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The Cyclostratigraphy of the Konkian Deposits of Eastern Georgia (Eastern Paratethys, Kura Basin)

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Abstract—The middle Miocene (mainly the Konkian) shallow marine sediments of Eastern Georgia (Eastern Paratethys, Kura basin) have been studied for the first time with cyclostratigraphy methods. Time series analysis (Lomb-Scargle and REDFIT periodograms, Gaussian filter) revealed a statistically significant signal with a 2.4–2.7-m wavelength, which most likely corresponds to the precession cycle. It was established that the sedimentation rate of the studied sediments varied from 8.75 to 13.75 cm/kyr in dependence on different sedimentation environments. It is assumed that the studied Eastern Georgia Konkian deposits (Sartaganian and Veselyankian beds) accumulated during at least 475–600 kyr. The Sartaganian Beds can be correlated with interval of the highest sea-level rise at the TB 2.5 cycle.

Keywords: Konkian, Middle Miocene, Eastern Paratethys, sedimentation rate, cyclostratigraphy

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INTRODUCTION

In order to correlate the regional stages of the Eastern Paratethys with the General Stratigraphic Chart it is necessary to study deposits that accumulated under normal marine conditions during connection with the open-marine basins. The middle Miocene (Konkian) deposits of the Eastern Paratethys contain associations of flora and fauna, which indicate their accumulation under the influence of normal marine waters. Due to this, a comprehensive study of these strata is of high importance. Despite the long-term history of studying the Konkian deposits, thus far the issues of their subdivision, their comparison with the General Stratigraphic Chart, and their dating remain debatable in many respects (Nevesskaya et al., 2004; Palcu et al., 2017).

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 dates of the Konkian deposits. It is proposed that the accumulation of the Konkian deposits could occur from 13.8–13.4 to 13.0–12.1 Ma (Nevesskaya et al., 2004; Palcu et al., 2017; Popov et al., 2013). The maximum estimates of this regional stage duration are no more than 1 Ma (approximately 800–900 kyr) (Hilgen et al., 2012; Nevesskaya et al., 2003; Popov et al., 2013). According to recent data (Palcu et al., 2017), obtained on relatively deepwater middle Miocene deposits 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 1.4 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.

To establish regimes of sedimentation and evaluate the duration of formation of the strata, cyclostratigraphic analysis of the shallow-water marine Konkian deposits of the Kura Basin (Ujarma section, Kakheti, Eastern Georgia) was performed for the first time. The results we obtained are discussed in the present paper. This work is based on the regional stratigraphic scheme of Neogene deposits of the South European Russia (Nevesskaya et al., 2004; the recent edition), in which the Konkian Regional Stage is distinguished in the volume of Sartaganian and Veselyankian beds.

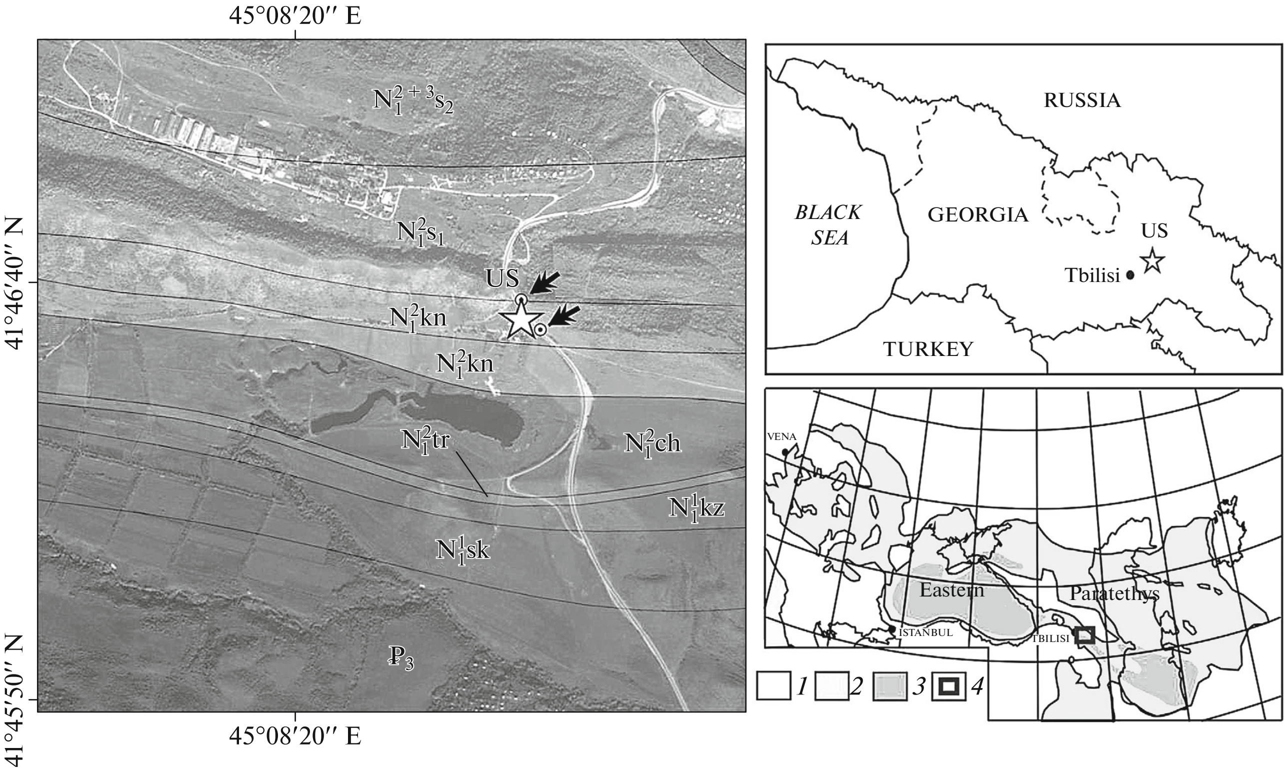

Fig. 1. The location of the studied deposits, exposed in the Ujarma section (US), Eastern Georgia. The Eastern Paratethys during the last marine transgression in the middle Miocene, modified after (Studencka et al., 1998): (*1*) land areas, (*2*) shallow-water settings; (*3*) deepwater settings, (*4*) location of the studied area.

RESEARCH OBJECT

Konkian deposits of the Ujarma section (41°77′62.24″ N, 45°14′95.65″ E) exposed in the new outcrop in the environs of the settlements of Mukhrovani and Ujarma (Kakheti, Eastern Georgia) served as the main object of research (Fig. 1). The Middle Miocene deposits in the environs of the settlement of Ujarma have been studied by many scientists (M.M. Grachevskii (1954), O.I. Dzhanelidze (1961, 1970), V.A. Krasheninnikov (2003), E.M. Zhgenti, and L.S. Maissuradze (2016), etc.). Due to these works, the paleontological characteristic of the studied sequences was obtained, the species composition of macro- and microfaunistic assemblages was determined, a general description of the section was made, and the first data on the lithological features and sedimentation conditions were obtained. It was established that the Kartvelian (Pholad), Sartaganian, and Veselyankian beds are traced in the Ujarma section. Upsection, they are followed by the Lower Sarmatian deposits (Dzhanelidze, 1970; Krasheninnikov et al., 2003). A diverse mollusk assemblage including *Anadara turonica*, *Turritella atamanica*, *Mactra basteroti*, *Ervilia trigonula*, *Chlamys sartaganicus*, *Cardium* sp., etc. was recognized in the Konkian strata (Dzhanelidze, 1970).

During the research, the layer-by-layer structure of the studied strata was described (Fig. 2). For a more detailed stratigraphic subdivision of deposits, foraminiferal assemblages were studied (determinations made by K.P. Koiava) (Figs. 3, 4). Foraminiferal shells were not found in all beds of the section.

Based on the foraminiferal composition, deposits of beds 2–4, containing *Varidentella reussi sartaganica* (Krasheninnikov), *Rotalia maschanliensis* Pronina, *R. conquisita* (Krasheninnikov), *Borelis melo* (Fichtel et Moll), *Porosononion granosum* (d'Orbigny), *Cibicides* aff. *dorzotumidus* Serova, *Ammonia beccarii* (Linnaeus), *A.* aff. *viennensis* (d'Orbigny), and *Quinqueloculina akneriana argunica* Gerke correspond to the Konkian regional stage. The presence of *Borelis melo* (Fichtel et Moll) and *Varidentella reussi sartaganica* (Krasheninnikov) allowed us to attribute these deposits, as well as deposits of the Bed 6 with Borelis melo, to the Sartaganian Beds (Fichtel et Moll). In terms of the taxonomic composition, the foraminiferal assemblage in the studied deposits is similar to the Sartaganian foraminiferal assemblages of the Cis-Caucasus (Bogdanovich, 1965) and Crimea (Krasheninnikov et al., 2003).

The overlying beds 11, 16, and 18 include *Ammonia beccarii* (Linnaeus), *A.* aff. *viennensis* (d'Orbigny), *Discorbis kartvelicus* Krasheninnikov, *Discorbis* sp.,

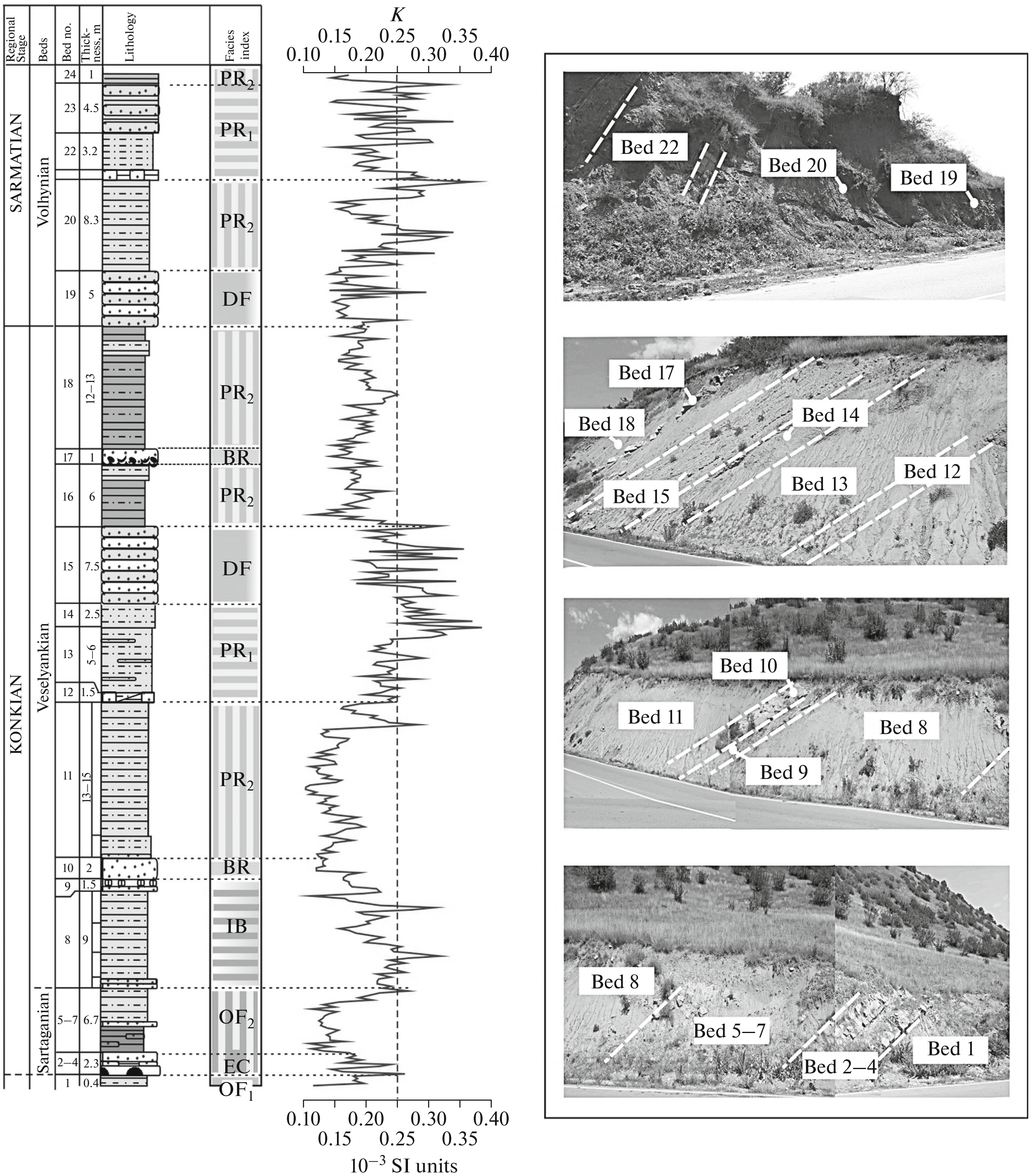

Fig. 2. The lithology of the studied deposits with the characteristic of the magnetic susceptibility of the rocks. Facies types of sediments: setting with low hydrodynamic regime (OF2), setting with moderate hydrodynamic regime (OF1), marginal parts of sand sheets (IB), central parts of sand sheets (BR), transgression erosion beds (EC), lower part of a prodelta (PR2), the upper part of a prodelta (PR1), marginal parts of a delta front (DF).

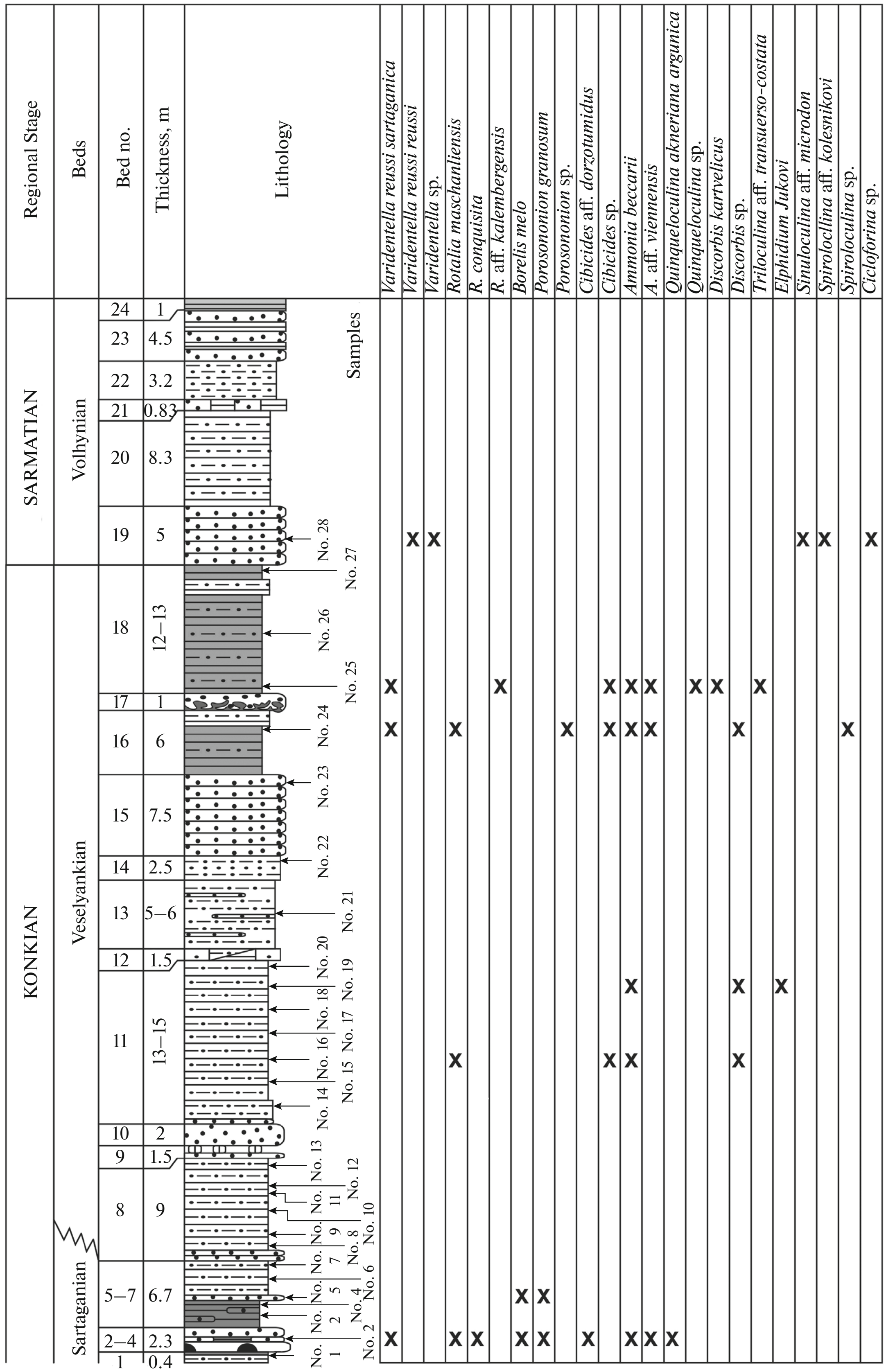

Fig. 3. The distribution of foraminifers in the Konkian and Sarmatian deposits of the Ujarma section (Kakhetia, Eastern Georgia; determinations by K.P. Koiava)

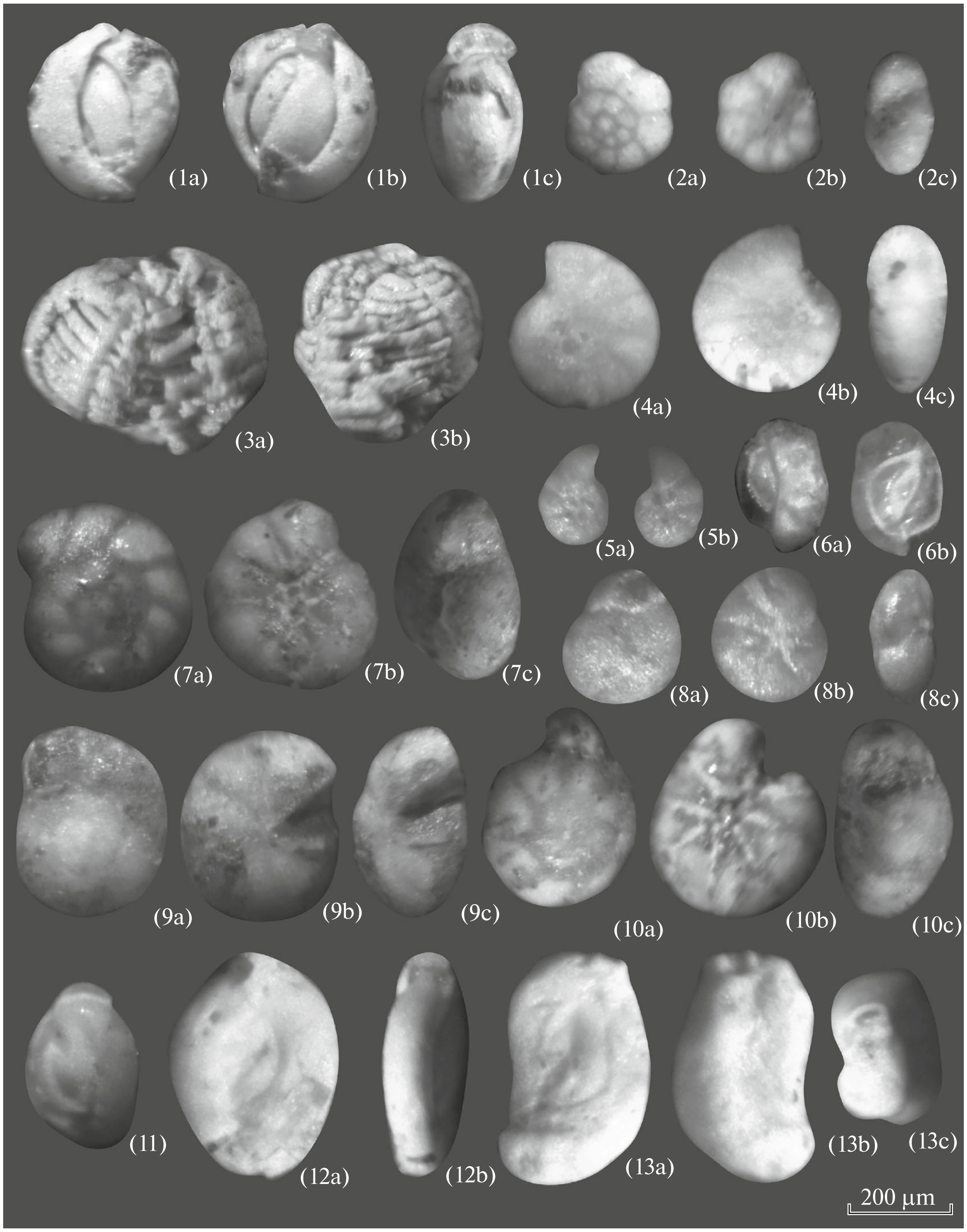

Fig. 4. Foraminifers from the Konkian and Sarmatian deposits of the Ujarma section (Kakhetia, Eastern Georgia; determination by K.P. Koiava): 1a, 1b, 1c, *Varidentella reussi sartaganica* (Krasheninnikov); 2a, 2b, 2c, *Rotalia conquisita* (Krasheninnikov); 3a, 3b, *Borelis melo* (Fichtel et Moll); 4a, 4b, 4c, *Porosononion granosum* (d'Orbigny); 5a, 5b *Porosononion* sp.; 6a, 6b *Triloculina* aff. *transuerso-costata* Didkovskiy; 7a, 7b, 7c *Rotalia maschanliensis* Pronina; 8a, 8b, 8c *Rotalina* aff. *kalembergensis* (d'Orbigny); 9a, 9b, 9c *Cibicides* aff. *dorzotumidus* Serova; 10a, 10b, 10c *Ammonia beccari* (Linnaeus); 11 *Varidentella reussi reussi* (Bogdanovich); 12a, 12b *Spiroloculina* aff. *kolesnikovi* Bogdanovich; 13a, 13b, 13c *Sinuloculina* aff. *microdon* (Reuss)

Rotalia maschanliensis Pronina, *Rotalina* aff. *kalembergensis* (d'Orbigny), *Triloculina* aff. *transuerso-costata* Didkovskiy, *Elphidium jukovi* Serova, *Varidentella reussi sartaganica* (Krasheninnikov), *Cibicides* sp., *Porosononion* sp., *Quinqueloculina* sp., and *Spiro loculina* sp. Representative of the genus *Ammonia* are abundant. The Konkian age of these deposits is confirmed by the presence of *Varidentella reussi sartaganica* (Krasheninnikov) and *Discorbis kartvelicus* Krasheninnikov (Maissuradze et al., 2014). It is proposed that the studied deposits are likely belong to the Veselyankian Beds.

Deposits of Bed 19 are characterized by the presence of single *Varidentella reussi reussi* (Bogdanovich), *Sinuloculina* aff. *microdon* (Reuss), *Spirolocllina* aff. *kolesnikovi* Bogdanovich, *Cicloforina* sp., and *Varidentella* sp. Despite the poor foraminiferal assemblage, the development of miliolids and the first occurrence of *Varidentella reussi reussi* (Bogdanovich) allowed attribution of the studied deposits to the Lower Sarmatian (Maissuradze and Koiava, 2011).

The deposits of the Ujarma section (approximately 90 m thick) are mostly composed of clays. As well, the section includes interbeds of sandstones, rare gravellites, and fine-pebble conglomerates. Silty material occurs mainly as an admixture; less often, it forms separate independent layers. Carbonate rocks, represented by two horizons of small microbial nodules (Bed 9), are observed only at one level in the section. The deposits contain shells and their fragments, sometimes forming separate accumulations. There are single interbeds with signs of secondary carbonatization.

MATERIALS AND METHODS

The magnetic susceptibility (*K*) was measured in order to obtain the data on cyclostratigraphy of the studied deposits. The measurements were carried out continuously every 20 cm with a KT-5 kappameter (Geofyzika, BRNO, Czech Republic) through the section across the strike of the rocks. Three measurements were made at each point. In total, approximately 1314 estimates were obtained. The data were processed by statistical methods, including the PAST 3 (construction of Lomb-Scargle and REDFIT periodograms) and AnalySeries software (Hammer et al., 2001; Paillard et al., 1996; Schulz and Mudelsee, 2002). Cyclostratigraphy analysis was performed following the common technique (Weedon, 2003).

According to the thermomagnetic analysis, magnetite and maghemite are the main minerals—carriers of magnetization in the studied rocks (Pilipenko et al., 2019). Magnetite is likely a detrital component.

The cyclostratigraphic studies were accompanied by a facies analysis of the strata, which is necessary to determine the environmental setting. It was established that deposits include transgressive erosion beds that lie at the section's base (Beds 2–4). Up the section, they are replaced by clays accumulated in the environmental setting with low hydrodynamic regime (Beds 5–7) (Rostovtseva, 2020). As well, the presence of silty—sandy—clayey and sandy deposits of marginal and central parts of sand sheets accumulated in the coastal shallow-water zone during wave-influenced sedimentation was established (Beds 8–10). Moreover, these facies occur in a separate interval higher in the section (Bed 17). Most of the section is composed of submarine-fluvial deposits, represented mainly by silty—sandy—clayey sediments of the prodelta (Beds 11–14, 16, 18, 20–24), and less often by sediments of the marginal parts of the delta front (Beds 15, 19), which generally correspond to the distal zone of subaqueous delta. The facies pattern of the studied strata indicates their accumulation in shallow coastal zones (at a depth of no more than 40–50 m). As well, the presence of different sedimentation regimes must be taken into account when interpreting cyclostratigraphic data (Rostovtseva et al., 2019).

DISCUSSION

We have established that the magnetic susceptibility (*K*) of the studied deposits varies from 0.103×10^{-3} to 0.387×10^{-3} SI units. Deposits with a higher content of sandy particles located in separate intervals of the section, are characterized by higher K values (up to 0.387×10^{-3} SI units). These intervals correspond to transgressive erosion beds (Beds 2–4), sediments of sand sheets (Beds 8–10), and some deltaic deposits (the marginal parts of the delta front and the upper parts of the prodelta) (Beds 12–15, 19–24). The lower *K* values ($\leq 0.250 \times 10^{-3}$ SI units) are characteristic of sediments of the environmental setting with low hydrodynamic regime and more clayey deposits of the prodelta lower parts (Beds 5–7, 11, 16, 18) (Fig. 2).

The spectral analysis of equidistant data sets of magnetic susceptibility for the whole section, including both Konkian and Sarmatian deposits, revealed the presence of several well-defined peaks. A single peak is distinguished on the Lomb-Scargle periodogram. It exceeds the spectral noise interval with a 99% confidence level and corresponds to a 166.5 m cycle. This cycle, which is almost two times longer than the total thickness of the section (approximately 91–98 m), cannot be used for the complete cyclostratigraphic analysis. Along with this peak, there is another peak on the REDFIT periodogram, which also exceeds the spectral noise interval with a 99% confidence level, corresponding to a 2.4 m cycle (Fig. 5). In general, this cycle meets all the parameters that need to be considered when identifying long-period astronomical oscillations.

Taking the existence of different sedimentation regimes during the accumulation of the studied deposits into account, the frequency peak values were also determined in separate intervals of the section, which characterize different environments of sedimentation. As a result, it was found that valid cycles of 3.3, 3.0; 2.4; 2.1 and 2.4 m are distinguished on REDFIT periodograms for predominantly clayey deposits of beds 5–9, 11, 12–15, 16–18, and 19–24, respectively. The deposits of the lower part of the section are characterized by slightly longer cycles, which may be associated with a higher sedimentation rate at that time. In the upper part of the section, cycles with similar lengths varying from 2.1 to 2.4 m are distinguished. In general,

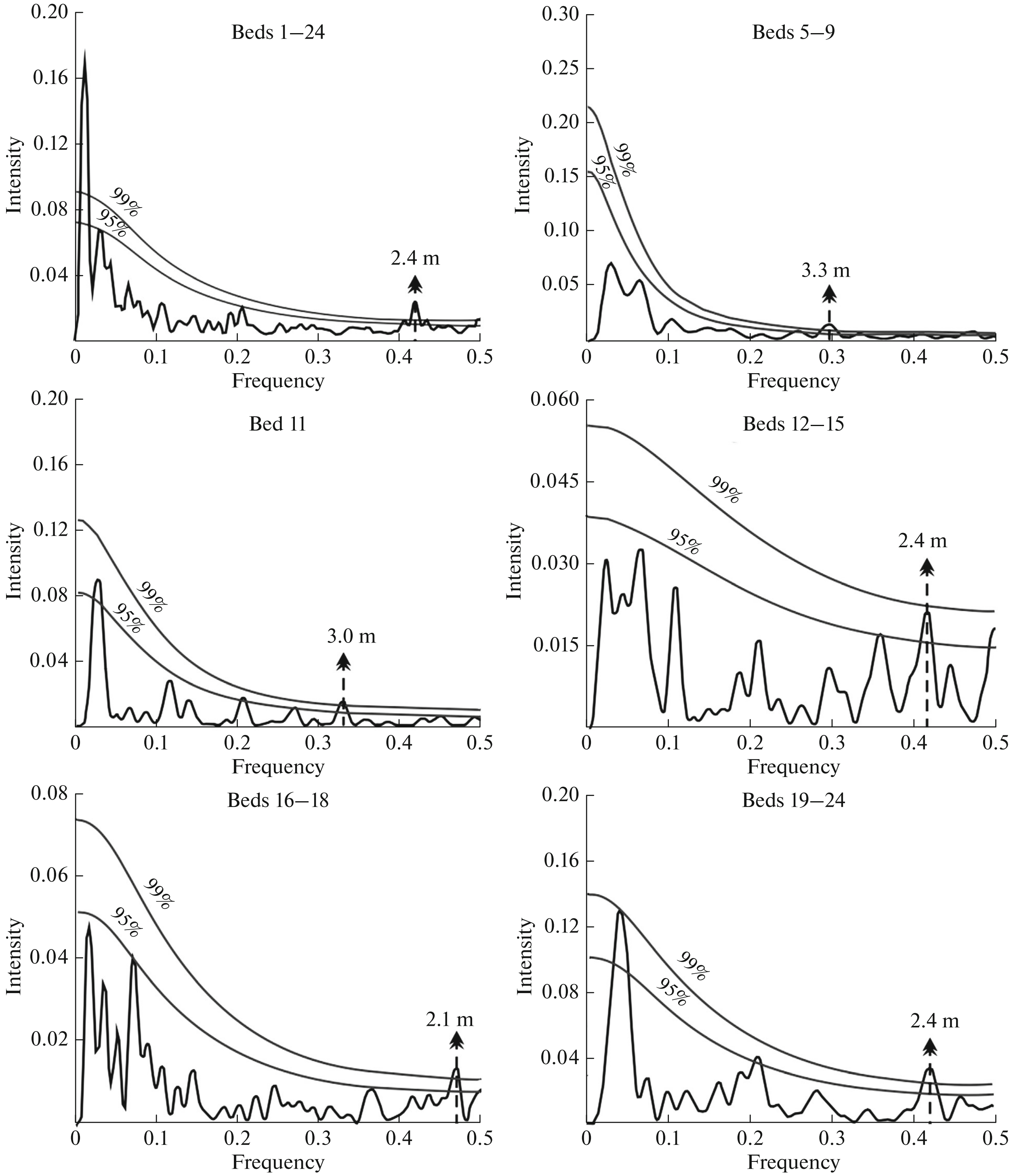

Fig. 5. REDFIT periodograms of the spectral analysis of the data on the magnetic susceptibility of the studied deposits (Ujarma section, Eastern Georgia) with the characteristic of the length of the studied cycles.

this coincides with the length of the cycle established for the entire section. The average cycle length in the Konkian deposits is 2.7 m; in the Sarmatian deposits it is 2.4 m. These cycle length values were chosen as the basis for further analysis of the magnetic susceptibility data using the AnalySeries software based on a Gaussian filter (Fig. 6).

The high convergence of the spectral analysis results obtained for different parts of the studied section indicates a general regularity in the structure of

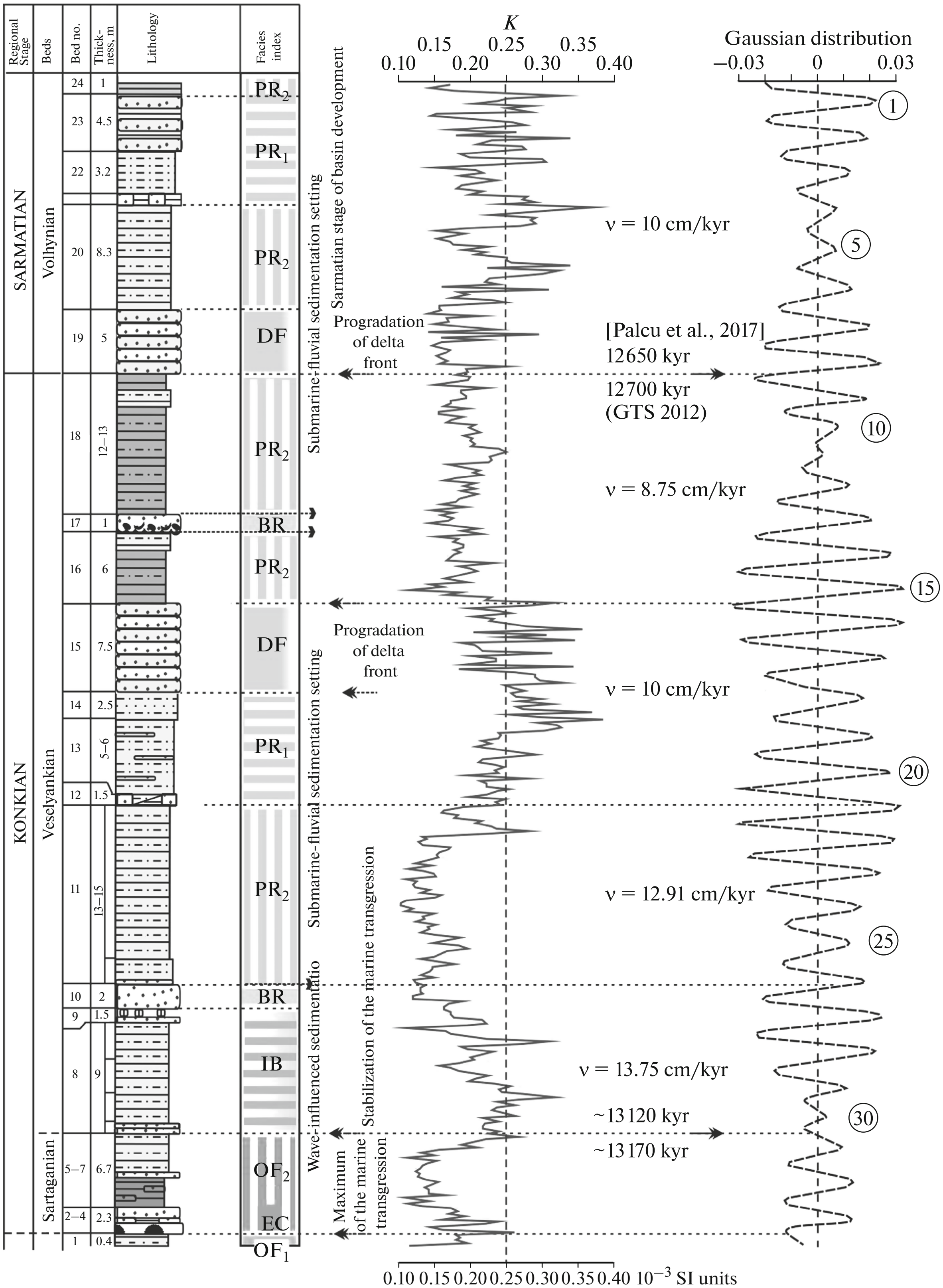

Fig. 6. The results of the AnalySeries analysis of the data on the magnetic susceptibility of the studied rocks (Ujarma section, Eastern Georgia). Designations of facies see in Fig. 2.

the strata, associated with the manifestation of factors at an astronomical scale (Milankovitch cycles). The Konkian Regional Stage of the Eastern Paratethys is compared with the Kosovian of the upper part of the Central Paratethys. The duration of the latter does not exceed 1 Ma (Hohenegger et al., 2014). According to new data (Palcu et al., 2017), the Konkian deposits in the Eastern Paratethys, including the Kartvelian, Sartaganian, and Veselyankian beds, accumulated during ~750 kyr. The thickness of the Konkian deposits, including the Sartaganian and Veselyankian beds in the studied section, is 67.8 (68) m. This sequence of sedimentary formations includes 25 to 28 cycles of 2.7 (for the Konkian deposits, on average) and 2.4 m (for the entire section on average), respectively. If a 2.4–2.7 m cycle is considered as a record associated with long-term astronomical oscillations in the angle of inclination of the Earth's axis and the eccentricity of the Earth's orbit with periods of 41000 and 100000 years, then the accumulation time of the studied deposits would be less than 1 Ma (1025–2800 kyr). Based on this, one can suggest that this cycle is better correlated with precession periods (~19000, 22000, and 24000 years). In this case, the maximum duration of the accumulation of the studied Konkian deposits can be estimated at ≤532–672 kyr. In general, this is in agreement with ideas on the possible duration of the Konkian regional stage. If the 2.4–2.7 m cycle is associated with the precession period, then the sedimentation rate of the studied deposits varied from 8.75 to 13.75 cm/kyr. The deposits of the lower part of the Ujarma section, corresponding to transgressive deposits and sediments of the sand sheets, were accumulated with a higher rate (~13.75 cm/kyr, on average). The submarine-fluvial deposits compose most of the section. These deposits, represented mostly by prodelta deposits, were accumulated at a somewhat lower rate, from 8.75 to 12.91 cm/kyr. The lowest sedimentation rates (8.75 cm/kyr, on average) were established in the Upper Konkian deposits.

Analysis of the magnetic susceptibility data using the AnalySeries software, which includes the ability to use Gaussian bandpass filter, allowed us to compare the recognized cyclicity in peak values (2.4 and 2.7 m) with the layer-by-layer structure of the section (Fig. 5). Based on the available data, one can obtain several proposed dates. According to (Hilgen et al., 2012; Hohenegger et al., 2014; Palcu et al., 2015, 2017; Popov et al., 2013), the boundaries between the Konkian and Sarmatian regional stages in the Eastern Paratethys, as well as those between the Kosovian and Sarmatian in the Central Paratethys generally coincide in age.

According to new data (Palcu et al., 2017), these boundaries correspond to 12.65 Ma; according to GTS2012 (Hilgen et al., 2012), they correspond to 12.7 Ma. Taking these data into account and the analysis results of the peculiarities of the cyclicity of strata, it is assumed that the Konkian deposits accumulated during at least 475–600 kyr (in the range from ~13300–13125 to 12700–12650 kyr), and the entire section during ~620–790 kyr (from ~13300–13125 to ~12500–12450 kyr).

Within this interpretation, the deposits of the lower part of the section (Beds 2–7) related to Sartaganian Beds based on the presence of *Borelis melo* (Fichtel & Moll) are older than 13 100 ka. In this case, the interval with normal polarity at the base of the studied section that was revealed during the paleomagnetic tests (Pilipenko et al., 2019) (Bed 8) can be compared with the part of the C5AAn chron (13183–13032 ka) of the general stratigraphic scale. The accumulation of Sartaganian Beds is comparable in time to the maximum water rise in the global TB 2.5 cycle (Hag et al., 1988). It is believed that the accumulation of the Kosovian deposits of the Central Paratethys, which corresponds to the last marine transgression of the Middle Miocene, began before 13.1 Ma (Hohenegger et al., 2014).

CONCLUSIONS

A detailed layer-by-layer description of the Ujarma section was made for the first time, taking the microscopic study of the rocks into account. As well, pilot cyclostratigraphic studies of the Konkian and Sarmatian shallow-water deposits of Eastern Georgia was performed.

It has been established that the magnetic susceptibility (K) of the studied deposits is from 0.103×10^{-3} to 0.387×10^{-3} SI Units. The increased K values are characteristic of intervals of sandy sediments.

The spectral analysis of equidistant datasets of magnetic susceptibility revealed a 2.4 m cycle comparable to long-term astronomical oscillations for the entire deposits of the section and a 2.7 m cycle on average for the Konkian regional stage. The established 2.4–2.7 m cycle is better correlated with the periods of precession oscillations (19000, 22000, and 24000 yr). Taking this into account, the sedimentation rate, which varied over time depending on the existing sedimentation conditions and ranged from 8.75 to 13.75 cm/kyr, was calculated. Compared to deposits represented mainly by prodelta clays that accumulated at the distal zone of subaqueous delta transgressive deposits and those of the marginal and central parts of the sand sheets were accumulated at a higher sedimentation rate. It is assumed that the entire section's formation took place during ~790 kyr, and the Konkian strata of the regional stage are during no less 475–600 kyr.

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