

MARINE GEOLOGY

Variations of the Geomagnetic Dipole Magnitude over the Past 400 My

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Abstract—The international bank of the virtual dipole moment data supplemented by the values from more recent publications is used as the basis for an analysis of the behavior of the virtual dipole moment values over the last 400 My. The results obtained revealed a positive linear trend from 4.1×10^{22} to 5.7×10^{22} A m² during the last 400 My. Against the background of the linear increase, fluctuations with a periodicity of about 40 My were observed. In the Phanerozoic time, minimums within the intervals of 340–370, 290–300, 240–270, 190–210, 165–140 (chrons M17–M43), 130–120 (chrons M2–M10), 100–110 (chron 34), 75–85 (chron C33 and the beginning of chron C34), 70–60 (chrons C31–C27), and 40–15 (chrons C18–C5AD) My B.P. are found. The distribution of the virtual dipole moment is strictly related to the distribution of the ancient geomagnetic field and may be taken into consideration when modeling the magnetization of the inversive magnetic layer of the ocean.

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INTRODUCTION

The expansion of the earth's magnetic field into a series with respect to spherical harmonics suggests that the first spherical harmonic of the geomagnetic field is equivalent to the field of a magnetic dipole placed at the center of the earth. Thus, the main part of the earth's magnetic field, to a first approximation, is described by the field of an axisymmetric dipole. An important characteristic of the magnetic field is the time history of the values of the virtual dipole moment (VDM), which is regarded as the dipole moment of the equivalent geocentric dipole that produced the known magnetic and inclination of the vector of the ancient dipole field [15] for a specified moment in the past. The results of the operation of the magnetic dynamo in the geological past are represented by the values of the virtual dipole moment recovered in the process of the studies of magnetic properties of the earth's rocks. These kinds of data on the distribution of the dipole component of the earth's magnetic field over time bring evidence about its significant variations in the Phanerozoic [3, 4, 7, 11, 14, 17, 19, 21–24]. Until recently, the great scattering of individual VDM values has allowed only a qualitative estimation of any regularity. In paper [3], a general methodological approach to the VDM data processing was suggested and the results of its application to a VDM analysis for the interval of 0–200 My B.P. were demonstrated. The objective of this study is to use the

quantitative approach described in [3] while analyzing such regularities for the interval of 0–400 My B.P.

MATERIALS USED

Recently, in order to examine the time history of VDM, an international database (IAGA PALEOINTENSITY DATABASE) was created; it is available at the site of the Geophysical Center in Boulder (Colorado) [12]. In the middle of 2006, this database contained 2825 VDM values for the last 400 My collected from 237 published sources [9]. This database, together with additional information from the database of the Borok Observatory [6] and the data published in [11, 16, 18], formed the base for this study. The updated database used by us included 3203 VDM values with corresponding absolute age determinations.

A qualitative analysis of the data shows that the value of the earth's magnetic field intensity was not constant in time. Meanwhile, the quantitative analysis of the qualitative regularities was deteriorated by the significant scattering of the actual individual values of the virtual dipole moment (Fig. 1).

Among other approaches to their interpretation, the sliding average method allows one to significantly smooth irregular fluctuations of the data used. We chose it as the main operation method used. Numerous estimates [3] made by us showed that the best size of the sliding window for averaging the data available for the

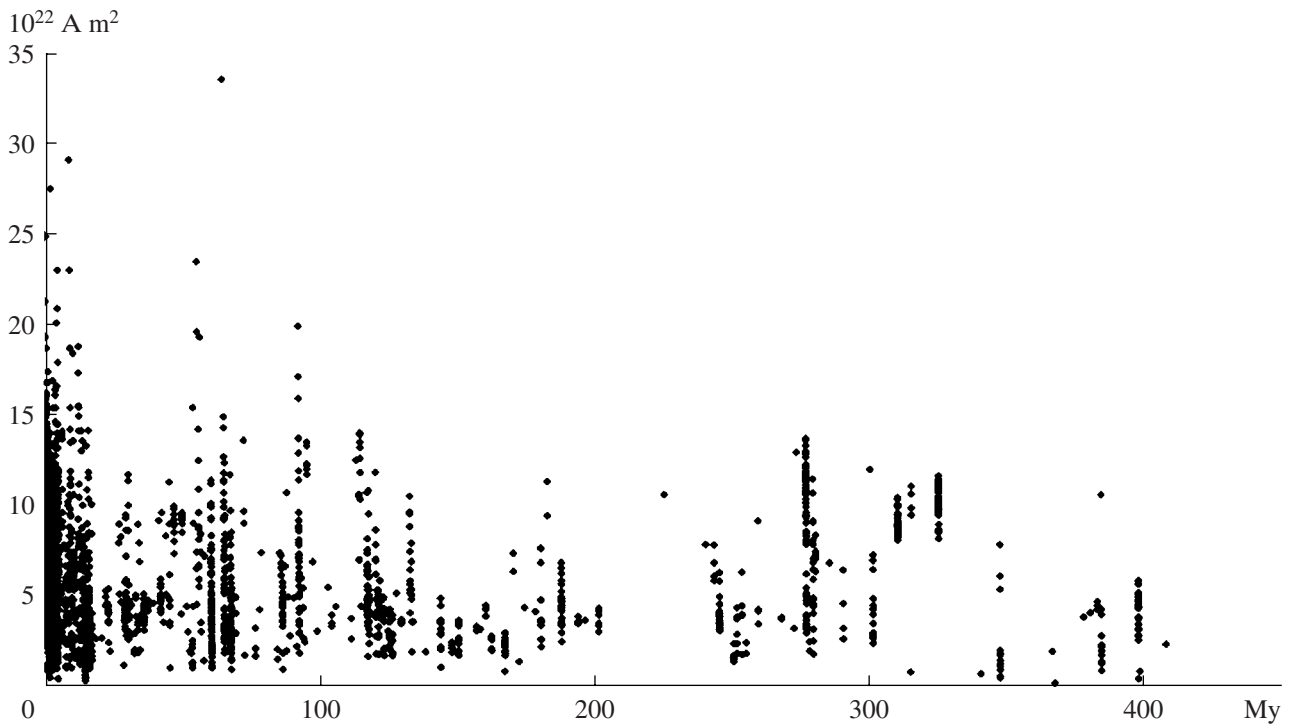


Fig. 1. Distribution of the values of the virtual dipole moment according to the extended database used in this paper.

interval down to 400 My B.P. is 10 My and the optimal sliding step comprises 5 My. With these parameters, in each calculation, one can involve, as a rule, no less than 10–50 values and strongly eliminate random fluctuations from the resulting curve. In this study, we used the scale of linear magnetic anomalies and corresponding polarity subchrons from [2, 8].

The maximal numbers of values used by us in this analysis fall in the intervals of 0–10 My B.P. (1858 values), 10–20 My B.P. (227 values), 60–70 My B.P. (179 values), and 275–285 My B.P. (110 values). The intervals of 220–230, 260–270, 265–275, 285–295, 310–320, 335–345, 360–370, 365–375, and 400–410 My B.P. are characterized by less than 7 values each; the intervals of 205–230, 330–340, 350–360, and 385–395 My B.P. contained no values available for calculations.

In all of the cases, we used mean VDM values and their standard deviations in the averaging interval. These values were referred to the average age values determined for the corresponding averaging intervals.

The modal value of the standard deviations of the age values from their means falls into the interval of ± 0.32 – ± 0.57 My. There are five values exceeding ± 1 My: ± 1.13 My B.P. in the interval of 75–85 My B.P., ± 1.5 My in the interval of 170–180 My B.P., ± 1.05 My in the interval of 95–105 My B.P., ± 1.49 My in the interval of 160–170 My B.P., and ± 1.43 My in the interval of 270–280 My B.P.

RESULTS OF THE CALCULATIONS

Figure 2 shows the distribution of the mean VDM values in the window 10 My wide with a shift of 5 My plotted using the data of our updated database containing 3203 values. The vertical bars denote the standard deviations, whose values represent the width of the scattering of individual values from their mean. The horizontal axis is the age corresponding to the mean age in the averaging window.

The plot proves that the virtual dipole moment, whose present-day value equals 8×10^{22} A m² [14], was not constant in the past. Over the last 400 My, the mean VDM values are characterized by the presence of a positive linear trend from 4.1×10^{22} to 5.7×10^{22} A m² toward the present-day epoch; 225 My B.P., it reached its maximal values of 10.58×10^{22} A m², while the minimal values of 0.98×10^{22} A m² are confined to 366.5 My B.P. Against this background, one can note significant fluctuations of the mean VDM values with a wavelength (the distance between the peaks of similar signs) of 20 My and greater.

In the Paleozoic, the peaks are determined for the Famennian–Tournaisian (370–340 My B.P.; peak with an absolute value up to 2.2×10^{22} A m² and a relative amplitude of about 2×10^{22} A m²), Viséan–Gzhelian (340–300 My B.P.; peak with an absolute value up to 10.2×10^{22} A m² at a relative amplitude of about 8×10^{22} A m²), and Sakmarian–Hoongurian (290–270 My B.P.; peak with an absolute value up to 7.9×10^{22} A m² at a relative amplitude of about 4×10^{22} A m²).

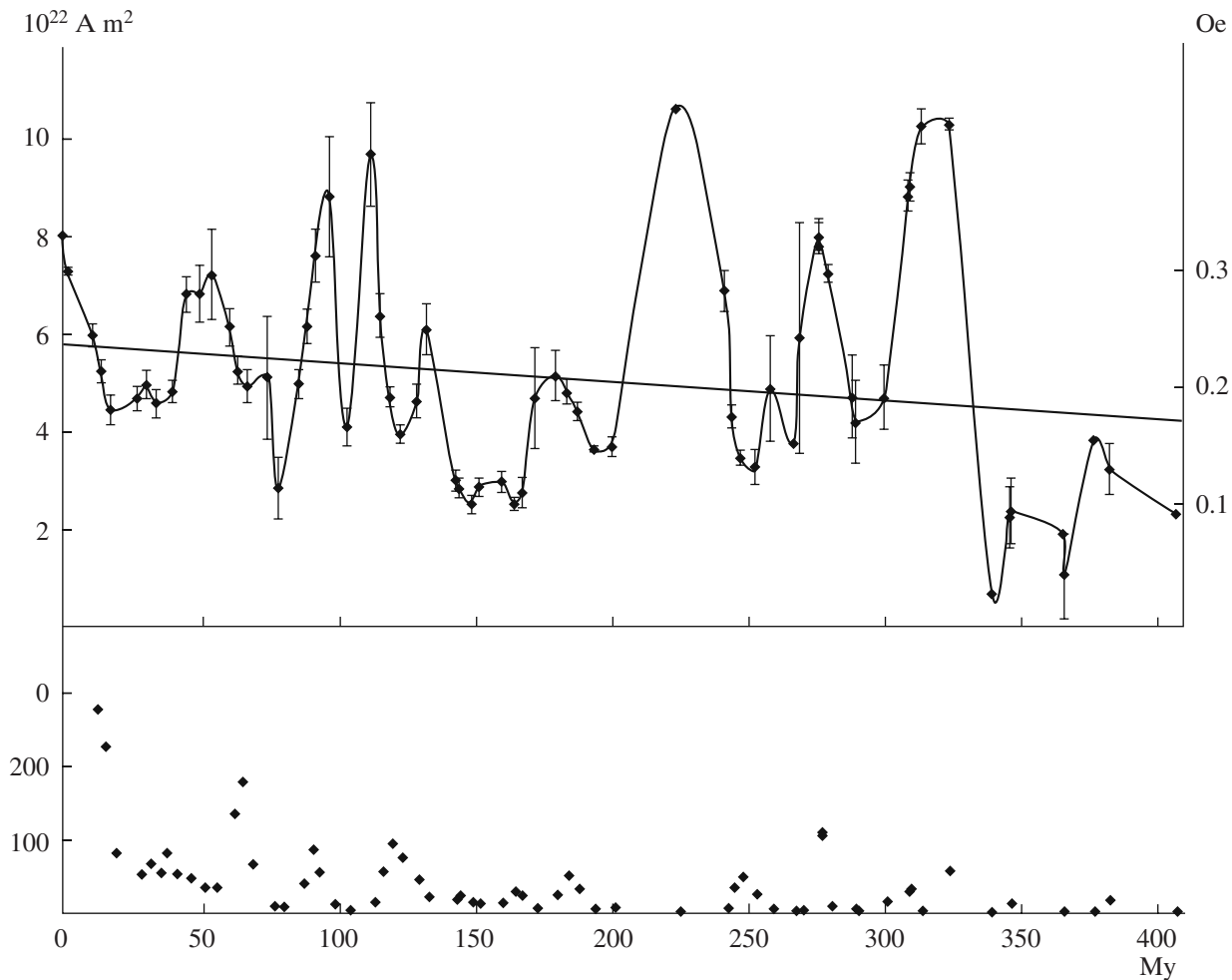


Fig. 2. Distribution of the mean values of the virtual dipole moment for the period of 0–400 My B.P. The values are calculated using the sliding average method with a window 10 My wide at a step of 5 My. The right-hand vertical axis represents VDM values converted into the equatorial intensity of the paleomagnetic field in 10^3 mOe. The vertical bars show the representativeness errors or root-mean-square deviations from the average value for each of the calculation windows. The dots below the time axis show the numbers of values in each of the calculation windows except for the windows of 0–10 My B.P. (1858 values); 5–15 My B.P. (278 values); 10–20 My B.P. (227 values); 60–70 My B.P. (157 values); and 205–225, 235–240, 330–340, 350–360, and 385–395 My B.P. (no values).

In the Mesozoic, the peaks are confined to the Indian–Gettangan (251–200 My B.P.; peak with an absolute value up to 10.6×10^{22} A m² at a relative amplitude of about 6.5×10^{22} A m²), Sinemurian–Bathonian (195–165 My B.P.; peak with an absolute value up to 5.1×10^{22} A m² at a relative amplitude of about 2×10^{22} A m²), Tithonian–Barremian (150–123 My B.P.; peak with an absolute value up to 6×10^{22} A m² at a relative amplitude of about 3×10^{22} A m²), Aptian–Albian (123–103 My B.P.; peak with an absolute value up to 9.6×10^{22} A m² at a relative amplitude of about 6×10^{22} A m²), Albian–Campanian (103–78 My B.P.; peak with an absolute value up to 8.8×10^{22} A m² at a relative amplitude of about 5×10^{22} A m²), and Campanian–Maastrichtian (78–67 My B.P.; peak with an absolute value up to 5.1×10^{22} A m² at a relative amplitude of about 4×10^{22} A m²).

In the Cenozoic, a peak with an absolute value up to 7.2×10^{22} A m² and a relative amplitude of about 2.5×10^{22} A m² is recognized in the Danian–Priabonian (67–33 My B.P.). Starting from 16.9 My B.P., the VDM value grew from 4 to 8×10^{22} A m² at present.

Between the above-listed peaks, minimums of the VDM are located. The shape of the extreme parts of the minimums is more complicated than that of the maximums and often contains additional local peaks with an amplitude up to 0.5×10^{22} A m². The distribution obtained (Fig. 2), to a significant degree, refines the previous data from [4, 5, 10] about the variations of the VDM in this interval.

DISCUSSION OF THE RESULTS

The results of the calculations of the mean VDM values obtained using the sliding average method sug-

gest that they are not chaotic in time and demonstrates a linear 1.4-fold VDM growth during the last 400 My toward the present-day epoch. Against the background of this growth, one observes fluctuations with a period estimated at approximately 40 My.

The magnitude of the virtual dipole moment and the modulus of the intensity of the ancient magnetic field H_{an} for the same age and at the same latitude are directly related to each other, which allows one to use the VDM to characterize the intensity of the main (dipole) component of the ancient magnetic field. We will express the corresponding values in the shares of the present-day intensity H_{pd} , whose equatorial value equals 0.33 Oe (26.3 A/m) [1]. The linear trend in the increase of the intensity of the dipole component of the earth's magnetic field at the equator over the past 400 My may be estimated as 0.132 mOe/ky.

In the Paleozoic, these fluctuations are represented by the region of reduced values (down to 0.2 of H_{pd}) in the interval of 370–340 My B.P. and down to 0.4 of the H_{pd} in the intervals of 300–290, 270–240, and 210–190 My B.P.

In the Mesozoic, the fluctuations are represented by the region of values reduced down to 0.3 of the H_{pd} in the interval of 165–140 My B.P. (chrons M43–M17). Regions of relative lows of the field intensity down to 0.5 of the H_{pd} are registered for the intervals of 130–120 (chrons M10–M2) and 100–110 (chron C34) My B.P.; values down to 0.35 of the H_{pd} are recognized for the interval of 75–86 My B.P. (chron C33 and the beginning of chron C34).

In the Cenozoic, these kinds of regions include the area of values reduced down to 0.7 of the H_{pd} at the boundary of the Danian and the Maestrichtian in the interval of 70–60 My B.P. (chrons C31–C27) and the area of values reduced down to 0.5 of the H_{pd} in the interval of 40–14 My B.P. (chrons C18–C5AD). Let us emphasize once more that, in the central parts of the minimums at 370–340, 270–240, 165–144, and 40–14 My B.P., one encounters areas of elevated values.

During the past 400 My, the total durations of the periods of the maximums and minimums of the VDM are close to one another. The significant (from 10×10^{22} A m² and higher to 0.3×10^{22} A m² and lower) variations of the dipole component of the Earth's magnetic field directly suggests the necessity of accounting for these variations when modeling paleomagnetic anomalies formed in the axial spreading zones in the Mesozoic–Cenozoic as well as when modeling the inversive magnetic layer of the portions of the oceanic crust of more remote geological epochs that might have existed on our planet.

CONCLUSIONS

An analysis of the data of the updated digital database on the virtual dipole moment brings evidence that the distribution of the VDM values over the past

400 My is characterized by the presence of a positive linear trend from 4.1×10^{22} to 5.7×10^{22} A m². Against the background of the linear growth, fluctuations with periods approximately estimated at 40 My are manifested.

The VDM distribution obtained using the sliding average method reflects the behavior of the ancient magnetic field; it should be taken into account when modeling magnetization values of the inversive magnetic layer of the ocean for the chron interval of C1–M43. The values of the VDM referring to times greater than 165 My B.P. (chron M43) may be used for magnetic modeling of the inversive magnetic layer for the portion of the oceanic crust of the geological past that might have existed on our planet.

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