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High-Precision Cyclic Correlation as a Basis for Detailed Paleoclimatic Reconstructions for Crimean–Caucasian Region in the Jurassic

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Abstract—Astrochronological (cyclostratigraphic) referencing of the lithological and geochemical characteristics of Jurassic deposits of the Crimea Mountains and the Caucasus to the eccentricity cycles of Earth's orbit is performed, the relationship of the determined variations in climate and paleotemperature with the times of coincidence of different orders of eccentricity cycles is analyzed, and their paleoclimatic description is given. New data on paleotemperatures of the Southern Demerdzhi Mountain section are presented.

Keywords: cyclic correlation, lithology, geochemistry, paleoclimatology, the Jurassic Period, Crimea, Caucasus

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INTRODUCTION

Correct paleogeographic reconstructions require a detailed stratigraphic basis. R.R. Gabdullin's proposed (2023) cyclostratigraphic scale for the Mesozoic and Cenozoic sections of Northern Eurasia can be used for this purpose. The advantage of astrochronology is the ability to perform variously detailed correlation constructions on a planetary scale. Long-period climate variations related to Milankovitch cycles (for example, to eccentricity cycles of the Earth orbit) may be a climatostratigraphic basis of a global scale in general (except for a local factor, affecting the climate system at a particular site).

The accuracy of paleogeographic and paleoclimatic reconstructions is determined by the accuracy of the stratigraphic basis used for them. Its greater detail is the key to more accurate reconstructions.

Examples of the application of the cyclostratigraphic and the climatostratigraphic approaches to studying sections of Jurassic deposits of the Crimean

Mountains for more detailed interpretation of its climatic history are given in this paper. The results obtained may be used for geological practical training and geological excursions in Crimea and the Caucasus.

MATERIALS AND METHODS

Cyclostratigraphic binding was first performed for deposits of the Upper Taurian series (Crimea) and for the Estosadok, Chvezhipsin, and Illarionovo series (Caucasus) with geochemical characteristics (Gabdullin et al., 2014). New data on the section of the Southern Demerdzhi Mountain were also obtained.

During terrain works, 18 samples were taken in the Crimean Mountains on the southwestern slope of the Southern Demerdzhi Mountain by M.D. Kazurov (Moscow State University) in 2022. The altitudes above sea level of extreme sampling sites were 690 and 910 m.

A complete geochemical analysis of the elements in 18 samples from the section of the Southern Demerdzhi Mountain was performed on a Bruker S8 Tiger wavelength dispersive X-ray fluorescence sequential spectrometer (analyst A.Yu. Puzik). The analytical study was performed at the center for collective use of Perm State National Research University. The samples were prepared for analysis by M.D. Kazurov.

S.I. Merenkova determined the paleotemperature based on the weathering index. Weathering indices usually reflect the depletion of mobile elements in rocks with respect to fixed elements during chemical weathering. The CIA index was first proposed in (Nesbitt and Young, 1982) and is widely used as an indicator of chemical weathering intensity:

$$\mathrm{CIA} = 100 \times \mathrm{Al_2O_3}/\left(\mathrm{Al_2O_3} + \mathrm{CaO^*} + \mathrm{Na_2O} + \mathrm{K_2O}\right),$$

where CaO* is noncarbonate CaO and all variables represent molar amounts of oxides of the main elements;

$$T = 0.56\,\mathrm{CIA} - 25.7\ (r^2 = 0.50),$$

where T is temperature, °C. More information about this method is given in (Gabdullin et al., 2021).

RESULTS AND DISCUSSION

The research objects are the deposits of the Upper Taurian series of Crimea (Upper Plinsbachian–Lower Aalenian); of the Estosadok, Chvezhipsin, and Illarionovo series of the Caucasus (Gettangian–Lower Aalenian); of the Demerdzhi series (Oxfordian (Middle Oxfordian)–Early Kimeridgian (Kimeridgian); and of the Yalta series (Tithonian).

Strata I–III (mudstone with tobacco sandstones of fine-rhythmic flysch) in the Upper Taurian series correlate with the 31st fourth-order eccentricity cycle of the cyclostratigraphic scale (CS) (Fig. 1). Stratum IV (of multirhythmic flysch) corresponds to the 32nd fourth-order eccentricity cycle of the CS. Stratum V of mudstone flysch corresponds to the 53rd and 54th third-order eccentricity cycles of the CS.

The Estosadok series (Fig. 2) corresponds to the 28th–30th cycles and partially to the 31st fourth-order eccentricity cycle of the CS; Chvezhipsin series, to large parts of the 31st and 32nd cycles; and the Illarionovo series, to the interval from the 32nd to 34th fourth-order eccentricity cycles of the CS.

Early–Middle Jurassic. Figure 1 shows variations in the geochemical temperature parameters (concentration of Ca, Al_2O_3, and TiO_2; the Ca/Mn and the Si/Al ratios; and the titanium modulus (TM)) for deposits of the Upper Taurian series of Crimea referenced to the time scale (according to (Gabdullin et al., 2014)), as well as to the third- (duration 1.29 Ma), fourth- (2.03 Ma), and fifth- (3.4 Ma) order eccentricity cycles of the CS (Gabdullin, 2023). The numbering of cycles in the proposed CS for the Mesozoic and the Cenozoic begins from the Triassic, and the cycles, corresponding to relative warming (are shown in orange) and cooling (are shown in blue) are distinguished.

The analysis of variations in geochemical temperature parameters reflects not only their synchronic fluctuations, but also their correlation with eccentricity cycles, with cycles of the third order, lasting 1.29 Ma, in particular. The correlation also testifies that the epochs (eccentricity cycles) of relative cooling (blue color) correspond to a decrease in the temperature according to geochemical parameters in deposits of the Upper Taurian series and vice versa.

Variations in geochemical temperature parameters for sections in the Caucasus according to (Gabdullin et al., 2014) bound to the CS (Gabdullin, 2023) are shown in Fig. 2. Most of them correlate with third-order eccentricity cycles or rather with the alternation of relatively warm and cold cycles.

Paleotemperature curves are shown on the right of Figs. 1 and 2 according to published data (a—(*Klimat...*, 2004), for the Crimean trough (b—according to (Gabdullin et al., 2014), and for low latitudes according to (Gabdullin, 2023): c—sea water temperature (SWT) and d—mean annual temperature (MAT)). All these curves reflect cyclic variations and correlate with cold and warm eccentricity cycles of different orders of the CS. In particular, curves a–d more strongly correlate with fourth-order eccentricity cycles. The most pronounced temperature change corresponds to the coincidence of different-order eccentricity cycles (they are shown by arrows in Fig. 2). The temperature values on the cumulative curves for the basins of low latitudes (Tethys) according to (Gabdullin, 2023) are either higher than or close to paleotemperatures in the sections of Crimea and the Caucasus.

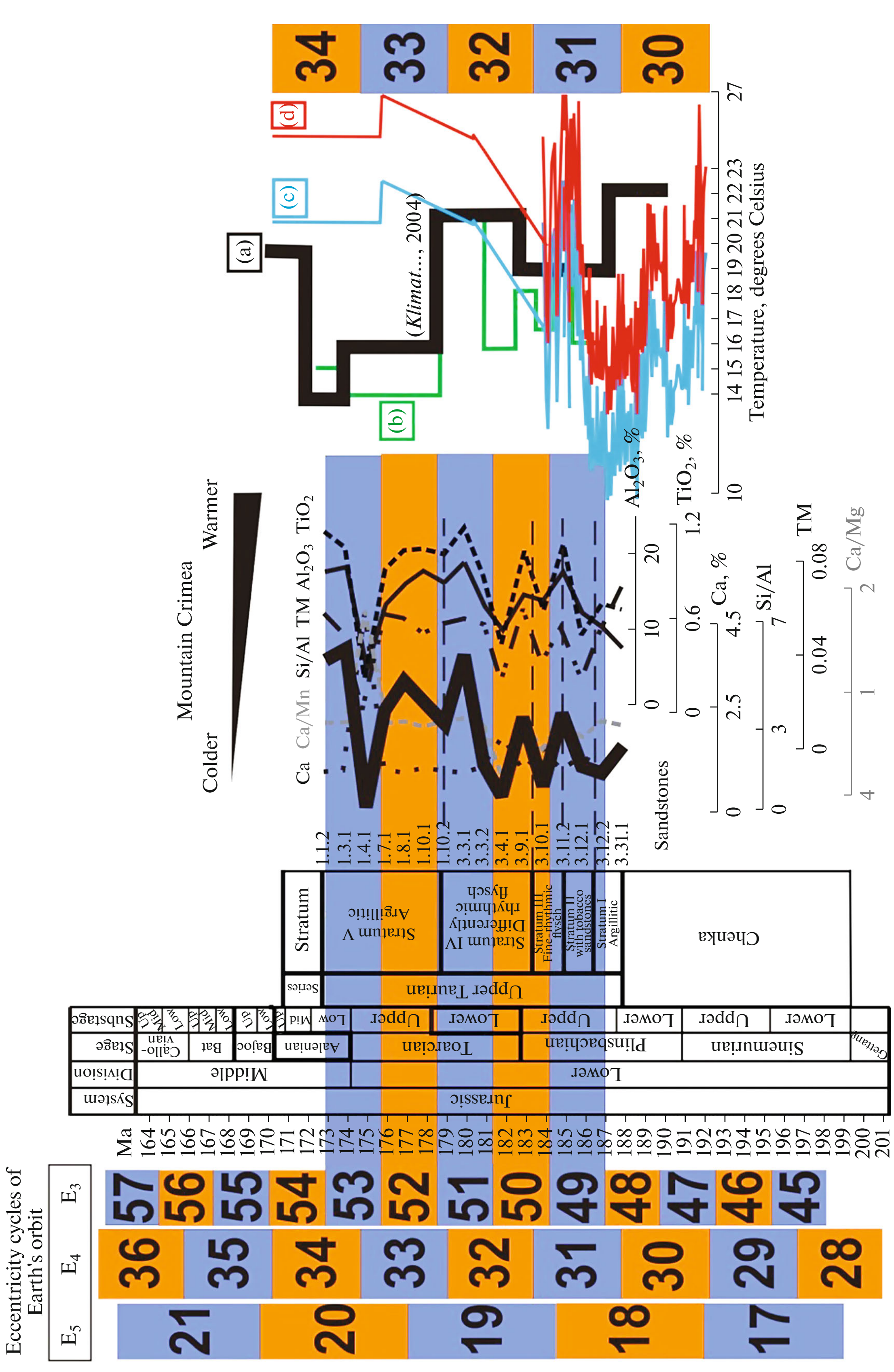

Fig. 1. Geochemical and paleotemperature characteristics of deposits of Late Plinsbachian–Early Aalenian of Crimean Mountains referenced to cyclostratigraphic scale after (Gabdullin, 2023). Eccentricity cycles correspond to relative cooling (blue) or relative warming phases (orange). Paleotemperature curves: (a) after (*Klimat*..., 2004) and (b) after (Gabdullin et al., 2014); cumulative curves for basins at low latitudes after (Gabdullin, 2021, 2023): (c) water masses, and (d) mean annual temperatures.

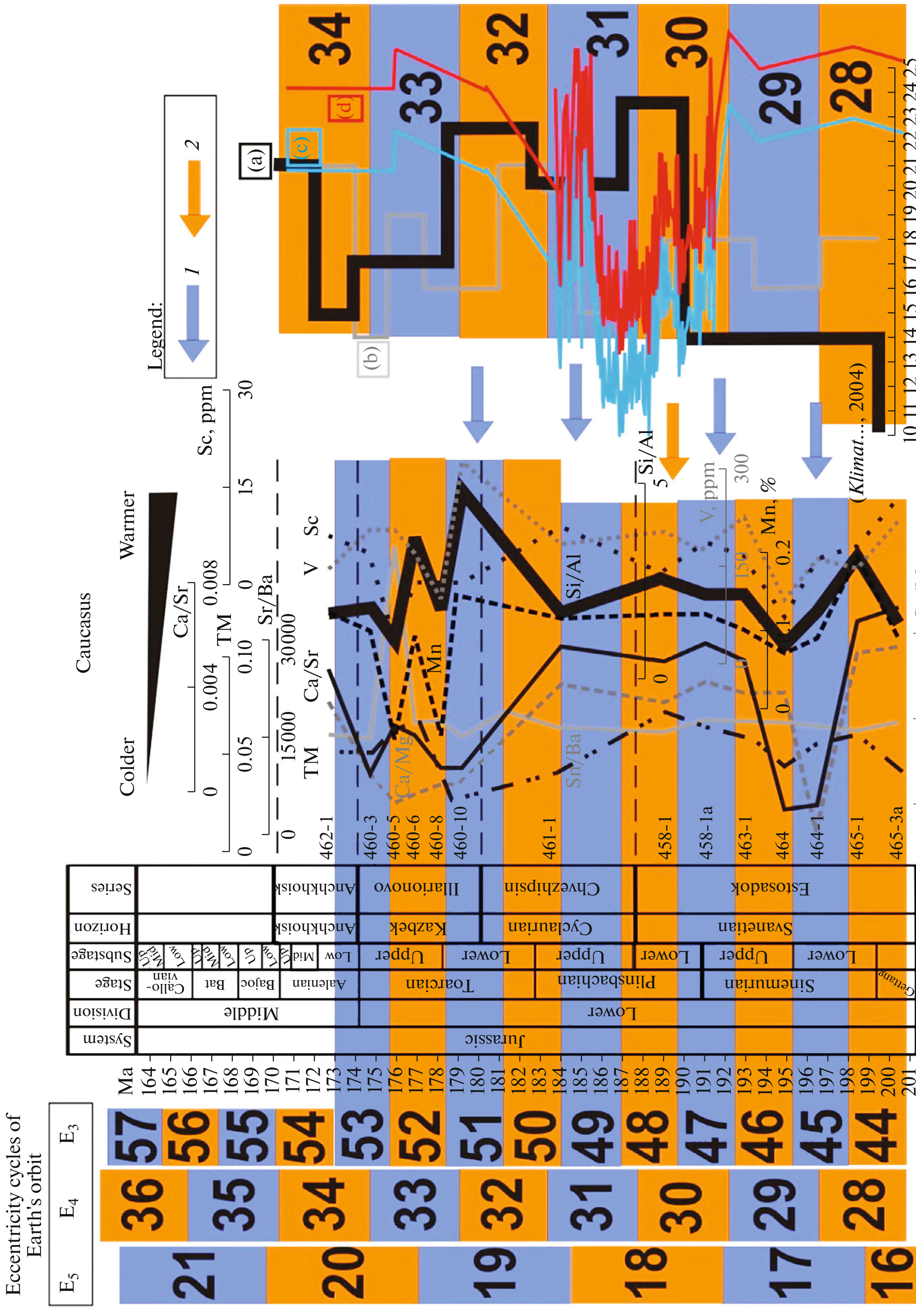

Fig. 2. Geochemical and paleotemperature characteristics of Gettangian–Early Aalenian deposits of Caucasus referenced to cyclostratigraphic scale after (Gabdullin, 2023). Phases of coincidence of different-order eccentricity cycles: (*1*) periods of relative climatic cooling and (*2*) periods of relative climatic warming. See Fig. 1 for notation.

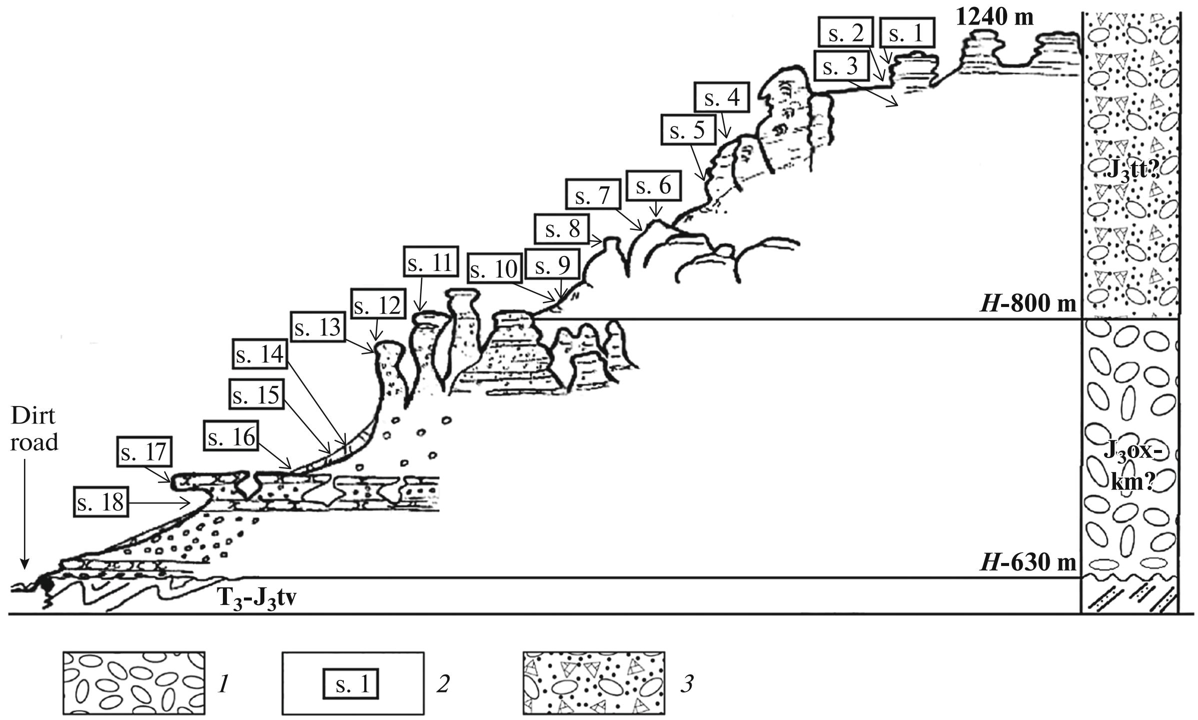

Fig. 3. Southwestern slope of Southern Demerdzhi Mountain: (*1*) conglomerates, (*2*) conglomerates with carbonate breccias, and (*3*) sampling sites.

The proposed cyclostratigraphic scale (Gabdullin, 2023) allows more accurate correlation, using the climatostratigraphic approach, as well as increased accuracy of stratigraphic constructions in monotonic cyclic sections of the flysch formation. The paleoclimatic history of the Central and Eastern Tethys in the Jurassic–Quaternary is given in (Gabdullin et al., 2021).

Middle–Late Jurassic. The section of the Southern Demerdzhi Mountain consists of Upper Jurassic terrigenous deposits that formed in the back-arc basin in the Gilbert-type delta at the final stage of the Cimmerian tectonic stage (Piskunov et al., 2012). The section is well studied, and the results are presented in a number of studies (Chernov, 1963, 1971; Andrukhovich and Turov, 2002; Nikishin et al., 2003; Mileev et al., 2006; Piskunov et al., 2012; Rud'ko et al., 2014, 2018, 2019; Vincent et al., 2018; Blaga and Pogomii, 2021).

Terrigenous deposits are represented by conglomerates, which can be divided into two strata (Fig. 3).

Stratum I consists of conglomerates with predominant medium- and large-pebble, poorly sorted conglomerates alternating with poorly and medium-sorted small-pebble conglomerates. Their color ranges from gray to brown, sorting is moderate or poor, and the composition of pebbles is polymictic. Conglomerates are underlain by rocks of the Taurian series, and the contact between them is sodded. The age of the strata is conditionally taken as the Oxfordian–Kimmeridgian (?) (Piskunov et al., 2012). The thickness of the rock outcrop in the studied area is about 160 m.

Stratum II is represented by conglomerates with horizons of subrounded and subangular carbonate breccias. Conglomerates include pebbles (from large to small), which are poorly and moderately sorted, mostly of gray color, and have a polymictic composition. The age of the stratum is conventionally Tithonian (?) (Piskunov et al., 2012). It is discordant with the conglomerates of stratum I. Its thickness is at least 300 m.

The height of the boundary between stratum I and stratum II is 800 m above sea level.

According to the explanatory note to the State Geological Map L-36—Simferopol (*Ob''yasnitel'naya...*, 2019), the studied interval corresponds to the Demerdzhi series (the Middle Oxfordian–Early Kimmeridgian) and to the Yalta series (the Tithonian). Different-grain sandstones alternate in the lower part of the Demerdzhi series and are stratified with conglomerates of various pebbles and gravelites in the middle part and with interlayers of organic limestones in the above stratum. Its upper part is represented by organic-fragmented, coral-detritus, algal-crinoid limestone with layers of gravelites. The total thickness is to 800 m. The Yalta series (the Early–Middle Tithonian) is represented by limestones, including coral-algae ones, to 900 m thick (*Ob''yasnitel'naya...*, 2019).

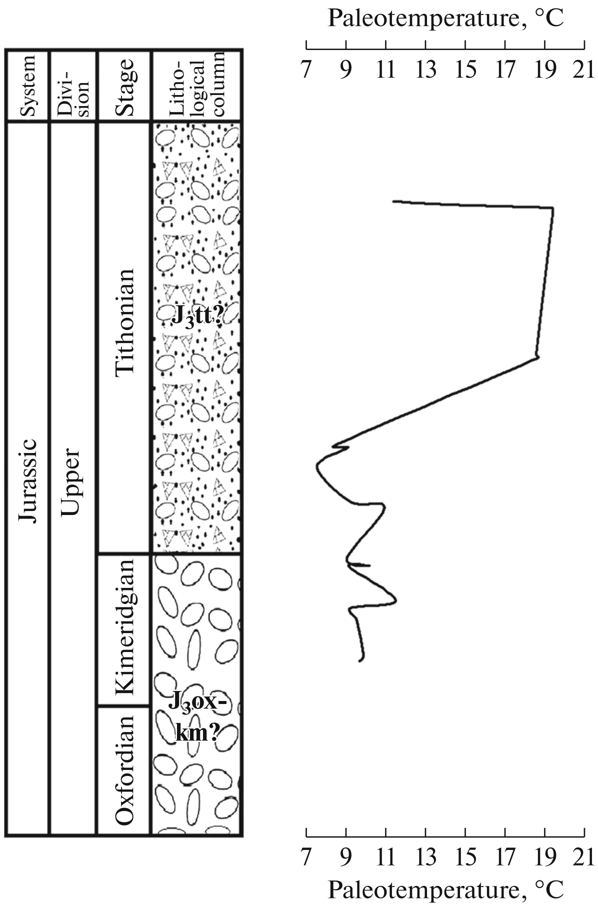

Fig. 4. Paleotemperature curve for strata I and II of south-western slope of Southern Demerdzhi Mountain.

The samples were taken for the complete geochemical analysis of the elements. The paleotemperature was determined by the weathering index based on the results of the geochemical analysis of the matrix (cement) of conglomerates (Fig. 4).

The obtained range of paleotemperature from 7.5 to 11.5°C characterizes the Upper Oxfordian–the Lower Tithonian interval as a cold period. It may be divided into two phases. The Upper Oxfordian and the beginning of the Lower Tithonian are characterized by temperatures above 9°C, which indicates the period of relative warming. The temperatures of the Lower Tithonian are 9°C and lower and correspond to the phase of relative cooling.

Astrochronological binding of the paleotemperature curve (Fig. 5) was performed, using the cyclostratigraphic scale (Gabdullin, 2023).

A fragment of the cyclostratigraphic scale (Gabdullin, 2023) for the Late Callovian–Malmian time with phases, combining different-order eccentricity cycles (horizontal lines) is shown in the left part of Fig. 5, and paleotemperature curves are given in its right part. Inset (a) is a fragment of cumulative curves for the low latitudes of the Northern Hemisphere (Gabdullin, 2023): the blue color shows the sea water temperature (SWT), and the mean annual temperature (MAT) is shown in red. The Kimmeridgian–Tithonian interval on the cumulative paleotemperature curve is shown by a dotted line due to lack of data. Inset (b) shows a diagram of the mean annual paleotemperature calculated by the weathering index for the

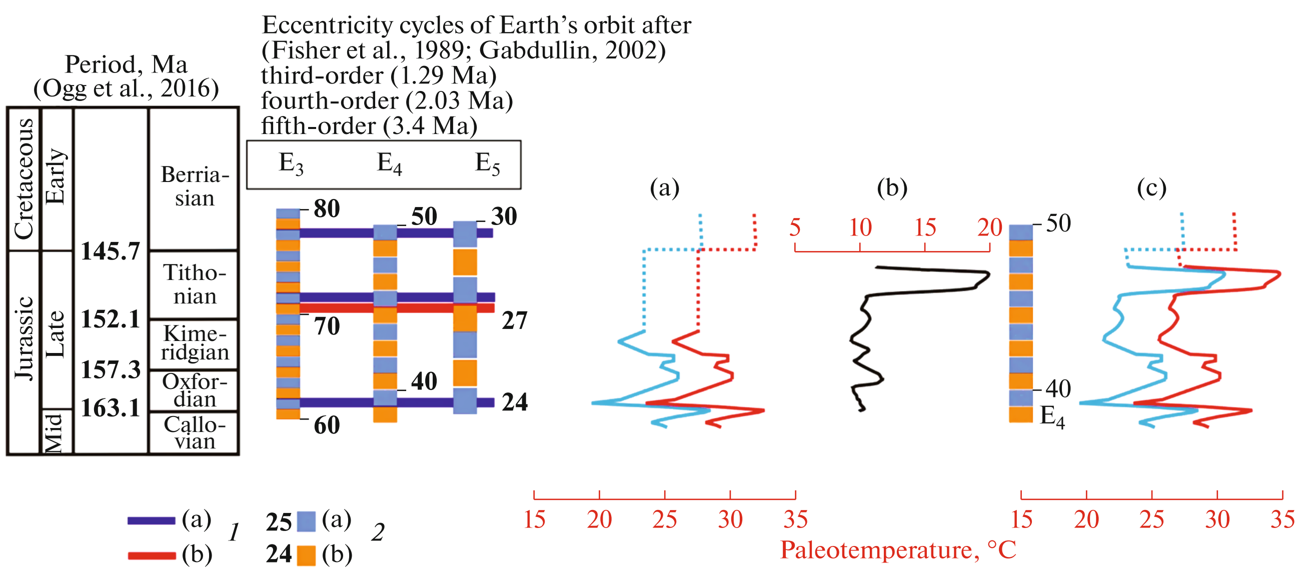

Fig. 5. Paleoclimatic variations during Oxfordian–Tithonian in Crimean Mountains referenced to cyclostratigraphic scale (according to Gabdullin, 2021, 2023). Insets: (a) cumulative paleotemperature curves for Tethys and its periphery (according to Gabdullin et al., 2021); (b) paleotemperature curve for Southern Demerdzhi Mountain section; (c) corrected cumulative paleotemperature curves for Tethys and its periphery taking into account data on Demerdzhi Mountain section: (*1*) phases of coincidence of different-order eccentricity cycles ((a) corresponding to phases of relative climate cooling; (b) corresponding to phases of relative climate warming); (*2*) eccentricity cycles and their ordinal numbering (a, corresponding to phases of relative climatic cooling; b, corresponding to phases of relative climatic warming). Temperature curves for water masses are shown in blue, and curves of mean annual temperatures, in red. See text for all other explanations.

section of the Southern Demerdzhi Mountain referenced to the CS (to fourth-order eccentricity cycles). The diagrams in insets (a) and (b) correlate well with each other and with the CS, which makes it possible to improve the cumulative paleotemperature curves for low latitudes of the Northern Hemisphere (with a lack of data), using a fragment of the paleotemperature curve obtained for the section of the Southern Demerdzhi Mountain.

Paleotemperature variations in the section of the Demerdzhi Mountain correlate with fourth-order eccentricity cycles and astrochronologically correspond to the range from the 38th to the 48th eccentricity cycles of the SC for Mesozoic–Cenozoic sediments after (Gabdullin, 2023).

CONCLUSIONS

The astrochronological referencing of stratigraphic units of the Jurassic system of Crimea and the Caucasus to the cyclostratigraphic scale (CS) has been performed. Strata I–III (mudstone with tobacco sandstones of fine-rhythmic flysch) in the Upper Taurian series correlate with the 31st fourth-order eccentricity cycle of the CS (Fig. 1), and stratum IV (multirhythmic flysch) corresponds to the 32nd fourth-order eccentricity cycle of the CS. Stratum V of mudstone flysch corresponds to the 53rd and the 54th eccentricity cycles of the third order of the CS.

The Estosadok series (Fig. 2) corresponds to the 28th–30th cycles and partially to the 31st fourth-order eccentricity cycle of the CS; the Chvezhipsin series, to large parts of the 31st and the 32nd cycles; and the Illarionovo series, to the interval from the 32nd to 34th fourth-order eccentricity cycles of the CS.

Paleotemperature variations in the section of Demerdzhi Mountain correlate with fourth-order eccentricity cycles and astrochronologically correspond to the range from the 38th to 48th eccentricity cycles of the CS for Mesozoic–Cenozoic deposits after (Gabdullin, 2023).

The most pronounced temperature change corresponds to periods of coincidence of different-order eccentricity cycles. Temperatures on the cumulative curves for the basins of low latitudes (Tethys) after (Gabdullin, 2021, 2023) are either higher than or close to the paleotemperatures in the sections of Crimea and the Caucasus.

The obtained range of paleotemperatures from 7.5 to 11.5°C in the section of the Southern Demerdzhi Mountain characterizes the Upper Oxfordian–Lower Tithonian interval as a cold period. It can be divided into two phases. The Upper Oxfordian and the beginning of the Lower Tithonian are characterized by temperatures above 9°C, which indicate relative warming; and the Lower Tithonian with temperatures from 9°C or less lower corresponds to the phase of relative cooling.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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