The orbital climatic diagram as a basis for comparing Pleistocene paleoclimatic records

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GEOGRAPHY

The Orbital Climatic Diagram as a Basis for Comparing Pleistocene Paleoclimatic Records

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The problem of correlating Pleistocene paleogeographical events reflected in deep-sea and continental deposits continues to remain urgent. In recent years, the isotope-oxygen (IO) climatochronostratigraphic scale has become a popular basis for such correlation. Although IO-records of different deep-sea columns reflect variations in the global ice volume, they usually somewhat differ from each other. There is no guarantee that the averaging of such records for several columns, similar to compiling the SPECMAP IO scale [1], most adequately reflects these variations. In addition, paleoclimatic events recorded in continental and oceanic deposits possess specific features. Therefore the availability of an independent standard, which is based on theoretical considerations and can reflect global paleoclimatic variations of the Pleistocene, would not only facilitate a more impartial comparison of paleoclimatic events recorded in various types of deposits but also elucidate the most adequate paleoclimatic records in deep-sea deposits. The orbital climatic diagram (OCD), constructed by the author in the process of developing a new concept of the astronomical theory of paleoclimate [2–5], can be offered as such an independent standard. This new concept eliminates basic discrepancies between the Milankovitch theory [6] and empirical data. Additionally, the OCD, which shows the relative probability ΔP of the appearance of glaciations or interglaciations during the last million years, corresponds well to IO data. The OCD was constructed on the basis of the following data [3, 5]: (1) the results of theoretical calculations of orbital element variations [7]; (2) the mechanism of climatic influence of orbital element variations adopted by Milankovitch [6]; and (3) the ratio of climatic significance coefficients (CSC) of orbital element variations based on different empirical data (the ratio is suggested by the new concept and differs from the value based on the Milankovitch theory).

The method of OCD construction was described in detail in [2–5]. Here, we note an important circumstance concerning clause 3. Originally [2], the ratio of CSC variations of individual orbital elements was obtained by fitting of various coefficients. In this case, the inference about the prevalence during the last million years of the climatic influence of eccentricity variations and about the least influence of precession formed the basis for determining the more or less qualitative ratio of climatic coefficients and the starting point for finding their numerical values. This inference was made by the author [2, 4] on the basis of analyzing various empirical data on deep-sea and continental sediments. In the subsequent fitting of climatic coefficients, primary emphasis was placed on the external similarity of the IO curves and the OCD. As a consequence, it has turned out [2–5] that the ratio of CSC values obtained in such a manner for the eccentricity, obliquity, and precession (1 : 0.7 : 0.4, respectively) agrees well with the average ratio of amplitudes of climatic changes associated with the same orbital parameters that can be obtained from the spectral analysis data on the IO curve in [8]. Hence, the OCD can be regarded as an independent, impartial standard of climatic changes during the last million years for the comparison of paleoclimatic records from various natural objects. In order to stress once again the fact that the OCD is independent of specific IO data, the OCD obtained for the new ratio of climatic coefficients equal to 1 : 0.7 : 0.55 (Fig. 1) is used in this work. Note as a positive factor the possibility of varying the CSC ratio of orbital elements for obtaining the maximum OCD similarity to paleoclimatic data. The specificity of climatic influence of variations of each orbital element for various climatic records, both in time and space, can be emphasized in this way.

The comparison of the OCD and the IO curve of Shackleton [9] in Fig. 2 displays, as was noted previously [3, 4], a much closer similarity of the IO curves with the OCD than with the insolation diagrams of Milankovitch and his followers. The main thing is that one can identify on the OCD with certainty almost all (seven out of eight) periods of glaciations within the Brunhes chron by minimums of ΔP values. In [3–5], the discrepancy between the amplitudes of ΔP value variations on the OCD and the $\delta^{18}O$ values on the IO

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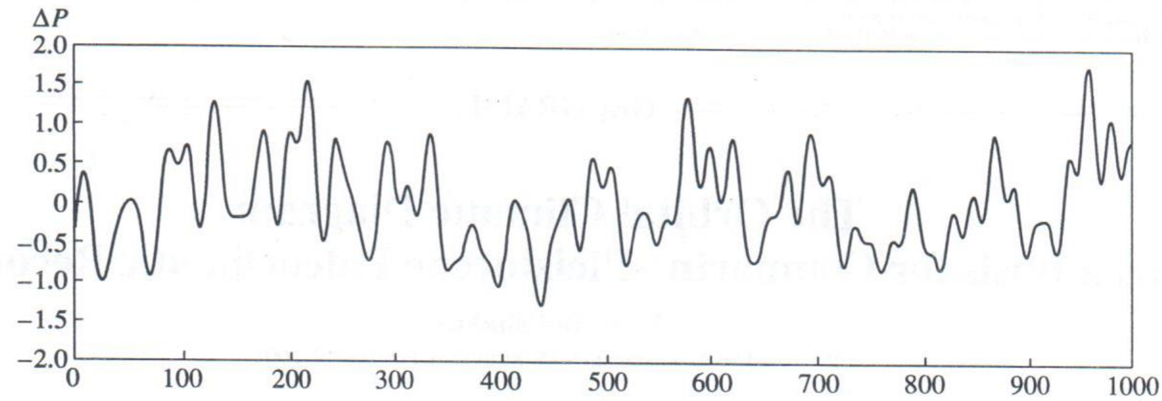

Fig. 1. The orbital climatic diagram (OCD) constructed for the ratio of climatic coefficients 1 : 0.7 : 0.55. Arbitrary units of the OCD represent the relative probability *P* of the appearance of glaciations (for negative values) or interglaciations (for positive values). The abscissa shows time (ka B.P.).

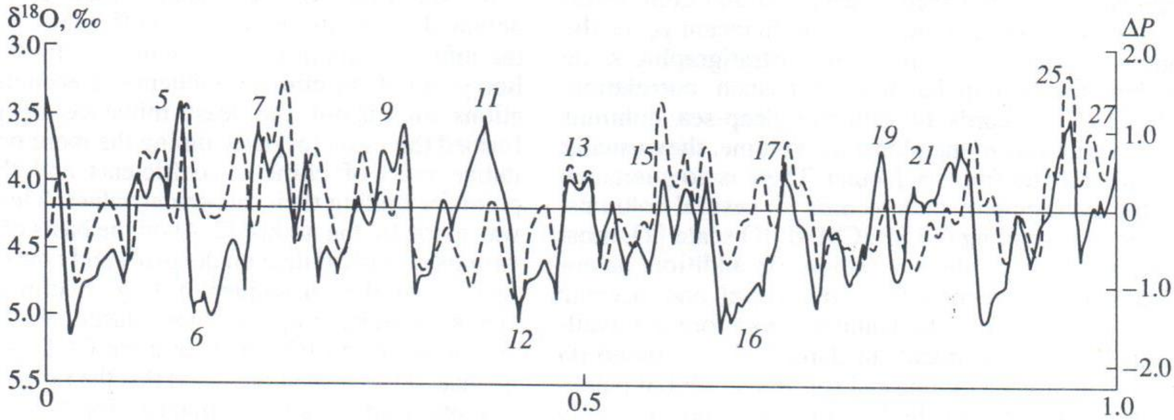

Fig. 2. Comparison of the OCD (the dashed line) with the IO curve of Shackleton [9]. The IO record is represented by the SPECMAP scale in the 0–620-ka interval and further by column 677. The figures above and below the IO curve represent the numbers of IO stages. The abscissa shows time (Ma B.P.).

curve for the OI stages, primarily 6 and 11, was mainly attributed to the specific character of the climatic response to the orbital signal, which allowed us to identify all IO stages on the OCD. External similarity between several IO stages and the relevant changes of the ΔP value on the OCD can be seen in Fig. 2. However, individual characteristics of some IO stages are not always identified on a real record. Therefore the correlation of IO curves with the OCD only by the shape can prove unreliable. At least one temporal reference point on the IO record within 1 Ma is needed. The Matuyama–Brunhes inversion that passes almost in the middle of the 19th IO stage usually serves as such a reference point. Knowing that eight glaciation–interglaciation cycles must be recorded above it, one can compare the obtained data with the OCD and make conclusions about the completeness of the geological chronicle and specific features of the paleoclimatic record represented by the considered IO curve. This conclusion concerns continental section as well. Naturally, the larger the number of dating levels, the more exact be the correlation will. It cannot be ruled out that the comparison of the OCD with independently obtained paleoclimatic data on continental and deep-sea deposits will also help in solving some less significant discrepancies between the OCD and the IO records (Fig. 2). What do these discrepancies mean: a manifestation of the fine structure of climatic changes associated with the terrestrial conditions that are not reflected on the OCD or some defects of the IO record? Discrepancies and defects of paleoclimatic records can also result from subjective reasons, for instance, from the quest for identifying orbital cycles in these records without fail.

A temporal displacement of the climatic record with respect to the orbital signal is seen in Fig. 2. It is natural, if we take into account the inertia of the planet's climatic system. It should be noted, however, that the reason for the temporal discrepancy between the climatic record and the OCD can also be an inaccuracy in the identification of orbital cycles in IO records by the authors of the relevant works. This is one more argument in favor of the use of the OCD as an impartial

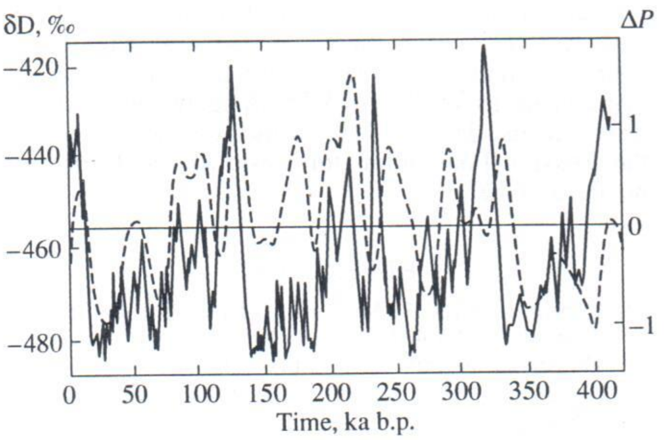

Fig. 3. The record of deuterium content variations in the ice core from the Vostok station (after [10]) compared to the OCD (the dashed line).

standard when various paleoclimatic records of the Pleistocene are compared.

In Fig. 3, the OCD is compared to deuterium variations in the unique ice core from the Vostok station [10], which encompasses four climatic cycles. Variations of δD reflect temperature changes at the core location [10]. Therefore, differences in the δD of the ice core and $\delta^{18}O$ of deep-sea sediments versus the time relationship cannot be ruled out. However the temporal correspondence of the OCD to deuterium variations is approximately the same as to oxygen variations in deep-sea sediments (Figs. 2, 3). This is evidently natural, since the time scale of the deuterium curve was adjusted to the IO scale. A certain change in the ratio of amplitudes of climatic variations, reflected in the $\delta^{18}O$ and δD records with respect to OCD value variations are probably associated with the specific character of the records of changes in the global ice volume and surface temperature in the relevant objects. A large amount of minor extremums in the δD record seems to be related to great detail of the record, since the ice core length exceeds 3.5 km. Nevertheless, a general similarity and basic discrepancies between the OCD and the δD curve remain the same as between the OCD and the $\delta^{18}O$ curve of deep-sea sediments (Figs. 2, 3).

The data on variations of the ratio of oxygen isotopes in the 36-cm-thick core section of calcite layer from the bottom of a water-filled cave in Nevada, USA, are presented in Fig. 4. According to [11], this record reflects temperature variations of sediments precipitated on the water catchment area surface in the cave area. The temporal record of $\delta^{18}O$ in the core is based on 21 datings by nonequilibrium uranium. This fact is especially important for comparison with the OCD, since these datings are unrelated to orbital cycles. Based on these datings, the 36-cm-thick calcite core represents the paleoclimatic record interval from 560 to 60 ka. The comparison of the OCD and the IO record chiefly displays the same similarity and the same discrepancies that were noted above, when the OCD was compared to other records. However, qualitative temporal discrepancies can be noted in Fig. 4. For example, the *beginning* of warming (or termination), which characterizes a sharp transition from the glaciation to the interglaciation period, is somewhat ahead of the orbital signal for terminations 2 (about 150 ka), 4 (about 350 ka), and 5 (about 440 ka). The largest temporal discrepancy is noted for termination 6 (about 520 ka). It is obvious that there must be no orbital signal delay with respect to the climatic response. Judging by the graphic data in Fig. 4, these temporal discrepancies lie within the errors associated with age determination, and the IO curve in [11] can be adjusted to the OCD. For doing this, it is necessary to compare the most typical minimums and maximums of the OCD and the IO curve and to take into account the climatic response delay equal to 5 ka [4]. At the same time, note once again that the intervals of glaciations and interglaciations distinguished on the OCD coincide, on the whole, with these intervals on the IO curve of calcite. In addition, the durations of the last four climatic cycles on the IO curve of calcite are equal to 79, 85, 113, and 128 ka. The

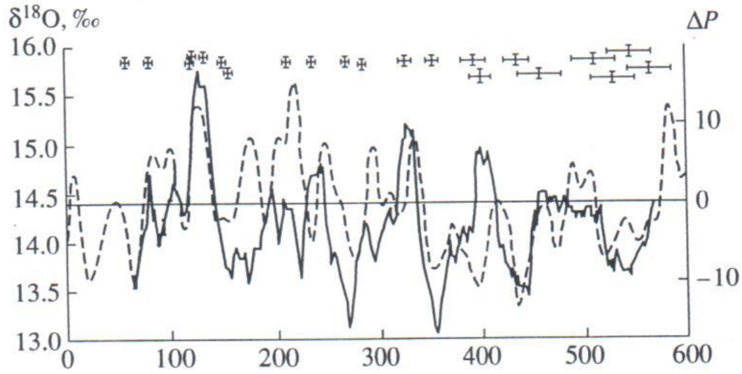

Fig. 4. Comparison of the record of $\delta^{18}O$ variations in the calcite core from a cave in Nevada, USA (after [11]), with the OCD. The crosses at the top denote the sample location (the vertical line) and the accuracy of age determination (the horizontal line). The abscissa shows time (ka B.P.).

yields gives quite similar durations of the same climatic cycles: 81, 87, 131, and 117.5 ka.

Summing up the work performed, it is possible to make the following conclusions. The orbital climatic diagram can be used as a general and, hence, sufficiently independent standard of global paleoclimatic variations during the Pleistocene. The comparison of the OCD with the paleoclimatic records in deep-sea deposits, the ice core from Antarctica, and the calcite from North America mainly displayed the same results. This points to an agreement between the main climatic events of the Pleistocene in different regions of the planet, as well as to the global character of factors controlling paleoclimatic cycles. Orbitally governed variations of insolation represent undoubtedly one of such factors. The above-performed comparisons of paleoclimatic records with the OCD also point to the similar (in all three cases) basic discrepancies associated with the record of paleoclimatic events corresponding to the 6th and 11th IO stages of deep-sea sediments. This fact can point to the global character of some other factors, in addition to orbital element variations, that affected the paleoclimate of the Earth during the Pleistocene. As was already noted [4, 5], the author of this work believes that the possibility of the mechanism of controlled autooscillations in the atmosphere–hydrosphere–cryosphere–lithosphere system [8 and others] during the Pleistocene is one of the most probable explanations for these discrepancies. A complex interaction of the above-mentioned four most important near-surface components of the planet can apparently ensure the global character of their impact on the Earth's climate. However, both these and smaller discrepancies between the OCD and paleoclimatic records require further studies, in particular, the comparison of the OCD with the largest possible number of paleoclimatic data that are independently obtained and correctly substantiated.

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