of 8,000 years and the amplitude of 0.5 times the present field intensity. This curve shows good agreement with other data from France (Thellier and Thellier, 1959), Tbilisi, Russia (Burlatskaya and Petrova, 1961), Czechoslovakia (Bucha, *ibid*) and southwestern and central Japan (Nagata et al, 1963; Sasajima and Maenaka 1966). It seems, therefore, likely that the overall tendency of the time change in field intensities is caused by a variation of the magnetic moment of the earth's main dipole field. The wobble of the dipole and the non-dipole field effect can not be the primary origin of this behavior because the changes in two sites as remote as by nearly 180° in longitude (e.g. Japan and Czechoslovakia) are still consistent.

In contrast to such a good agreement among data from middle to high latitudes abnormal curves are obtained from localities near the equator: i.e. south and central America (Peru, Bolivia, Mexico and Ecuador) (Nagata et al, 1965; Kitazawa and Kobayashi, 1968) and India (Athavale, 1966). Such abnormality can be explained neither by experimental

errors nor by scantiness of data.

The present article describes a theoretical calculation of the total force of geomagnetic field on the basis of a model of the earth's magnetic field consisting of the varying dipole and the drifting non-dipole fields. The theoretical curves are compared with the available data and plausibility of the model over 4,000 years is thus assessed to some extent.

2. A model of the earth's field

Spherical harmonic analyses of the directly observed geomagnetic field elements have revealed that the earth's magnetic field is represented to a first approximation as a dipole field. A distinct decrease in the dipole moment is seen since beginning of the instrumental observations (Nagata, 1965; Leaton and Malin, 1967).

On the other hand, it has also been proved by mathematical analyses of the data that non-dipole component is responsible for the secular variation of the declination and inclination of the field (Nagata, 1962; Yukutake, 1962; 1967; 1968). Moreover, Yukutake and Tachinaka (1968a; b; 1969) have shown that the non-dipole field consists of two types: the standing and drifting fields. Although a great number of non-dipole anomalies on the earth's surface belong to the standing type, the westward drift of the overall pattern of field is clearly seen.

Yukutake has estimated its drift rate by an analysis of the observational data on the basis of three different models A, B and C (Yukutake, 1968; Yukutake and Tachinaka, 1969). In his model A all the non-dipole components drift together, while the model C consists of perfect dispersion in the drift velocities of individual spherical harmonic components. His model B exists between the above two extremes and it is assumed there that each Fourier component along parallel circles moves with the same velocity irrespective of their longitude.

In the present article it is assumed that the non-dipole variation in the archeological period (at least for the past 4,000 years) was the same as that revealed from the observational data (since the 17th century). Yukutake's model B is thus adopted as the non-dipole field since 2,000 B.C. It is also assumed for the simplicity that change in the dipole moment M with time is represented by $M = M_0 \left(1 + 0.5 \sin \frac{\pi}{4,000} t \right)$ where M_0 is the present moment and t is time before present in the unit of year. Secular variation of the field intensity at any locality can be calculated from this hypothetical superposition of the dipole and non-dipole fields. Actual calculation was made possible with kind help of Dr. T. Yukutake of the Earthquake Research Institute to whom I am greatly indebted.

3. Comparison of field intensity data with the theoretical curves

Calculated curves of variation in the field intensity at three representative sites, Tokyo, London and La Paz (Bolivia) are shown in Fig. 1, 2 and 3 respectively. It is notable that at Tokyo and London the curves exhibit a predominant period of 8,000 years which is naturally caused by the periodicity of the dipole field. Shorter variations due to the non-dipole component have only minor influence on the general tendency. The features of two curves

Fig. 1 Intensity of the geomagnetic total force since 2,000 B.C. The curve is theoretically calculated change at Tokyo based upon the Yukutake's model B plus a periodical change in the dipole moment (see text).

- : archeomagnetic data from central Japan (Nagata et al, 1963).
- △: archeomagnetic data from southwestern Japan (Sasajima and Maenaka, 1966).
- : archeomagnetic data from northeastern Japan (Kitazawa, 1969).

Fig. 2 Intensity of the geomagnetic total force since 2,000 B.C

- Curve: theoretical change at London.
- : French data (Thellier and Thellier, 1959).
- : Russian data (Burlatskaya and Petrova, 1961).
- △: Czechoslovak data (Bucha, 1967).

Fig. 3 Intensity of the geomagnetic total force since 2,000 B.C.

Curve: theoretical change at La Paz (Bolivia).

△: Nagata et al (1965).

○: Kitazawa and Kobayashi (1965).

for Tokyo and London are similar for the same reason.

At La Paz, on the other hand, apparent periodicity of the curve is clearly different. The curve shows a distinct minimum at about 0 A.D. which can be attributable to the non-dipole component. It can be easily understood that the non-dipole field is relatively more effective in the equatorial regions than in the areas of high to middle latitudes, because the intensity of the dipole field at the equator is half that at the poles.

Archeomagnetic intensity data available at present are also indicated in the figures. In Fig. 1 three different sets of Japanese results (Nagata et al, 1963; Sasajima and Maenaka, 1966; Kitazawa, 1969) are plotted together. The experimental results are generally agreeable with the theoretical curve. French, Russian and Czechoslovak results are shown in Fig. 2. As their sampling sites are not really near London, some discrepancy may be expected. Nevertheless, the general mode of variation is still in good agreement with the theoretical change at London.

The most interesting is the consistency of the La Paz curve with data from Mexico, Peru and Bolivia. *Abnormally* low values of archeo-field intensity at these places around 0 A.D. can thus be beautifully explained by the non-dipole effect.

4. Concluding remarks

The agreement of the calculated curves with the general variations in the archeomagnetic intensity at a few but widely dispersed places seems to indicate that the present model is more or less successful. The amplitude and period of the oscillating dipole assumed there may not necessarily be correct and should be determined by more careful treatment of greater number of data from middle to high latitude areas over a longer time interval. It is, nevertheless, concluded that the drifting non-dipole field revealed by the mathematical analysis of the recent observational data has not been much different over the past 4,000 years. This conclusion may be meaningful in considering the origin of the non-dipole

field of the earth. Archeomagnetic investigations of the other areas near the equator will provide further evidence of the present statement.

If both intensity and direction (inclination and declination) at the ancient times are determined from these areas by the archeomagnetic method, a new clue will be provided for the archeomagnetic analysis of non-dipole variations. Although the theoretical variation has not yet been calculated, India may possibly be another site where the non-dipole is predominant. Athavale's result (1966) may be explained in this manner.

The present result also indicates that a statistical treatment of paleomagnetic intensity data as well as paleomagnetic directions from a sequence of lava flows or sediments collected at the paleomagnetic equator may yield some information about the behavior of non-dipole field in the geological times.

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