

On Paleomagnetism as the Basis of a New Method for Correlation and Subdivision of Sedimentary Sequences

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Abstract

Full Text

Geophysics

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On Paleomagnetism as the Basis of a New Method for Correlation and Subdivision of Sedimentary Sequences

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In an article ⁽¹⁾ the author proposed a new method for the correlation and subdivision of sedimentary sequences—by the vector of natural remanent magnetization I_n . It was suggested that abrupt changes, reaching 180° , in the direction of I_n , which were observed in sections of Pliocene deposits of Western Turkmenia, reflect corresponding changes in the Earth's magnetic field at that epoch. A similar vertical alternation of zones with opposite directions of I_n has recently been established for a whole series of sedimentary and volcanogenic sequences of different ages ⁽²⁻⁴⁾.

The present work is devoted to testing the connection of this phenomenon with the proposed repeated inversions of the Earth's magnetic field in the past. This test was carried out on material from the study of the magnetic properties of 650 oriented specimens—cubes with an edge of 4.5 cm, taken in 1955 from exposures of the red-bed suite of the Cheleken Peninsula. Measurements of I_n and of magnetic susceptibility χ were made on an astatic magnetometer with a scale division value of 0.13 γ/mm . The method for measuring the magnitude and direction of I_n consisted in determining the components of this vector along three axes parallel to the edges of the cube. The direction of I_n was expressed by the declination angle D and the inclination angle J , reckoned in a coordinate system related to the original horizontal bedding of the layers. Duplicate measurements made it possible to determine the direction of I_n with a mean square error equal to 5° for $I_n \geq 2 \cdot 10^{-6}$ CGSM. Magnetic susceptibility was determined in a field $H = 0.5$ oersted, produced by Helmholtz coils.

The red-bed suite on Cheleken composes the central part of the Cheleken fold, broken by faults into blocks with different elements of bedding of the strata. This circumstance made it possible to distinguish rocks that had preserved the direction of I_n acquired before the onset of movements that caused the present dip of the beds. Such rocks proved to be clays, marls, and siltstones of red and brown tones, characterized by elevated values of χ and especially I_n ($\chi_{\text{av}} = 21.4 \cdot 10^{-6}$ CGSM, $I_{n\text{av}} = 10.9 \cdot 10^{-6}$ CGSM). Bluish clays and greenish-gray sands, on the other hand, were completely or almost completely remagnetized in the direction of the present terrestrial magnetic field. Here $\chi_{\text{av}} = 11.0 \cdot$

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

10^{-6} CGSM, $I_{nav} = 1.5 \cdot 10^{-6}$ CGSM. The dependence between the degree of stability of I_n , its numerical magnitude, and the color of the rock is readily explained if one assumes that stable remanent magnetization is associated with finely dispersed iron oxides, which caused the reddish coloration of the rocks. As for the blue and greenish-gray coloration, in the opinion of N. M. Forsh, who is studying the lithology and stratigraphy of the Cheleken red-bed suite, it is secondary and arose as a result of the penetration of hydrogen-sulfide waters and the leaching of iron oxides. The latter led to the loss of the primary remanent magnetization.

The vectors I_n of magnetically stable red-colored rocks are grouped, with respect to the bedding planes, around two preferential directions, almost opposite to one another. The first is characterized by a declination $D = 12^\circ$ and an inclination $J = 37^\circ$, the second by $D = 196^\circ$, $J = -30^\circ$. The distribution of I_n by azimuths is shown in Fig. 1, on the left. Let us note the presence of intermediate directions of I_n , all of them falling on western rhumbs.

Fig. 1

Figure 2 shows the variation of inclination along sections of the Cheleken red-colored formation, spaced 2-4 km apart. The curves are constructed only on the basis of results relating to samples of magnetically stable rocks. The broken lines show the correlation of the sections according to geological data—according to the scheme of subdivision of the red-colored formation kindly communicated to the author by N. N. Forsh. It is seen that all sections are divided into zones of approximately equal thickness; in neighboring zones the values of D differ from one another by approximately 180° , while beds with intermediate values of D are confined to the boundaries between zones. The zones preserve their stratigraphic position throughout all sections. The inclination curves (not presented here) have a similar form: positive values of J always correspond to values of D close to 0° , and negative values to those close to 180° . In Fig. 3, as an example, the variation of D and J is shown in a boundary interval between two zones in one of the sections. It is seen that, in passing

Fig. 2

from zone to zone, the vector I_n begins to turn downward and, until it assumes the opposite direction, rotates approximately in a plane rather steeply inclined to the northwest. An analogous pattern was also observed in all other cases, when the frequency of sampling along the section made it possible to reveal it.

Fig. 3

Figure 3: Fig. 3

Two interbeds from the lower—

of the lower and upper parts of the upper transitional layer were specially traced over a distance of 4 km. In Fig. 1 on the right is shown the distribution of I_n by azimuths for samples taken from these interbeds. It also indicates the identical character of the change in the direction of I_n in the transitional layers within the exposures of the red-bed suite on the Cheleken. Calculation of the mean values of I_n for vectors with normal, intermediate, and reversed directions of I_n revealed no significant differences among them, giving $(12.7 \pm 0.8) \cdot 10^{-6}$, $(9.8 \pm 1.4) \cdot 10^{-6}$, and $(10.0 \pm 0.9) \cdot 10^{-6}$ CGSM, respectively.

In addition to the deposits of the Cheleken red-bed suite, coeval sediments on Maly Balkhan were sampled for oriented specimens, as were deposits of the Akchagylian and Apsheronian stages on Cheleken, Maly Balkhan, and Kyurendag. The inclined bedding of the strata made it possible here also to distinguish magnetically stable rocks, represented by red-brown, brown, and gray clays and siltstones. In all the sections studied, changes in the direction of I_n in magnetically stable rocks consist of an alternation of normally and reversely magnetized zones. The zones occupy definite stratigraphic positions. Thus, the upper parts of the Apsheronian deposits both on Cheleken and on Kyurendag are normally magnetized; below lies a zone of reversed magnetization, occupying a large part of the section of the Apsheronian stage; then follows a zone of normal magnetization, through which passes the boundary between the Apsheronian and Akchagylian. The next three zones are noted in the sections of the Akchagylian stage of Maly Balkhan and Kyurendag; the Cheleken red-bed suite and the coeval deposits of Maly Balkhan begin with a zone of normal magnetization, below which lies a zone of reversed magnetization, etc. In all, from the top of the Apsheronian stage to the base of the Middle Pliocene deposits of Maly Balkhan, one can count 7 zones of normal magnetization and 7 of reversed magnetization.

Fig. 3

All the facts set forth above can evidently be satisfactorily explained only on the assumption that changes in the direction of I_n of magnetically stable sedimentary rocks in the sections of the Pliocene of Western Turkmenia reflect changes in the Earth's magnetic field during the Pliocene. Apparently, these changes represented inversions of the Earth's dipole magnetic field. Confirmation of such an interpretation is provided by the simultaneity and identical character of the changes in the direction of I_n in sections 170 km apart, as well as by the fact that the phenomenon of alternation of normally and reversely magnetized zones was also established for some volcanogenic-sedimentary sequences of Western Europe^(3,4), coeval with the sediments we studied.

Our data show that inversions of the Earth's magnetic field in the Pliocene occurred by rotation of the Earth's magnetic axis. In this process the north magnetic pole passed through Western Europe. The duration of the stable state of the Earth's magnetic field was previously estimated by Hospers⁽⁵⁾ at $(0.25 \div 0.5) \cdot 10^6$ years. Apparently the second figure is more correct, since it leads to a more plausible date for the beginning of the Middle Pliocene— $7 \cdot 10^6$ years ago. With this estimate, judging from the ratio of the thicknesses of the magnetic zones and transitional layers in the sections

of Western Turkmenia, the process of reversal of the Earth's magnetic field itself must have occupied several tens of thousands of years.

The new method of correlation and subdivision of sedimentary sequences, by virtue of the foregoing, has grounds to be called paleomagnetic. Since the alternation of normally and reversely magnetized zones is, evidently, a consequence of reversals of the Earth's magnetic field that occurred simultaneously over the entire Earth, the paleomagnetic method opens up the fundamental possibility of absolute correlation of any sections, at least those partially composed of magnetically stable rocks—regardless of their geographic position; there also appears the possibility of creating a unified scheme for their subdivision. This method will probably make it possible to synchronize various events of geological history with an accuracy on the order of $10^4 \div 10^5$ years. The presence of a slow directed change in the Earth's magnetic field, revealed by paleomagnetic studies and thought to be connected with the migration of the geographic poles^(6,7), will substantially facilitate the creation of a paleomagnetic time scale.

The paleomagnetic method allows the possibility of subdivision and correlation of sequences not only by samples from outcrops, but also by cores from boreholes (in this case it is necessary to record the position of the top of the sample). In addition, the phenomenon of alternation of normally and reversely magnetized zones and the considerable magnitude I_n of a number of sedimentary rocks apparently open new prospects for magnetic-field logging in boreholes.

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