Russian Journal of Earth Sciences

Special Issue: "25th anniversary of the Russian Journal of Earth Sciences"

The Cyclostratigraphy of the Eastern Paratethys Konkian: Zelensky Section (Taman Peninsula)

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Abstract: The Eastern Paratethys Konkian sedimentary succession of the Zelensky section (Taman peninsula, Russia) was investigated by cyclostratigraphy methods based on magnetic susceptibility measurements. Cyclostratigraphy is a new scientific direction in stratigraphy and sedimentology, the purpose of which is to identify astronomical cyclicity for the reconstruction geochronology using high-precision technologies. Time series analysis (Lomb-Scargle and REDFIT periodograms, wavelet) revealed statistically significant signals corresponding most likely to long-term insolation periodicities in studied sediments. In the deep-water Konkian sediments of the Zelensky section, the signal at 3.3 m corresponds to the 100-kyr eccentricity cycle. The astronomically tuned these sediments result in an average sedimentation rate of about 3.3 cm/kyr with the duration of accumulation of the Sartaganian and Veselyankian beds about 200 kyr. The obtained cyclostratigraphic results generally do not contradict the new data about the possible duration of the Konkian (Kartvelian, Sartaganian and Veselyankian beds) of about 750 kyr [*Palcu et al.*, 2017].

Keywords: Eastern Paratethys, Konkian, Taman peninsula, Zelensky section, cyclostratigraphy, magnetic susceptibility.

Citation: Rostovtseva Yu. V. (2024), The Cyclostratigraphy of the Eastern Paratethys Konkian: Zelensky Section (Taman Peninsula), *Russian Journal of Earth Sciences*, Vol. 24, ES1011, https://doi.org/10.2205/2024ES000900

1. Introduction

It is often the term cyclostratigraphy understood as a subdiscipline of stratigraphy that uses the cyclicity of sediments to subdivide and correlate sedimentary strata [*Gladenkov, Yu. B.*, 2004]. However, there are other interpretations of the term. According to [*Hilgen et al.*, 2012], cyclostratigraphy is a new scientific direction in stratigraphy and sedimentology, the purpose of which is to identify, characterize, correlate, and interpret cyclic changes in sedimentary successions, thereby reconstructing geochronology using high-precision technologies. In this case, the priority is the definition of astronomical cyclicity, globally appearing and reflected in the structure of sedimentary rocks. Analysis of the astronomical cyclicity primarily evaluates fluctuations in the Milankovitch cycles. These fluctuations in insolation significantly influence climate conditions, the variability of which is reflected in the action of different sedimentation factors, leading to the accumulation of sediments differing in lithology. The duration of the Milankovitch cycles can be different, depending on the orbital parameters, and vary from the first tens to hundreds of thousands of years, as well as amount to millions of years. One of the features of these cyclostratigraphic studies is the possibility to analyze also monotonic sedimentary successions, in which there is no clear alternation of different rock types. For these cyclostratigraphic studies, a generally accepted methodology has been developed [*Weedon*, 2003]. These cyclostatigraphic studies allow dating of rocks and estimation of sedimentation rates.

The Neogene sediments, including the Konkian rocks, of the Eastern Paratethys are much less studied by cyclostratigraphic methods. In this paper, the astronomical cyclicity

Research Article

Received: 15 October 2024
Accepted: 15 January 2024
Published: 29 February 2024

of the Konkian sediments of the Eastern Paratethys (Zelensky section) will be considered, which is important when studying basins whose stratigraphy is based on complexes of endemic fauna, the regional correlation of which is difficult due to this.

2. Material and Methods

The objects of cyclostratigraphic studies were the Konkian sediments, which were exposed in the Zelensky section of the Taman Peninsula (Russia) (Figure 1). In the Zelensky section (N 45°13′54.6″; E 36°65′21.7″), Konkian deposits about 22–23 m thick are represented by clays containing separate interbeds of carbonate rocks (up to 0.2–0.3 m). According to the micropaleontological data, the studied sediments are divided into Kartvelian (about 16 m), Sartaganian (about 2–2.5 m), and Veselyankian (about 4–4.5 m) beds [*Palcu et al.*, 2017; *Vernigorova, Yu. V. et al.*, 2006]. The Konkian sediments of the Zelensky section accumulated in relatively deep-water environment [*Rostovtseva, Yu. V. et al.*, 2019]. According to the new data [*Palcu et al.*, 2017], the Konkian stage is distinguished in the volume of Kartvelian, Sartaganian and Veselyankian beds.

The cyclostratigraphic studies were based on measurements of rock magnetic susceptibility. The magnetic susceptibility was measured in situ with a "KT-5" portable magnetic susceptibility meter with a sensitivity of 10^{-5} SI units (Geofyzika BRNO, Czech Republic). Three measurements at each point were made every 20 cm across the strike of the layers. In total, 345 determinations have been obtained for Zelensky section. Average values of the magnetic susceptibility were obtained from three measurements made at each sampling point. These average data were taken as the basis for the statistical analysis. Furthermore, these average values were logarithmically transformed before the trend along the section was removed. For the statistics, the program PAST [*Hammer et al.*, 2001] was used for spectral analysis (Lomb–Scargle periodograms) including REDFIT [*Schulz and Mudelsee*, 2002] and wavelet analysis. The frequency values of the Lomb–Scargle and REDFIT periodograms were then transformed into the depth-domain to indicate the statistically relevant cycles.

The main mineral carrying of primary magnetization is magnetite in the Konkian sediments of Zelensky section [*Palcu et al.*, 2017].

According to paleomagnetic data, the studied Konkian sediments, including Kartvelian, Sartaganian, and Veselyankian beds, are characterized by the presence of three intervals of reversed and normal polarity [*Palcu et al.*, 2017] (Figure 2).

3. Results

The magnetic susceptibility (K) of the Zelensky section sediments varies from 0.060×10^{-3} to 0.240×10^{-3} SI (average 0.150×10^{-3} SI) (Figure 2). Spectral analysis of the magnetic susceptibility data from this section revealed the presence of two well-defined peaks. The REDFIT analysis supports the peak at 3.3 m, passing the 95% and 99% confidence interval, indicating the reliability of the orbitally calibrated record. Another peak at 14.3 m, passing through the 95% confidence interval, is observed on the REDFIT periodogram (Figure 3a). This peak is only 1.5 times smaller than the total thickness of the section, making its use less valid. The peak values were determined based on statistical processing of the magnetic susceptibility data both for the whole section and for the sediments of the Veselyankian and Sartaganian beds as well as the top of Kartvelian beds. The spectral analysis of the data from the lower part of Kartvelian beds did not reveal a strong periodicity.

In the lower part of Kartvelian beds, along with clays, there are microbial carbonate interlayers associated with the development of benthic cyanobacterial communities [*Rostovtseva, Yu. V. et al.*, 2019]. The Sartaganian and Veselyanskian beds contain separate carbonate interlayers consisting mainly of nannoplankton (coccolith). Different sedimentation regimes of microbial and nannoplanktonic carbonate rocks as well as clays may be reflected in the orbitally calibrated record, making interpretation difficult. Taking this into account, it is assumed that the data related to the upper part of the section (to the Sartaganian and Veselyankian beds) are the most validity to estimate the duration of accumulation of the studied sediments by cyclostratigraphic methods.

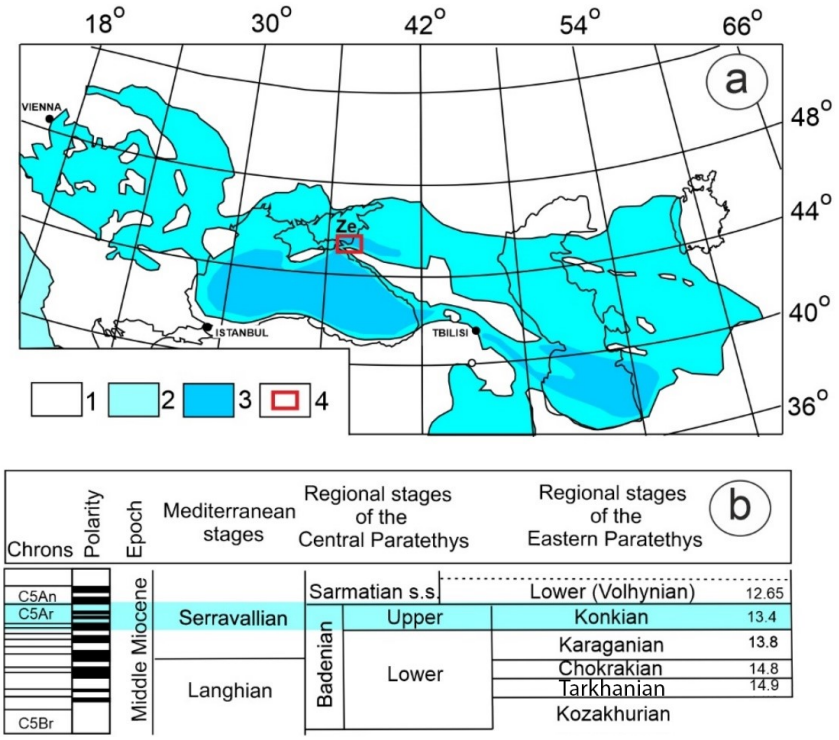


Figure 1. Paratethys during the last large marine transgression in the Middle Miocene (in the Konkian), modified after (*Studencka et al.*, 1998) (a) and scheme of correlation of the Paratethys Lower-Middle Miocene divisions with the Mediterranean stratigraphic scale (b). Land zones (1), shallow-water (2), deep-water (3), location of the study area (Ze – the Zelensky section) (4).

The repetitive signal is also clearly visible in the wavelet analysis for the sediments of the Veselyankian and Sartaganian beds as well as the top of Kartvelian beds (Figure 3b).

4. Discussion

Stratigraphy. One of the problems of stratigraphy of the Neogene of the Eastern Paratethys is the determination of the age of the Miocene and Pliocene regional stages boundaries, as well as the correlation of these regional stages with the Geologic Time Scale (GTS). The duration of the stratigraphic units, including the Konkian, are particularly debated. The Konkian rocks contain flora and fauna of complexes, indicating that these sediments accumulated during the connection the Eastern Paratethys with marine waters (the last large marine transgression in the Middle Miocene). Due to this, the study of the Konkian sediments is very importance.

According to [*Nevesskaja et al.*, 2004], the Konkian Regional Stage includes Sartaganian and Veselyankian beds, which reflect the stage-by-stage onset of marine transgression. According to other scientists [*Andrusov*, 1903; *Merklin*, 1953; *Palcu et al.*, 2017; *Popov et al.*, 2016], the Konkian Regional Stage should also include Pholadidae or Kartvelian beds, which some researchers consider as part of the Karaganian [*Nevesskaja et al.*, 2004] or propose to distinguish them as a separate regional stage [*Il'ina*, 2000; *Jgenti and Maissuradze*, 2016]. At the same time, there is an opinion that the established units of the Konkian Regional Stage are only facies types of sediments without a consistent stratigraphic position [*Belokrys*, 1987; *Vernyhorova*, 2017]. The presence of problems in stratigraphic division of Konkian sediments makes it difficult to select the necessary intervals of the section for cyclostratigraphic studies, as well as to provide regional correlations.

Based on the presence of mollusk fauna, microfauna, and nannoplankton of undivided NN6–NN7 zones, it is assumed that the Konkian regional stage of the Eastern Paratethys corresponds to the lower Serravallian of the Mediterranean and the upper Badenian (Kosovian) of the Central Paratethys [*Hilgen et al.*, 2012; *Popov et al.*, 2013]. There are no absolute

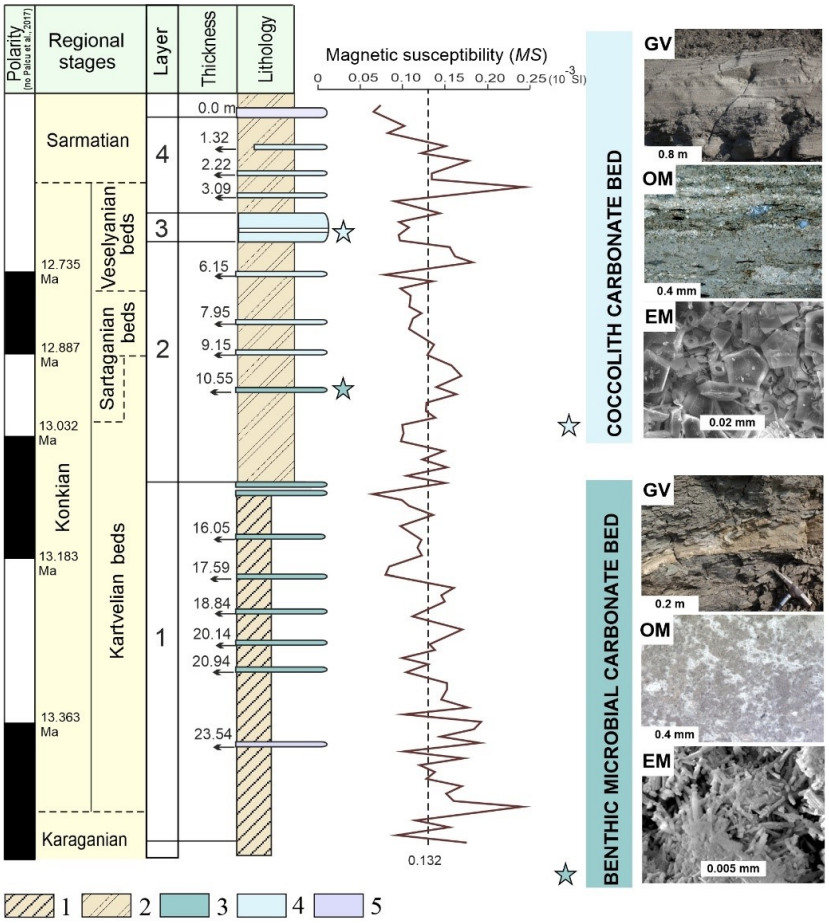
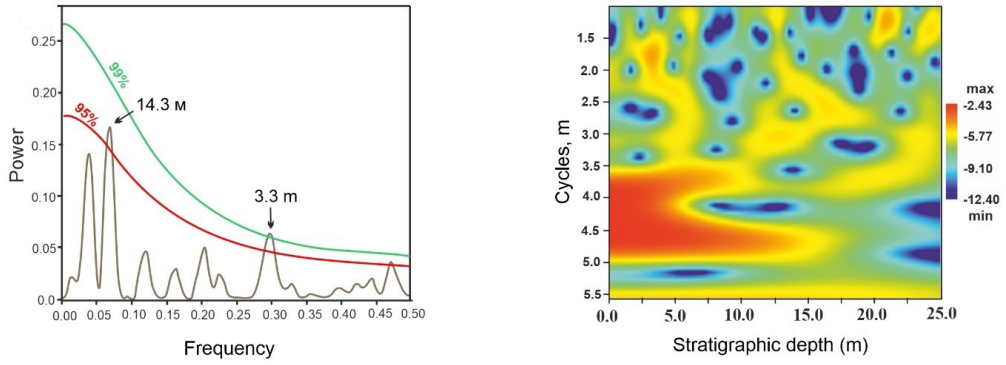


Figure 2. Lithological column, the results of the magnetic susceptibility (MS) measurements and main types of carbonate rocks of the studied Konkian sediments. Stratigraphic subdivision, polarity and possible age dating of rocks according to (*Palcu et al.*, 2017). 1–2 – weakly calcareous (1) and calcareous (2) clays; 3–5 carbonates: microbial (3), coccolith (4), and strongly dolomitized (5). Carbonate beds: general view (GV), in thin section (OM), under an electron microscope (EM).

dates of the Konkian deposits. It is proposed that the accumulation of the Konkian sediments could occur from 13.8–13.4 to 13.0–12.1 Ma [*Nevesskaja et al.*, 2004; *Palcu et al.*, 2017; *Popov et al.*, 2013]. The maximum estimates of this regional stage duration are no more than 1,7 Ma [*Hilgen et al.*, 2012; *Nevesskaja et al.*, 2004; *Popov et al.*, 2013]. According to new data [*Palcu et al.*, 2017], obtained on relatively deep-water middle Miocene sediments in the Zelensky section (Taman Peninsula), the upper and lower boundaries of the Konkian Regional Stage (including Veselyankian, Sartaganian or Kartvelian Beds) are dated to 12.65 and 13.4 Ma, respectively. It is believed that Veselyankian and Sartaganian beds generally correspond to the middle part of the C5Ar chrone (C5Ar.2n, C5Ar.2r, C5Ar.1n, and the lower C5Ar.1r); they accumulated within ~240 kyr (approximately from 12.89 to 12.65 Ma) with a sedimentation rate of approximately 2.2 cm/kyr. The Konkian sediments in the Eastern Paratethys, including the Kartvelian, Sartaganian, and Veselyankian beds, accumulated during ~750 kyr.

Astronomical forcing. The spectral analysis suggests the signals at 3.3 and 14.3 m, which very likely is an astronomical cyclicity imprint in studied sediments. The ratio between the observed periodicities is 1 : 4 (1 : 4.3), which correlates with long-term insolation variations associated with 24-kyr and 100-kyr cycles (precession and eccentricity). If the signal at 3.3 m corresponds to the 24-kyr precession cycle, the duration of accumulation of Sartaganian and Veselyanian beds with the total thickness of about 6–7 m is about 50 ka. In this case, the sedimentation rate was about 12–14 cm/1000 years. If we consider this



(a) **(b)**

Figure 3. REDFIT spectral analysis (a) and wavelet analysis (b) of the magnetic susceptibility data from Konkian sediments of Zelensky section (the Taman Peninsula).

signal as a record of 100-kyr eccentricity cycle, the Sartaganian and Veselyankian beds were deposited at an average rate of 3.3 cm/kyr for about 200 ka. In this case, the obtained values are well consistent with new published data [*Palcu et al.*, 2017]. However, it should be noted that these are rather low values of sedimentation regims, which are generally not typical for the intracontinental paleobasins. Apparently, this can be explained by the difference in the rates of accumulation of clayey and carbonate sediments, among which microbial calcareous layer might differ in a duration formation.

5. Conclusion

Based on spectral analysis and frequency-selective filtering of magnetic susceptibility data, the influence of astronomical cycles could be detected in Konkian sediments of the Zelensky section (Taman Peninsula, Russia). Spectral analysis revealed a likely 100-kyr eccentricity cycles.

The relatively deep-water Konkian sediments of the Zelensky section are characterized by low sedimentation rates (3.3 cm/kyr) and the presence of a record of astronomical cyclicity, possibly related to eccentricity changes in insolation.

According to the cyclostratigraphic results, the accumulation duration of the Sartaganian and Veselyanian beds in the Zelensky section is about 200 kyr.

If the Kartvelian, Sartaganian and Veselyanian beds are biofacies (not substage) in the Konkian sediments of the Eastern Black Sea region, these beds could have appeared in the Konkian at different times. In this case, the duration of accumulation of these beds may be different depending on the conditions of sedimentation in certain parts of the paleobasin. Considering these and other problems in the stratigraphy of the Konkian, the study of the astronomical cyclicity of these sediments should be continued on the example of other sections of the Eastern Paratethys.

The obtained cyclostratigraphic results generally do not contradict the new data about the possible duration of the Konkian (Kartvelian, Sartaganian and Veselyankian beds) of about 750 kyr [*Palcu et al.*, 2017].

Acknowledgments. This research was funded by budgetary funding of the Geophysical Center of RAS, adopted by the Ministry of Science and Higher Education of the Russian Federation (project 075-00764-22-00). Alena Rybkina and Alexsandra Rylova are thanked for their field support and fruitful discussions.

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