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GEOPHYSICS

A New Method for the Chronometry of Oxygen-Isotope Records in Deep-Sea Sedimentary Cores

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Based on the orbital-climatic diagram (OCD) elaborated by the author of this work [1, 2], chronometry of the oxygen-isotope (OI) curve of Core MD 900 963 studied by Bassinot *et al.* [3] was carried out. The present paper demonstrates advantages of this chronometry for the spectral analysis of OI data relative to the commonly used laborious procedures of the identification of orbital periods. Thus, a previously overlooked significant period of climatic variations (~29.4 ka) with the spectral amplitude exceeding that of precession peaks was revealed in the OI record.

The OI scale of deep-sea sediments is a recognized standard of Pleistocene climatochronostratigraphic records. Chronological boundaries of OI stages in this scale are based on paleoclimatic records and the identification of climatic periods corresponding to cycles in variations of the Earth's obliquity (~41 ka) and precession (~23 and 19 ka) [4, 5]. According to the theory of M. Milankovitch, which serves as an ideological basis of this procedure, global climatic changes during the last million years were governed by insolation variations related to only obliquity and precession. The 100-ka eccentricity variations should not be individually manifested in the climatic variations. However, it is well known that precisely these variations predominate in climatic records of the Brunhes chron. This and other contradictions between Milankovitch's theory and empirical data stimulated the author of the present work to elaborate a new concept of the astronomical (more precisely, orbital) theory of paleoclimate (OTP) [2, 6]. Let us recall that the principal (original) concept of OTP is rather general and suggests that global climatic changes are related to insolation variations caused by orbital factors. The theoretical OCD based on the new concept (Fig. 1a) shows a relative probability of the realization of glaciations and interglacials during the last million years [1, 2, 6]. The OCD correlates well with OI records of deep-sea sediments. Since OI curves of different deep-sea cores, which commonly match each other, exhibit some peculiarities, we proposed to use the OCD as an unbiased independent standard for the comparison of different paleoclimatic records obtained from both deep-sea and continental sediments. The realization of such a procedure exhibited a rather good agreement between different paleoclimatic records and the OCD spectrum, as well as their main discrepancies that are generally similar [7].

The present work reports results of the application of OCD for the spectral analysis of OI data of Core MD 900 963 from the Indian Ocean [3]. Spectral analysis of OI data is usually aimed at an identification of the role (amplitude) and periods of major climatic cycles of the Pleistocene. Preliminary results of the spectral analysis revealed periods of global climatic oscillations, which are close to periods of orbital element variations and confirmed the general hypothesis of correlation between orbital element variations and global climatic changes in the Pleistocene [4]. The new timing of Matuyama–Brunhes inversion (~780 ka [3, 8, 9]) should also be considered an achievement of the general OTP concept and spectral analysis on OI data of deep-sea cores.

The quality of results based on the spectral analysis is primarily governed by precision of the time scale of variations in the studied phenomenon and by the detail of data presented in each time interval. Based on OI data related to Core MD 900 963, a climatochronostratigraphic scale for the time interval 0–880 ka was reported in [3]. The initial time scale used by these researchers included 25 reference points obtained by a visual comparison of the OI record with the theoretical curve of variation in the global ice volume [10] based on Milankovitch's theory. This procedure served as a basis for the subsequent mathematical processing of OI data (including their spectral analysis) and resulted in the creation of one of the most popular versions of the climatochronostratigraphic scale. It should be noted that paleomagnetic investigations of Core MD 900 963 revealed an important chronological reference point (Matuyama–Brunhes inversion), which significantly promoted and refined the visual comparison of OI

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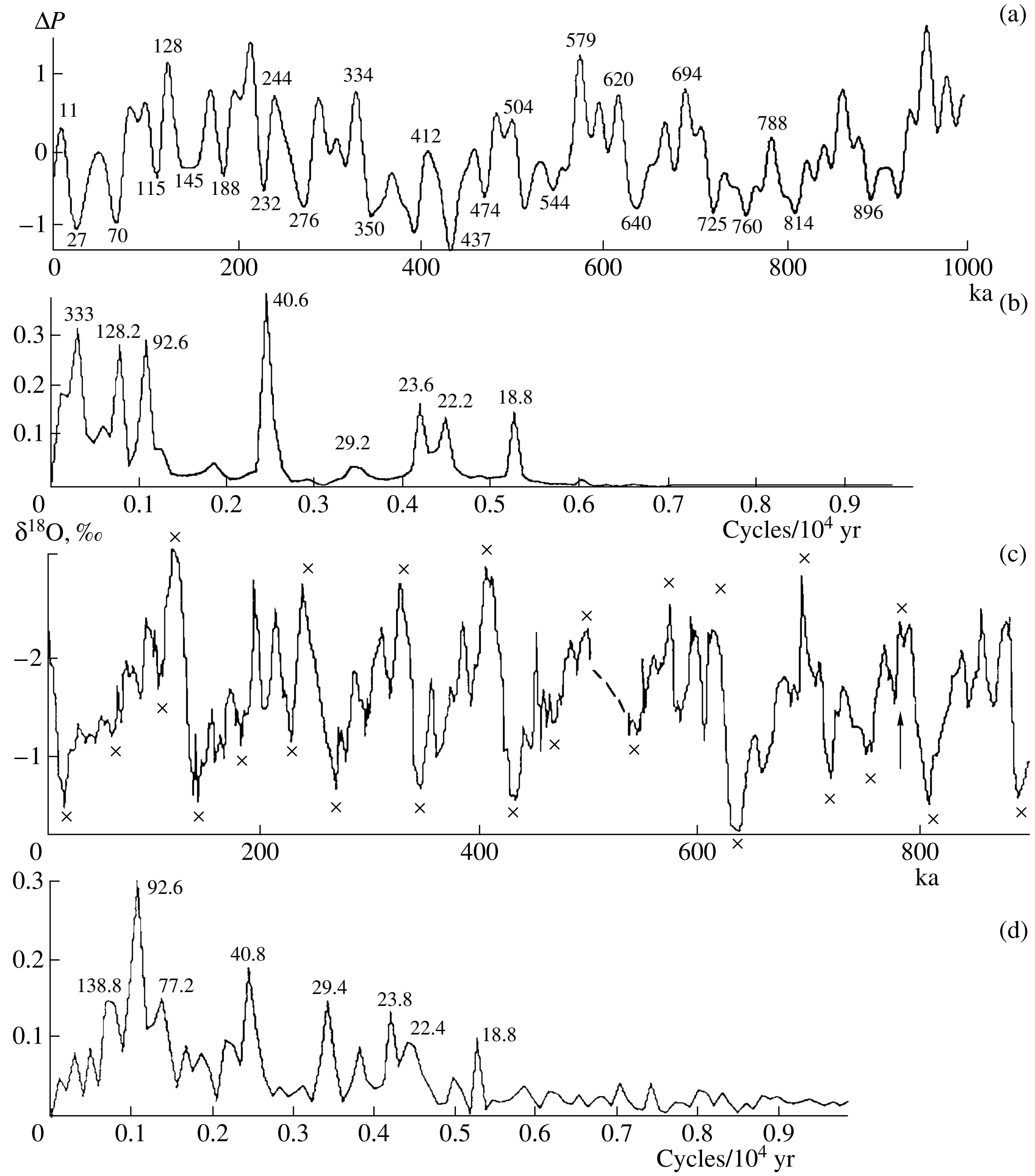

Fig. 1. Chronometry of the oxygen-isotope record of Core MD 900 963 based on the orbital-climatic diagram. (a) OCD constructed for the coefficients of climatic significance of variations in the eccentricity, obliquity, and precession (1 : 0.7 : 0.55, respectively [6]). (Δ*P*) arbitrary relative probability of glaciations (negative values) and interglacials (positive values). Figures near the curve are extreme dates (in ka). The values presented should be diminished by 5 ka to determine ages of the corresponding extremes on the OI curve (Fig. 1c). (b) OCD spectrum. The ordinate shows relative amplitudes of different harmonics of the spectrum. Figures near the curve are values of the respective periods (in ka). (c) OI curve of Core MD 900 963 obtained after the processing of primary data [7] for their uniform (step = 2 ka) presentation on the time scale. Crosses near the curve are time reference points based on dates of respective extremes in Fig. 1a. The dashed line shows OI record area excluded from the consideration. The arrow indicates the position of Matuyama–Brunhes inversion in the core. (d) Spectrum of the OI curve presented in Fig. 1c. Symbols are as in Fig. 1b.

curves with other plots reflecting paleoclimatic variations. Major periods of climatic changes distinguished in [3] based on the spectral analysis are 100, 41, 23, and 19 ka.

In the present work, comparison of the OI curve with the OCD based on their visual similarity was used to carry out the spectral analysis of OI record of Core MD 900963. It should be noted that the chronometry method used in this work is based on a principle similar to that in [3, 4, 5, 9]; global climatic changes during the last million years are mainly governed by variations of the orbital elements. However, our approach has certain advantages relative to the common approach adopted in [3, 4]. First, the OCD is based on a new OTP concept that is free of contradictions with empirical data, as opposed to Milankovitch's theory that provided basis for the theoretical curve of ice volume variations [10] used for comparison with the OI record in [3]. Second, we conducted the time comparison based on the most prominent minimums and maximums on the curves (Figs. 1a, 1c). This method is more accurate and easier than the comparison based on OI stage boundaries used in [3]. Moreover, dates of OCD minimums and maximums can directly serve as the basis of chronostratigraphic scale [4–6] without the procedure of identification of different orbital periods in OI records [3, 5, 9].

The calculated orbital elements variations used for construction of the OCD with a step of 1 ka are presented in [11]. The OCD obtained is shown in Fig. 1b. Let us note once again the important significance of detection of the Matuyama–Brunhes inversion at OI stage 19 of Core MD 900963 (Fig. 1c) for visual comparison of OCD and OI plots. This point correlates with the ΔP maximum in the region of 788 ka on the OCD (Fig. 1a).

In order to carry out the spectral analysis of OI data, we distinguished 25 most reliably correlating reference points on OCD and OI plots (Figs. 1a, 1c). Dates of maximums and minimums of the theoretically obtained OCD are presented in Fig. 1a. Taking into account the lag of climatic response to the controlling orbital insolation signal as a result of the strong inertness of the planetary climatic system owing to interactions in the hydrosphere–atmosphere–cryosphere–lithosphere system, one can suppose that the ages of maximums and minimums on the OI curve will be 5–6 ka younger than the corresponding dates on the OCD [2]. The lag of 5 ka used in this work is based on the following observations. Dates of the last glaciation maximum and Holocene optimum are estimated at 22 and 6 ka, respectively, while the respective minimum and maximum on the OCD correspond to 27 and 11 ka [2]. Within each of the 24 time intervals thus obtained, the OI record was represented by δ^{18}O values at equal time intervals of 2 ka, which was required for the conduction of spectral analysis. Sedimentation rate within each of the intervals was supposed to be constant. Since the original measurements were presented for different sampling depths, δ_k, i.e., the δ^{18}O value for time points not coinciding with sampling localities, was calculated according to the formula

$$\delta_k = \delta_i + \frac{\delta_{i+1} - \delta_i}{l_i}\Delta l_i,$$

where δ_i and δ_{i+1} are δ^{18}O values experimentally measured at the adjacent core sampling levels situated above and beneath, respectively, relative to the determined δ_k value; l_i is the distance between these sampling levels; and Δl_i is the distance between the upper sampling level and the time value based on the averaging procedure. Data on the interval of 24.0–26.5 m characterized by sharp variations in δ^{18}O values were excluded by me from the δ^{18}O–t plot, because the paleomagnetic anomaly noted at this same interval [3] suggested an artifact nature of these OI data (Fig. 1c). The δ^{18}O values thus obtained were subjected to spectral analysis according to the spectral–temporal analysis procedure described in [12]. The obtained results are presented in Fig. 1d. Taking into account the method used for the OI curve chronometry, it would be natural to expect that results of the spectral analysis of the OCD (Fig. 1b) and OI data (Fig. 1d), particularly for relatively longer periods, will be close to each other. Figures 1b and 1d show that this is not entirely so. However, the purpose of this study is to reveal new implications of the OCD as a chronological standard for the determination of peculiarities in the relationship between orbital variations and global climatic changes, rather than detection of orbital periods in the OI record or verification of the correctness of the general OTP concept, which has already been demonstrated in a series of works [2–4, 6].

To solve this problem, it would be logical to compare our results of spectral analysis with those presented in [3], primarily because they are related to the same OI record with an analogous step of the presented data (2 ka). It can be noted that our spectrum (Fig. 1d) has a relatively higher resolution, since the spectral peaks are narrower and background values have a lower relative amplitude than those in [3]. Moreover, the wide maximum corresponding to ~100 ka in [3] is divided into three peaks in our spectrum, and the main peak corresponding to 92.6 ka coincides with the respective peak on the theoretical OCD (Figs. 1b, 1d). The advantage of our method, particularly the spectral analysis procedure, is illustrated by the following fact. The wide 23-ka peak on the OI curve spectrum [3] is bimodal in our version (Fig. 1d) and practically coincides with the respective bimodal maximum on the OCD spectrum. It is also necessary to emphasize a new result that was not previously reported by other researchers. In addition to the most significant spectral maximums (100, 41, 23, and 19 ka), which are commonly distinguished based on OI records, we recognized a maximum corresponding to 29.4 ka with an amplitude higher than that of the 23-ka peak (Fig. 1d). In the OI curve spectrum presented in [3], one can see a maximum corresponding to ~29 ka; however, it was not distinguished by the authors as a significant result, probably because its amplitude is noticeably lower than that of the 19-ka peak. The predominance of periods of about 29 ka was previously noted in variations of the granulometric composition of sediments and the average surface temperature of equatorial Pacific and Indian oceans [13, 14]. This fact was rather indefinitely treated as a result of the nonlinear interaction of variations in eccentricity and obliquity of the Earth's axis with resonant phenomena in the planetary climatic system, which are related, in particular, to variations in the intensity of trade winds and monsoons. Let us note, however, that the OCD contains a peak corresponding to the period 29.2 ka, which represents a harmonics of the cyclic variation of the Earth's obliquity, although it is characterized by a very low amplitude (Fig. 1b). The similarity of the prominent period 29.4 ka obtained from the empirical OI data with the theoretically obtained vague period 29.2 ka allows us to suppose the existence of a yet unknown mechanism of nonlinear amplification (or response) of the Earth's climatic system to the orbital insolation signal related to this harmonic of the Earth's obliquity variation.

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