

Neogene Regional Scale of the Eastern Paratethys, Stratigraphy and Paleontological Basis

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Abstract—The stratigraphic scale of the Eastern Paratethys is revised based on a study of the Neogene stratotype and reference sections, their biotic characteristics, and paleomagnetic and sedimentological data. New data on the correlation of its regional subdivisions with the Central Paratethys and Mediterranean stratotypes are presented. The section “Regional Stage Scale of the Eastern Paratethys” considers the history of identification and a brief description of the horizons of the regional scale, which later became regional stages, as well as their historical stratotypes and lectostratotypes, and division into Beds and Substages. The section “History of Separate Biota Groups” provides reviews on the most important groups of fauna, phytoplankton, and terrestrial vegetation, as well as on magnetostratigraphy, the possibility of correlation and dating of sections based on these data, and comparison with the Central Paratethys and stratotypes of the Mediterranean. In conclusion, the main results of the revision of the stratigraphic scheme of the Neogene of the Eastern Paratethys are given.

Keywords: Miocene, Pliocene, mollusks, foraminifers, nannoplankton, organic-walled phytoplankton, ichthyofauna, terrestrial vegetation, paleomagnetism, cyclostratigraphy

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INTRODUCTION

The regional scale of the Eastern Paratethys was developed in the second half of the 19th to the early 20th century (Barbot de Marny, 1866, 1869; Andrusov, 1884, 1917a, 1917b; Davitashvili, 1933, 1934, etc.) and has remained generally stable up to now (*Stratigrafiya...*, 1940; Nevesskaya et al., 1975, 1984, 2004; *Neogenovaya sistema*, 1986; *Unifitsirovannaya...*, 2004; Popov et al., 2013a, 2018). It was initially based mainly on data on mollusks; therefore, sections represented by shallow-water facies with the largest amount of malacofaunal remains were chosen as stratotypes. Even now, this stratigraphic scheme makes it possible to very accurately divide and correlate sections within the basin, in particular, in the shallow water zone. However, its correlation with neighboring basins, zonal scales, and Mediterranean stratotypes has always caused significant problems due to the incompleteness of the shallow-water sections, endemism of the biota, and the rare occurrence or absence of the main orthostratigraphic groups used in global Neogene stratigraphy.

The Mediterranean stratigraphic scale, the stages of which became subdivisions of the General Neogene Scale, was revised in the 1970s, when new stratotypes were proposed, the use of the Helvetian stage was rejected, and the ranges of the Aquitanian and Burdigalian were changed (*Stratotypes...*, 1975). Around the same time, a regional stage scale of the Neogene of Central Europe was developed and accepted (Seneš, 1975; Steininger and Rögl, 1983; Steininger and Seneš, 1985). As a result of this revision, it was decided to rerank the divisions of the Neogene in the south of the former Soviet Union (previously recognized as horizons) as regional stages (Nevesskaya et al., 1975; *Trudy...*, 1976, pp. 65, 66). A new regional stage, the Caucasian Regional Stage, was proposed for the lower part of the Miocene (Bogdanowicz et al. in Nevesskaya et al., 1975; Nosovskii and Bogdanowicz, 1980).

The accuracy of age determination of the divisions of the Mediterranean scale and possibilities of their recognizing and correlation have dramatically increased since that time thanks to the development and application of zonal scales based on planktonic foraminifers and phytoplankton, as well as on paleomagnetic and isotopic data and methods of astronomically driven cyclicity. The use of all these methods in the ICS Global Boundary Stratotype Section and Point program (GSSP) has increased the possibility of recognizing the divisions of the Mediterranean scale.

Later, these methods also began to be used in sections of the Eastern Paratethys. However, the possibility of using plankton zonal scales in these methods remains very limited due to the paleogeographic isolation and incomplete salinity of Paratethys basins: it is hardly possible to use a scale based on planktonic for-

aminifers and nannoplankton, which characterize only short episodes of the most extensive relationships with open basins. Euryhaline phytoplankton groups, such as diatoms and dinocysts are more promising for creating a biostratigraphic scale in basins where the salinity periodically changed; however, such studies are now only in the development stage, and the existing scales based on these groups also involve oceanic or open-sea taxa, which only occasionally colonized Paratethys water bodies (Radionova et al., 2012; Popov et al., 2016).

When it was impossible to fully use plankton zonal scales, the paleomagnetic data for the Miocene of the Eastern Paratethys could not be unambiguously interpreted for a long time, which caused fierce debates (*Unifitsirovannaya...*, 2004). The situation has only recently begun to change owing to more detailed integrated phytoplankton, paleomagnetic, and isotopic studies (Golovina and Muzylev, 1987; Vernigorova et al., 2006; Filippova and Trubikhin, 2009; Vasilev et al., 2011; Radionova et al., 2012; Popov et al., 2016; Palcu et al., 2017) and studies of astronomically driven cyclicity (Rostovtseva and Rybkina, 2014, 2017; Rybkina et al., 2015) at complete, relatively deep-water sections of the Taman Peninsula and Ciscaucasia with stable sedimentation. The presence of some index species of diatoms, dinocysts, nannoplankton, and plankton foraminifers, as well as fairly complete sequences of polarity reversal, were established for the Miocene for the first time; it became possible to correlate them with more seaward facies of the Central Paratethys and, based on this comparison, more confidently interpret paleomagnetic data and correlate them with the divisions of the global scale (Palcu et al., 2017, 2019a, 2019b; Popov et al., 2013b, 2018; Golovina, 2019). It became possible and necessary to identify the most complete reference sections for the boundaries of regional stages and substages in other deeper facies. These were the outcrops of the Kerch and Taman peninsulas and sections of Ciscaucasia, western Kazakhstan, and Georgia (Fig. 1).

In this paper, based on the study of the Neogene stratotype and reference sections, their biotic characteristics, and paleomagnetic data, we will try to evaluate changes that occurred in the assessment of the ranges and positions of the boundaries of the regional stages and substages of the stratigraphic scale of the Eastern Paratethys, and present data on the correlation of these divisions with the Central Paratethys and Mediterranean stratotypes.

The section "Regional Stage Scale of the Eastern Paratethys" considers the history of identification and a brief description of the horizons of the regional scale, which later became regional stages, as well as their historical stratotypes and division. The position and criteria for drawing the division boundaries are discussed

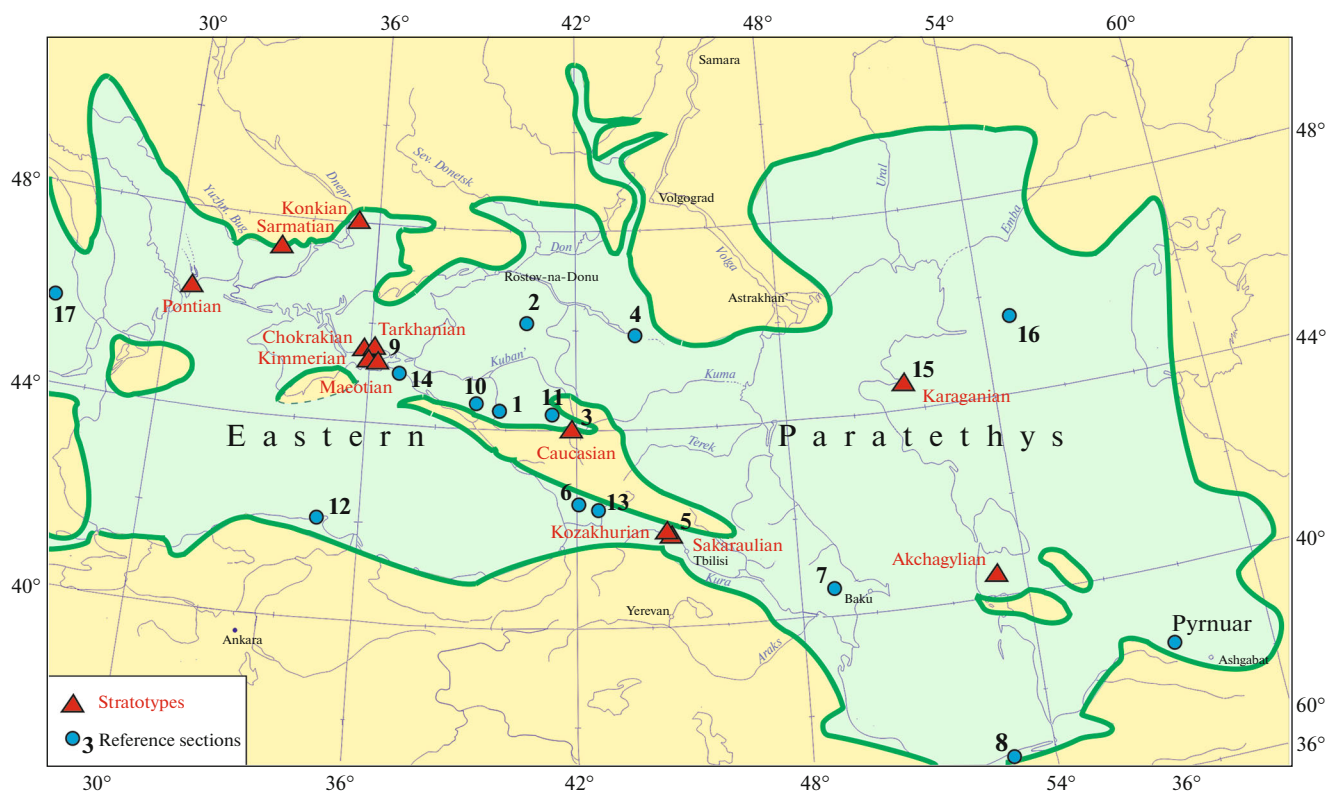


Fig. 1. Scheme of location of the stratotype and reference sections of the Neogene of the Eastern Paratethys. Stratotypes of the regional stages are highlighted in red. Numbers indicate the sections mentioned in the text. The green line and color show the maximum distribution of the basin during the Middle Sarmatian transgression (according to Popov et al., 2004b). Sections: (1) Belaya River (*Maikopian–Sarmatian*); (2) Novopokrovskaya-4 well (*Upper Maikopian*); (3) Kuban River near the city of Cherkessk (*Maikopian–Chokrakian*); (4) wells in Primanyche (*Maikopian–Pontian*); (5) Kartli, Georgia (*Maikopian–Sarmatian*); (6) Megrelian depression, Georgia (*Maikopian–Sarmatian*); (7) Sumgait, Azerbaijan (*Maikopian–Chokrakian*); (8) Babol River, Iran (*Maikopian–Sarmatian*); (9) Bulganak syncline (*Maikopian–Chokrakian*); (10) Pshexha River (*Maikopian–Sarmatian*); (11) Bolshoy Zelenchuk River (*Tarkhanian–Sarmatian*); (12) Sinop, Turkey (*Tarkhanian–Chokrakian*); (13) Naspere, Georgia (*Chokrakian–Konkian*); (14) Taman (*Karaganian–Kimmerian*); (15) Uiratam, Kazakhstan (*Karaganian–Sarmatian*); (16) Northern Ustyurt, Kazakhstan (*Chokrakian–Sarmatian*); (17) Dacian basin, Romania (*Sarmatian–Romanian*).

and stratotypes and lecto- and hypostratotypes are illustrated.

The final sections provide reviews on different groups of fauna and phytoplankton, terrestrial vegetation, magnetostratigraphy, the astronomically driven cyclicity of sedimentation, and possibility of correlation and dating of sections based on these data, as well as comparison with the Central Paratethys and Mediterranean stratotypes and conclusions and substantiations of the dating of boundaries in the stratigraphic scheme of the Eastern Paratethys.

The sections began to be studied from the late 1960s in different compositions by different researchers; therefore, the table of contents indicates the names of the authors of each section or group of sections, as well as essays on groups and methods. Sections for which no names of authors are indicated were written by S.V. Popov, and then discussed with other authors of the monograph.

REGIONAL STAGE SCALE OF THE EASTERN PARATETHYS: HISTORY OF IDENTIFICATION, STRATOTYPES, AND DIVISION

The division of Neogene deposits began with the identification and tracing of the most striking and noticeable stages in the development of the Euxinic basin, which were characterized by a unique, well-traced mollusk fauna from the Pontian and Sarmatian horizons (later regional stages) of the Middle–Upper Miocene. On the contrary, the situation with the possibility of identifying and tracing the Lower Miocene regional stages (*Caucasian*, *Sakaraulian*, and *Kozakhurian*) was and still remains the most difficult problem. In most of the regions of the Paratethys, these divisions are represented by a uniform, noncalcareous argillaceous series of the upper middle and upper subdivisions of the *Maikopian* Group, which contains few fossils and is difficult to subdivide lithologically. The lower, *Caucasian* Regional Stage was recognized in deep-water facies within this series in

Ciscaucasia, while the Sakaraulian and Kozakhurian regional stages were recognized in the shallower sandy facies of the Kartli Depression of Georgia.

In most of the other areas of the Eastern Paratethys, the equivalents of the Sakaraulian and Kozakhurian deposits are argillaceous, usually anoxic Upper Maikopian facies without fossils or with strongly impoverished assemblages, not correlated with stratotypical ones. The maximum thickness of the Miocene part of the Middle–Upper Maikopian is observed in the central parts of the West Kuban Trough and in the area of the Taman Peninsula (500–800 m, up to 1000 m, according to A.K. Bogdanowicz and V.N. Buryak in (*Neogenovaya sistema*, 1986)).

Caucasian Regional Stage

This regional stage was first proposed by A.K. Bogdanowicz, M.V. Muratov, M.F. Nosovskii, L.S. Ter-Grigor'yants (Bogdanowicz et al. in (*Neveeskaya et al.*, 1975)). The stratotype is on the Kuban River downstream of the city of Cherkessk (Fig. 2), where the regional stage includes the Alkun, Septarian, and Zelenchuk formations and lower half of the Karadzhalsa Formation (Nosovskii and Bogdanowicz, 1980). The parastratotype is a section of the Derbetovskaya-37 Borehole on the northeastern slope of the Stavropol Uplift; the reference section is the Novopokrovskaya-4 Borehole near the town of Tikhoretsk (Neveeskaya et al., 1975; Nosovskii and Bogdanowicz, 1980; *Neogenovaya sistema*, 1986).

The Caucasian stratotype along the Kuban River is currently exposed only in places and had long been described and rather poorly characterized by general lists of microfossils from the constituent formations (Prokopov, 1937b; Grossgeym, 1960; Nosovskii and Bogdanowicz, 1980). K.A. Prokopov did not recognize the Alkun Formation in his stratigraphic scheme of Central Ciscaucasia; however, in his main study on the division of the Maikopian of Central Ciscaucasia, he noted an analogy of the section along the Kuban River with the section of the Assa River, where he established the Alkunian Horizon on Alkunka Creek. In both sections, he identified the level of sandstone, below which there is a horizon with septarian concretions, underlain by “... a horizon of coarse-layered marls (sandy or dolomite) (Alkunian Horizon)” (Prokopov, 1937b, p. 35). Later, the level of formation of calcareous clays and concretions below the Beds with large septarian concretions and Zelenchuk sands in the Kuban section near the city of Cherkessk was described by R.G. Dmitrieva, V.D. Somov, and Bogdanowicz (1959, pp. 92–93) as the Alkunian Horizon 35–40 m thick with marine foraminifers: *Bolivina* ex gr. *plicatella*, *Discorbis* sp., *Ammodiscus tenuiculus*, and *Uvigerinella* sp. The top of the Batalpashinsk Formation is assumed to be the lower boundary of the regional stage in the stratotype; this boundary is determined by the appearance of bedded siderite concretions, as well

as by the carbonate content of clays and finds of these foraminifers. There is no carbonate microfauna in the underlying and overlying beds.

Nannoplankton from *Cyclicargolithus floridanus* Beds was found in the Alkunian Horizon of the Kuban section; this nannoplankton does not contain stratigraphically important species; however, in more complete assemblages (the Kuban River in the Karamurzhinsky section and Belaya River), it includes an index species of the NN1 zone, *Triquetrorhabdulus carinatus*, according to Martini (1971), which, together with the finds of *T. milowii* (Karamurzhinsky section) and in the absence of Oligocene species, indicates that the beds belong to the lowermost strata of the Miocene (data from L.A. Golovina in (Filippova et al., 2015; Beluzhenko et al., 2018)).

Based on dinocysts, *Deflandrea spinulosa* Beds were identified in the section along the Kuban River at the level of the Alkunian Horizon and in the Septarian beds of the Zelenchuk Formation. On the whole, the systematic composition of the assemblage is close to that recorded in the section along the Belaya River in the *Deflandrea spinulosa* (non *typica*) subzone of the *Chiropteridium partispinatum* zone (Zaporozhets and Akhmetiev, 2017), established at the level of the NP25 zone by nannoplankton. In the section along the Kuban River, *Deflandrea spinulosa* Beds are correlated with the *Chiropteridium galea* zone (DN1) of the North Atlantic (de Verteuil and Norris, 1996; de Verteuil, 1997), *Deflandrea* spp. zone (Def) of the *Ectosphaeropsis burdigalensis* zone (Ebu) of the Mediterranean (Zevenboom, 1995), DM1 zone and D16b Subzone of Northwestern Europe (Powell and Brinkhuis, 2004; King, 2016), and *Chiropteridium galea* and *Deflandrea phosphoritica* zones of the Danish basin (Dybkjær and Piasecki, 2010), which cover the chronostratigraphic range of the terminal part of the Chattian–Lower Aquitanian based on the latest occurrence of *Chiropteridium galea* and abundance of *Deflandrea* spp.

Sumatradinium spp. Beds are recognized in the overlying Zelenchuk Formation and lower part of the Karadzhalsa Formation (Aleksandrova et al., 2023, in press). The co-occurrence of *Cousteaudinium aubryae* and *Sumatradinium soucouyantiae* in the absence of other stratigraphically important taxa dinocysts makes it possible to correlate beds containing *Sumatradinium* spp. with the *Cousteaudinium aubryae* (DN2) zone in the de Verteuil and Norris scale (1996), correlate them with part of the NN2 nannoplankton zone, and date them to the upper part of the Aquitanian–?lower part of the Burdigalian (about 22.2–19.1 Ma).

In the parastratotype of the Caucasian Regional Stage (the Derbetovskaya-37 Borehole), the lower boundary of the Caucasian in a shallower zone, which is more fully characterized by foraminifers, is marked between “Beds with untypical and depleted microfauna” and “*Bolivina goudkoffi* Beds” with a polyha-



line deep-water association of small foraminifers and pteropods (“*Spiratella*” = *Limacina*, *Vaginella*) and radiolarians (Nosovskii and Bogdanowicz, 1980; *Neogenovaya sistema*, 1986).

In the Novopokrovskaya-4 Borehole, it is characterized by contradictory data on dinocysts. It was initially assigned to the local *Wetzeliiella gochtii* + *Rhombodinium draco* Zone and dated as Oligocene (Andreva-Grigorovich, 1980). Later, N.I. Zaporozhets (Akhmetiev and Zaporozhets, 1996) assigned the undivided Alkun–Lower Zelenchuk interval, characterized by the middle part of *Bolivina goudkoffi* Beds based on benthic foraminifers and to the *Deflandrea spinulosa*–*Dapsilidinium pseudocolligerum* Subzone of the *Chiropteridium partispinatum* zone based on dinocysts. Above this bed, *Deflandrea spinulosa* Beds are established in the part of the section that is assigned to the Upper Caucasian (the upper part of the Zelenchuk Formation and lower part of the Karadzhhalga Formation); the dinocyst assemblage in these beds is essentially monotaxonic. With respect to the range, *D. spinulosa* Beds correspond to the uppermost *Bolivina goudkoffi* Beds and *Uvigerinella californica* Beds based on benthic foraminifers.

The base of the Upper Uplistsikhe Subformation of the Kartli Depression of Georgia is correlated with the Alkunian Horizon of Ciscaucasia with respect to the composition of calcareous nannofossils (finds of *Triquetrorhabdulus carinatus* in the absence of *Sphenolithus cyperoensis*) (Ananiashvili and Minashvili, 2000; Minashvili and Ananiashvili, 2017)), (for details, see Popov et al., 2022, in press).

The Caucasian Regional Stage was subdivided by its authors into two regional substages. In Southern Ciscaucasia (stratotype section), where foraminifers were found only in the Alkunian Horizon, substages were recognized based on lithology and the tentative correlation with foraminiferal beds from the northern sections. Here, the Alkunian Horizon and lower part of the Zelenchuk Formation, including the Septarian Beds, were assigned to the lower substage; in Northern Ciscaucasia (parastratotype section), the lower substage included *Bolivina goudkoffi caucasica* (Beds Bogdanowicz, 1971). The upper part of the Zelenchuk Formation and lower half of the Karadzhhalga Formation was assigned to the upper regional substage in the Kuban section near the city of Cherkessk and *Uvigerinella californica* Beds to the upper regional substage in Northern Ciscaucasia (Nosovskii and Bogdanowicz, 1980).

The upper boundary of the Caucasian in the stratotype is also conditionally defined in the middle part of the Karadzhhalga Formation (Nosovskii and Bogdanowicz, 1980) according to the tentative correlation with foraminiferal beds of the northern zone; in the parastratotype, the boundary is determined by the change of impoverished assemblages with *Uvigerinella californica* for richer assemblages with *Caucasinella elongata* (= *Bulimina* or *Neobulimina elongata*). The stratigraphic distribution of all these index species is much wider than the faunal beds corresponding to them. Thus, all the three “index” species are indicated in *Spiroplectammina terekensis* Beds in the Kerleut Formation of the Upper Oligocene of Crimea (Vernyhorova and Ryabokon, 2020), while *Bolivina goudkoffi* and *Uvigerinella californica* in the lower strata of the Uplistsikhe Formation of Kartli and in the Khashuri Region, also together with characteristic Oligocene forms (according to A.P. Pechenkina in Voronina et al., 1991), as well as in the Sakaraulian and even Chokrakian (*Caucasinella elongata*) of western Georgia (Dzhanelidze, 1970).

Correlation. The identification and correlation of the base of the Caucasian became much more confident and substantiated after data on the composition of nannoplankton and dinocysts in the Alkunian Horizon became available (data from J. Krhovsky in (Akhmetiev et al., 1995) and (Filippova et al., 2010, 2015); Beluzhenko et al., 2018, data from Golovina and G.N. Aleksandrova, in (Aleksandrova et al., 2022) and in this paper, which confirmed that this level was really regionally traceable and that it occupied a position close to the Oligocene–Miocene boundary in the stratotype region of the Mediterranean with respect to phytoplankton.

Cyclicargolithus floridanus Beds in the Alkunian Horizon of Ciscaucasia, recognized from finds of *Triquetrorhabdulus carinatus* and *T. milowii* in the absence of *Sphenolithus cyperoensis*, are correlated with the upper part of the NN1 zone of *Triquetrorhabdulus carinatus* (for details, see the chapter “Calcareous nannofossils”).

In the Kuban stratotype, the cooccurrence of dinocysts *Coosteaudinium aubryae* and *Sumatradinium soucouyantiae* was recorded in the interval from the Septarian beds of the Zelenchuk Formation to the middle part of the Karadzhhalga Formation in the absence of *Chiropteridium* and other stratigraphically important Oligocene taxa, which makes it possible to correlate the *Sumatradinium* spp. Beds with the *Coosteaudinium aubryae* (DN2) Zone in the Verteuil and Norris scale (1996), which is correlated with the

Fig. 2. Location of sections of the upper part of the Maikopian Group along the Kuban River from the city of Cherkessk to the Yaman–Dzhalga gully, Ritsa Hill, and southeastern outskirts of Kochubeevskaya settlement (former Olginskaya) and scheme of these sections with indication of the position of specimens taken. Photographs: (a) first small bedded concretions in clays of bed 2 of the Alkunian Horizon near the northeastern edge of the village of Psyzh, which were exposed at low water; (b) large bedded concretion of bed 3 in normal position; (c) Septarian concretions of bed 4 in the channel; (d) layer of siderite concretions in the lower strata of the Karadzhhalga Formation (bed 9).

middle—upper part of the NN 2 nannoplankton zone of the upper part of the Aquitanian—Lower Burdigalian and dated to about 22.2–19.1 Ma (de Verteuil, 1997).

Sakaraulian Regional Stage

It was proposed as a horizon by Davitashvili (1933). The stratotype was not designated; according to the name, this is probably the section of the southern slope of the Sakaraulo Hill on the left bank of the Mtkvari River (Kura) opposite the Skra station (Mdzinarishvili, 1954). Indeed, Sakaraulian sandstones crop out here; however, this outcrop is open only incompletely and has unclear lower and upper boundaries and this section has never been described in the literature. Therefore, a section along the Nadarbazevi Gully near the Metekhi Station was proposed as a hypostratotype, based on the description by Kvaliashvili (1970) (*Stratotypes...*, 1975; Voronina et al., 1991). In the stratotype region of the middle reaches of the Mtkvari River, the Sakaraulian Regional Stage is represented by massive coarse-grained sandstones with cross-bedded gravelstones in the lower part and clayey sandstones and siltstones in the upper part, about 200 m thick (Fig. 3). Sakaraulian deposits cropping out here have a gradual facies transition on heavily sanded Maikopian-like clays with jarosite (section along the Nadarbazevi Gully) or with a conglomerate at the base on sandstones of the Uplistsikhe Formation (in the Uplistsikhe section), interbedded with chocolate clays with jarosite. Upstream, they change gradually (or with a conglomerate at the base) for Kozakhurian deposits; Kozakhurian deposits are represented by similar facies, which, however, differ in the appearance of abundant brackish-water fauna.

The Sakaraulian sandstones is characterized by mollusk remains that occasionally occur in the middle and upper parts of the section and are represented by a warm-water, shallow-water assemblage, including large species (*Acanthocardia kuebeckii*, *Glossus maior*, *Pholadomya alpina*, *Chlamys csepreghymezhericsae*, etc.) (Kharatishvili, 1952; Popov et al., 1993). Benthic foraminifers are known only from the clayed—sandy sections of the Sakaraulian Regional Stage in western Georgia (Dzhanelidze, 1970), where they are represented by marine species and genera inherited from the Oligocene, anadromous forms, and numerous endemic species unknown in Ciscaucasia (conclusion by L.S. Ter-Grigor'yants according to our collection materials). Therefore, the correlation of the Sakaraulian of Georgia with the deeper facies of the Upper Maikopian, developed in Ciscaucasia, has remained problematic until recently.

In Ciscaucasia, deposits of the Olginskaya Formation (up to 160–180 m, according to A.S. Stolyarov and E.I. Ivleva, 2006), which are also recognized in the sections of the Maikopian Group by the coarsening of facies and a wider spread of benthic fauna (the

replacement of clays for micaceous silts, which are often bioturbated and have a richer assemblage of benthic foraminifers of the *Caucasinella elongata* Beds), are conditionally assumed to be Sakaraulian equivalents in Ciscaucasia. Some authors correlate the Sakaraulian with the upper half of the Karadzhalga Formation and Olginskaya Formation (Nosovskii and Bogdanowicz, 1980).

The stratotype of the Olginskaya Formation is on the left bank of the Kuban River on the southern outskirts of the village of Kochubeevskaya (former village of Olginskaya, Fig. 2). An impoverished, relatively deep-water fauna of mollusks with *Palliolium incomparabile*, *Nuculana*, *Limatula*, and *Thyasira* was found in this section and in boreholes (Volkova, 1962), which is incomparable with the Sakaraulian assemblage of the stratotype region due to facies differences. On the slopes of the Stavropol Anticline, the malacofauna is richer and includes (along with Oligocene species) new species groups (large *Glossus* (ex gr. *maior*), *Saxolucina*, and *Modiolus*), probably of Mediterranean origin.

Correlation. Based on the similarity of the mollusk composition of the Sakaraulian of Georgia and Eggenburgian Regional Stage (Western Paratethys) (1/3 of species in common according to Popov et al., 1993), these assemblages are considered as stratigraphic equivalents, although their boundaries may not coincide. The Sakaraulian Regional Stage is correlated with the lower half of the Burdigalian through the Eggenburgian.

N.I. Zaporozhets and G.N. Aleksandrova studied dinocysts in the upper part of the Sakaraulian hypostratotype (Nadbazevi). Based on the cooccurrence of *Cousteaudinium aubryae* and *Lingulodinium multivirgatum*, this assemblage can be correlated with *Sumatradinium soucouyantiae* (DN2)—*Cousteaudinium aubryae* (DN3) zones in the dinocyst scale (de Verteuil and Norris, 1996), which are correlated with the NN2 (upper part)—NN4 (lower part) zones of the Upper Aquitanian—Lower Burdigalian according to the Martini scale (1971) based on nannoplankton. The presence of *Trinovantedinium harpagonium* (known from higher beds) in these samples makes it more probable to correlate the upper part of the Sakaraulian Regional Stage only with the Burdigalian.

In the upper greater part of the Karadzhalga Formation and in the Olginskaya Formation and lower part of the Ritsa Formation, which are attributed to the Sakaraulian Regional Stage and lower part of the Kozakhurian Regional Stage (Kuban stratotype), *Hetelaulacacysta campanula*—*Hetelaulacacysta leptalea* Beds, also correlated with the Burdigalian, were established based on dinocysts.

The Lower Miocene deposits of the Mazanderan Province (northern Iran) contain a bivalve assemblage common with that in the Sakaraulian of Georgia (Popov et al., 2015). A nannoplankton association, including the species *Triquetrorhabdulus challengerii*

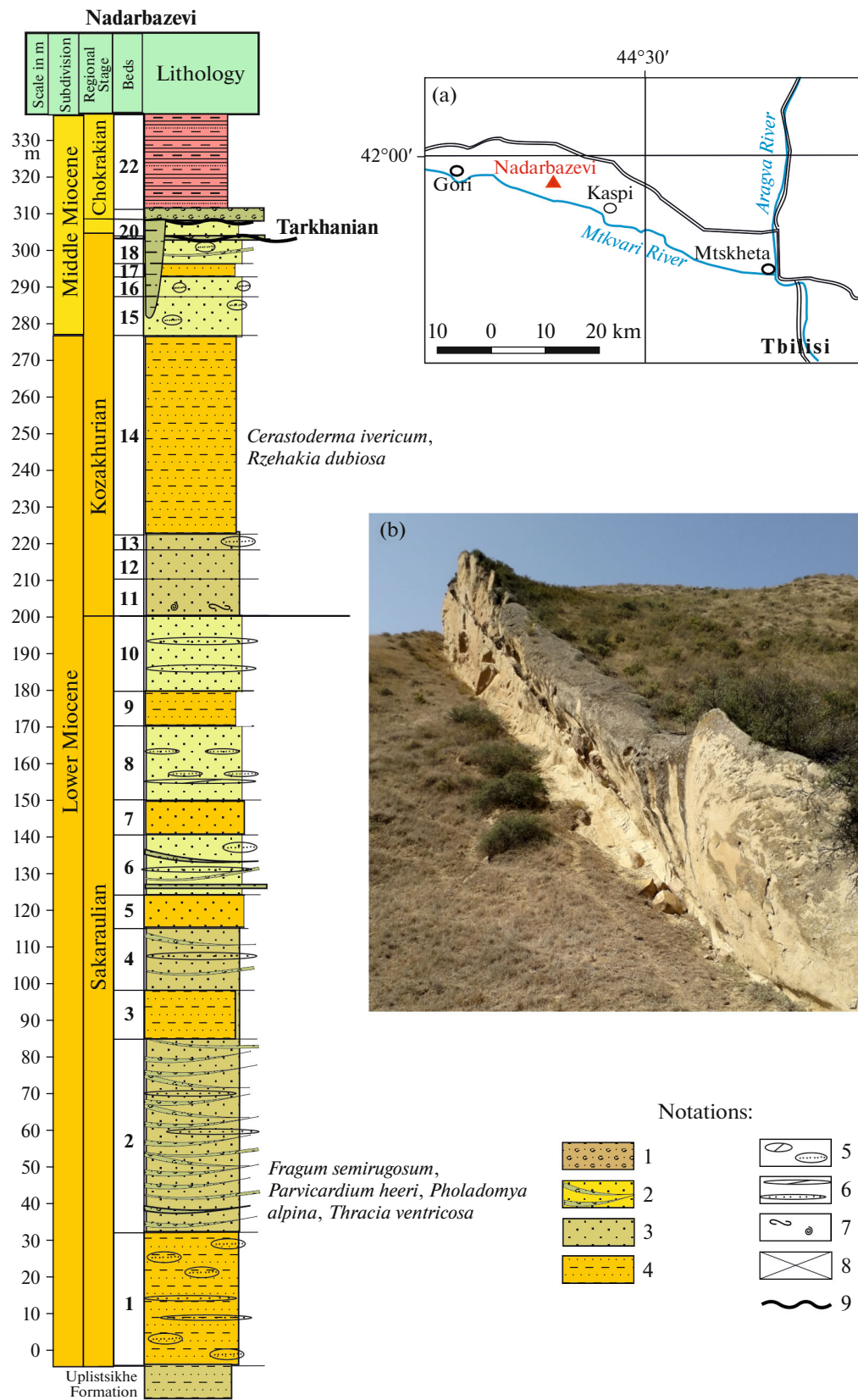


Fig. 3. Hypostratotype section of the Sakaraulian and Kozakhurian regional stages along the Nadarbazevi gully of the Kartli depression in Georgia. (A) geographical location of the section; (B) photograph of the sandstone at the base of Kozakhurian deposits. Notations: (1) conglomerates; (2) cross-bedded sandstones; (3) sandstones; (4) sandy clays; (5) marl and sandstone concretions; (6) lenticular interbeds of marls and sandstones; (7) traces of bioturbation and fauna; (8) stratigraphic breaks; (9) unconformities in the section.

and *Sphenolithus conicus*, was also found in these deposits. The first species has a stratigraphic distribution within the NN1–NN2 zones of the Lower Miocene; in the Central Paratethys, its finds were recorded in the upper part of the Egerian Regional Stage and in the Lower Miocene deposits of the frontal zone of the Ukrainian Outer Carpathians (Andreeva-Grigorovich et al., 2008).

Kozakhurian Regional Stage

The Kozakhurian was also recognized as a horizon by Davitashvili (1933). The section on the left bank of the Mtkvari River was chosen as a lectostratotype on the western outskirts of the town of Kaspi (*Stratotypes...*, 1975) on the slope of the Kozakhuri-Kedi Ridge, described by Kvaliashvili (1962). The continuation of the section along the Nadarbazevi Gully near the Metekhi Station that was chosen as a hypostratotype of the Sakaraulian Regional Stage was proposed as a hypostratotype of the Kozakhurian (Popov and Voronina, 1983). In the stratotype area of the Kartli Depression, the regional stage is represented by massive sandstones with concretions in the lower part and by clayey siltstones with concretions and sandstone interbeds in the upper part (Fig. 3), including a peculiar assemblage of endemic brackish-water mollusks with *Rzehakia* (= *Oncophora*), *Eoprosodacna*, *Limnopappia*, *Congerina*, *Melanopsis*, etc. The malacofauna of the stratotype area does not change significantly along the section and, like to the Sakaraulian Stage, is unique both with respect to the composition of mollusks (Davitashvili, 1934; Kvaliashvili, 1962; Popov, 1983; Popov et al., 1993) and with respect to their preservation. Only a few species of this malacofauna were encountered in western Georgia and Kopetdag foothills (Voronina et al., 1993).

The lower boundary of the regional stage is marked in the stratotype area by the appearance an assemblage of brackish-water mollusks with *Rzehakia dubiosa* in the sections. The upper boundary in deep-water facies is determined by the replacement of dark anoxic facies characteristic of the Maikopian Group for lighter carbonate facies, as well as by the appearance of rich marine foraminifer and mollusk assemblages of the Tarkhanian age. In shallower sections, including the stratotype area, there is a depositional break at the top of the Kozakhurian.

Unlike brackish-water mollusks, dinocysts recorded in the lower and middle parts of the Kozakhurian in the stratotype area are represented by a rather diverse marine assemblage with *Achomosphaera* sp., *Apteodinium* sp., *Batiacasphaera* sp., *Brigantedinium* sp., *Cleistosphaeridium* sp., *Minisphaeridium latirictum*, *Cribroperidinium* sp., *Cribroperidinium tenuitabulatum*, *Dapsilidium* spp., etc.

The tentative correlation of the Kozakhurian Regional Stage with the Ritsa and Zoramakent forma-

tions of Ciscaucasia is based on the appearance of signs of reduced or unstable salinity in the Upper Maikopian sections: a depleted assemblage of foraminifers in *Saccamina zuramakensis* Beds (Bogdanowicz, 1965), determined by the disappearance of secretory species and predominance of Saccaminae; *Batiacasphaera* Beds, determined by dinocysts. In the shallower facies of Primanychye and Ergeni, brackish-water mollusks with *Rzehakia dubiosa* were encountered in the Ritsa Formation.

The stratotype of the Ritsa Formation is on the right bank of the Kuban River on Ritsa Hill near the city of Nevinnomyssk (Central Ciscaucasia), where a series of brown noncalcareous clays with many interbeds of siderite concretions and with an apparent thickness of about 70–80 m is exposed (Fig. 2). The fauna is known from wells: foraminifers were found in the middle part of the formation and are represented by the extremely euryhaline *Saccamina zuramakensis* and *S. ovalis*; however, marine forms also continue to occur along with these species. Mollusks are rare and were found only in shallower facies on the Stavropol uplift (*Rzehakia dubiosa* and *Hydrobia*) (Volkova, 1962) and in Primanychye (Priyutnensky district) (*Rzehakia dubiosa* and, higher up, together with *Nucula* sp. and *Parvicardium*). In Priyutnensky boreholes, layers with *Rzehakia* and *Cerastoderma* alternate with interbeds containing *Nucula* and *Parvicardium*. The marine fauna in these strata is also known from the literature (Liverovskaya, 1938; Prokopov, 1938; data of E.V. Liverovskaya in Grossgeym, 1960). The upper boundary of the formation is defined by the unconformity in the top or in the complete sections by lithology (the appearance of carbonate content) and appearance of pteropods, marine foraminifers, or characteristic forms of marine benthic mollusks.

In Eastern Ciscaucasia, the Zoramakent Formation, also characterized by foraminifers from *Saccamina zuramakensis* Beds and represented by nonsilty clays, is considered an analog of the Ritsa Formation. The ichthyofauna of its upper part (Buinaksky beds) includes *Aeoliscus apscheronicus*, which indicates a higher salinity than the current Black Sea level (Danil'chenko, 1980), with significant conformable Tarkhanian deposits 30–50 m thick (Zhizhchenko, 1953, Table 3). It is quite possible that the Buinak Beds should also be attributed to the Lower Tarkhanian (Goncharova, 1989; *Unifitsirovannaya...*, 2004) if we correlate them with the Kuvinian beds of Western Ciscaucasia.

Correlation. With respect to common species and specific mollusk genera endemic to the Paratethys, the Kozakhurian Regional Stage is correlated with the Upper Ottnangian of the Central Paratethys, where *Rzehakia dubiosa*, *Cerastoderma ivericum*, and *Eoprosodacna kartlica* and the genus *Limnopappia* were recorded in Bavaria, Moravia, Slovakia, and Hungary,

and are also characteristic of the Kozakhurian (Popov and Voronina, 1983).

The presence of *Cousteaudinium aubryae* dinocysts in the middle part of the Kozakhurian in sections of the Kartli depression of Georgia indicates that this interval can be matched with the *Distatodinium paradoxum* (DN4) zone (de Verteuil and Norris, 1996) of the Atlantic coast of the United States, *Cousteaudinium aubryae* zone, and, partly, *Labyrinthodinium truncatum* zone in the Danish part of the North Sea (Dyb-kjær and Piasecki, 2010; Dybkjær et al., 2020), and Cte Zone of the Central Paratethys (Jiménez-Moreno et al., 2006; Bakrač et al., 2012). These dinocyst zones were calibrated with the NN4–NN5 zones (lower strata) by nannoplankton according to the Martini scale (Martini, 1971). Therefore, the age of the middle part of the Kozakhurian is taken as Late Burdigalian–lower part of the Langhian.

Tarkhanian Regional Stage

Stratotype: Cape Tarkhan on the Azov coast of the Kerch Peninsula (Andrusov, 1918; *Stratotypes...*, 1975). The hypostratotype is the section in the Malyi Kamyshlak area, 5.5 km east of the stratotype (Nosovskii et al., 1976, 1978; Goncharova, 1989). The Tarkhanian Regional Stage in this section is represented mainly by a clayey series conformably overlying the Upper Maikopian clays (Fig. 4). It is characterized by a diverse fauna of foraminifers of the *Globigerina tarchanensis* Beds (Bogdanowicz, 1965) and by nannoplankton of the NN5 zone (Andreyeva-Grigorovich and Savitskaya, 2000). The rich mollusk association with *Neopycnodonte navicularis*, *Lentipecten corneus denudatus*, and *Aporrhais pespelecani* indicates marine polyhaline conditions (Nosovskii et al., 1978; Goncharova, 1989; Andreyeva-Grigorovich and Savitskaya, 2000b; Goncharova et al., 2001; Vernigorova et al., 2012).

In the Tarkhanian Regional Stage, the following beds are recognized (from bottom to top): the Kuvinian, Terek (=“Tarkhanian marl”), and Argun Beds. *Kuvinian beds* (Merklin et al., 1964) in the stratotype on the Bolshoy Zelenchuk River (Central Ciscaucasia) are represented by clays varying in thickness from 40 cm to 2 m, which is probably explained by indeterminate boundaries in this section, it does not contain dense Tarkhanian marl. The beds are characterized by the appearance of planktonic and benthic marine fauna and still contain brackish-water relicts (*Rzehakia dubiosa* and *Saccamina zuramakensis*).

Terek beds (Zhizhchenko, 1937; Eastern Ciscaucasia), also referred to as “*Lentipecten corneus denudatus* Beds” or “Tarkhanian marl,” are represented by marl (usually 0.1–0.2 m) or calcareous clays (up to 25 m) and contain the most diverse marine fauna and phytoplankton. *Rzehakia* almost completely disappear at

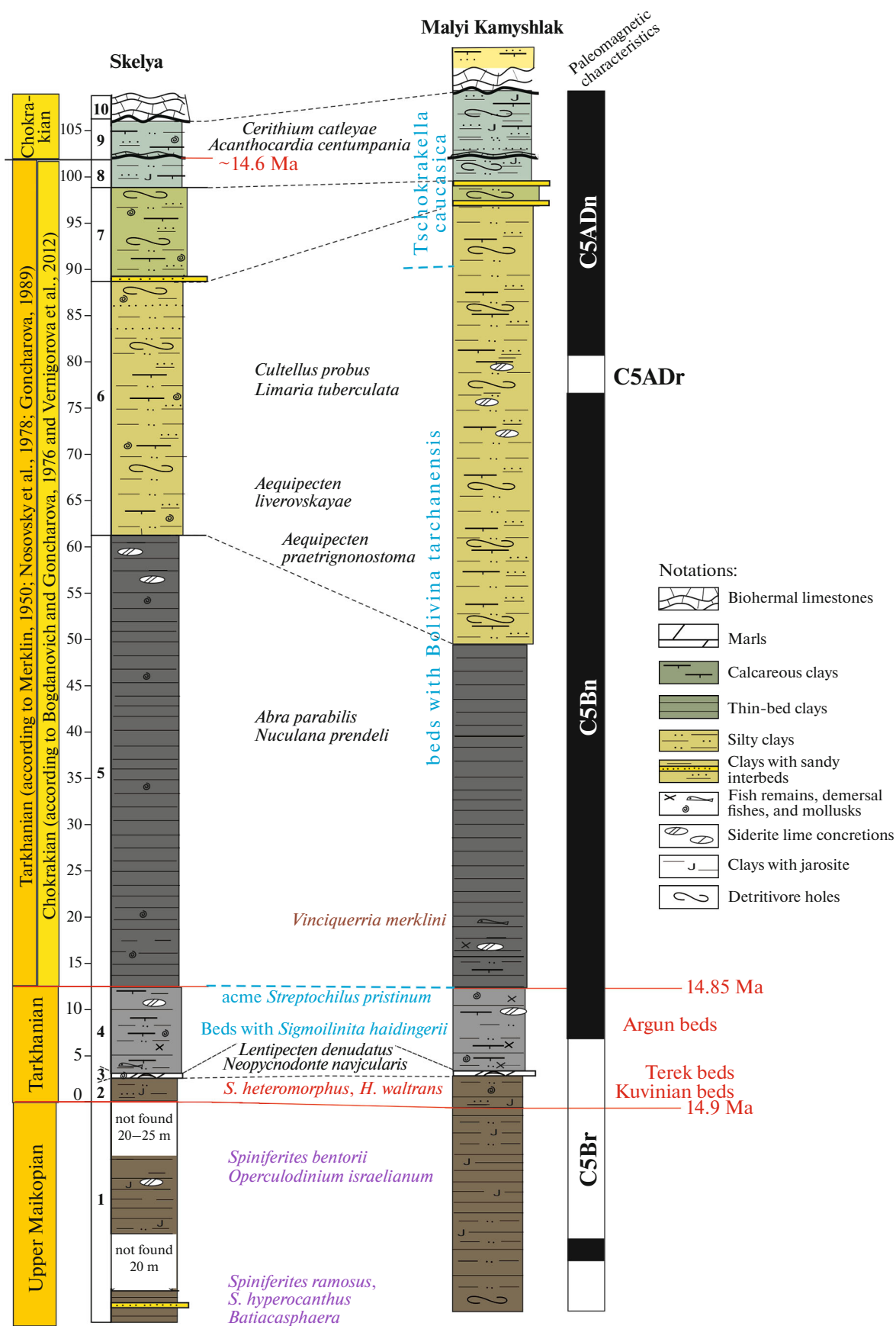
this level, being preserved only in some areas of Georgia.

Argun Beds (Zhizhchenko, 1937; Eastern Ciscaucasia) are represented mainly by clays overlying the “Tarkhanian marl” (Zhizhchenko, 1937; *Unifitsirovannaya...*, 2004) and characterized by pteropods (*Limacina* (= *Spiratella*, *Spirialis*), with some depletion of other groups of marine fauna and nannoplankton. The author of this division analyzed in detail the range and criteria for identifying the Argun layers in his later study (Zhizhchenko, 1940): “... the above-presented material shows that the name of the Argun Beds of the Tarkhanian Horizon should only be understood as a low series with microfauna typical of the Terek Beds, such as *Cristelaria* sp., *Nodosaria* sp., *Virgulina* sp., *Sigmoilina* aff. *tenuis* Cz., *Miliolina* aff. *boueana* Orb., *Textularia tarchanensis* Bogd., and *Globigerina tarchanensis* Subb.” (Zhizhchenko, 1940, p. 92). Subsequently, they were also considered in this range by other foraminiferal specialists (Bogdanowicz and Goncharova, 1976; Konenkova and Bogdanowicz, 1994b; Vernigorova et al., 2012). Thus, Bogdanowicz (Bogdanowicz and Goncharova, 1976) believed that only the lower 10 m of Andrusov’ “*Spirialis* beds” in the hypostratotype, which contain the Tarkhanian fauna of benthic foraminifers, should be attributed to the Tarkhanian (Fig. 4, see Table 3).

However, other researchers fully correlated Argun Beds with “*Spirialis* Beds” (Merklin, 1950; Nosovskii et al., 1976, 1978; Goncharova, 1989) by completely attributing them to the Upper Tarkhanian. This point of view has now been shown to be incorrect by paleomagnetic data, according to which the tops of the “*Spirialis* beds” of the Kamyshlak section correspond to the level of the middle part of the bioherms on the Belaya River (see Fig. 19); i.e., they are obviously proved to be in the Chokrakian regiostage. Therefore, we assume the position of the Tarkhanian/Chokrakian boundary in the hypostratotype based on the change in composition of benthic foraminifers (in the top of bed 4) (Fig. 4). In this case, the Tarkhanian is a very short period and does not exceed 50–100 thousand years.

The Tarkhanian nannofossils are rich and well-studied. The concurrent presence of *Sphenolithus heteromorphus* and *Helicosphaera waltrans* in the richest associations with the absence of *Helicosphaera ampli-aperta* makes it possible to correlate this assemblage with the *Sphenolithus heteromorphus* NN5 zone (Palcu et al., 2017).

An important role in the composition of the microfauna is played by planktonic foraminifers: *Globigerina* (in particular, *G. tarchanensis*), *Turborotalia quinqueloba*, *Globigerinita glutinata*, *G. uvula*, *Tenuitella pseudoedita*, *Globorotalia*, and *Ciperoella*. The assemblage includes about 25 species; almost all of them were identified in the sections of the upper part of the Lower and in Middle Miocene of the Central Para-



tethys as associations with small globigerinids. These assemblages are considered markers of transgressive events and rather cool conditions. In the hypostratotype, the appearance of nannoplankton at the very top of the Kuvinian (=Kamyshlak) Beds was simultaneously accompanied by the appearance of planktonic foraminifers, the distinctive feature of which (according to M.E. Bylinskaya) is a large number of aberrant specimens due to ecological transformations.

Among the stratigraphic species of planktonic foraminifers, single *Orbulina suturalis*, *Globorotalia peripheroronda*, and *G. scitula* were encountered in the Tarkhanian Regional Stage of Ciscaucasia (Golovina and Bylinskaya, 2020). They were found in a section along the Pshekha River, and their composition indicates that they belong to the **M6 *Orbulina suturalis* Zone** according to the scale of Wade et al. (2011) and that their age is older than the Middle Langhian (from 15.1 to about 14 Ma).

Among benthic foraminifers, the common representatives along with euryhaline families were polyhaline nodosariids and textulariids. The most widespread species are members of the orders *Miliolida*, *Lagenida*, and *Rotaliida*, which amount to about 90% of the total association. With respect to the composition of benthic foraminifers, the lower part of “*Spiralis* Beds” (8–10 m), where some of polyhaline Tarkhanian species are still preserved, belongs to ***Sigmoilinita haidingerii* Beds** of the Upper Tarkhanian.

An additional marker of the upper boundary of the Tarkhanian can be the flourishing of planktonic foraminifers *Streptochilus pristinum* in the association, which was established by M.E. Bylinskaya in the hypostratotype in the lower part of “*Spiralis* Clays” (about 7.5 m above the top of Tarkhanian Marl). The species *S. pristinum* is known from different regions of the World Ocean from the Upper Oligocene to the Middle Miocene inclusive, including sections of the Central Paratethys (Beldean et al., 2013).

Based on mollusks, the boundary with the Chokrakian Regional Stage is marked by the beginning of the dominance of endemic Paratethyan species; therefore, it is recorded only in facies rich in mollusks. Changes in lithology are also typical for them: an increased sandy content and the appearance of bioherms and sedimentation breaks. These boundaries become indefinable in the deep-water sections of the West Kuban and Taman troughs in Eastern Ciscaucasia: within the Tarkhanian and even Chokrakian, noncalcareous clays of the Maikopian type can be preserved here almost without fauna.

Correlation. The attribution of the Tarkhanian to the **M6 *Orbulina suturalis* Zone** according to plank-

tonic foraminifers and to the **NN5 *Sphenolithus heteromorphus* Zone** according to nannoplankton suggests its correlation with the upper half of the Lower Badenian (taking into account its binary division) of the Central Paratethys and with the second half of the Langhian of the Mediterranean. Judging from the cooccurrence of the species *Orbulina suturalis*, *Globorotalia peripheroronda*, and *G. scitula* among planktonic foraminifers (Pshekha River), the age of the Tarkhanian containing this assemblage is dated from 15.1 to 14 Ma.

According to paleomagnetic data, which interpretation is based on these biostratigraphic determinations, the base of the Tarkhanian corresponds to short normal polarity subchron C5Bn.1n or descends slightly lower to subchron C5Bn.1r and is dated to 14.85–14.9 Ma (Palcu et al., 2017), while the Chokrakian base determined by the appearance of Chokrakian endemics in benthic foraminifers in the Malyi Kamyshlak and Skelya sections corresponds to about 14.8–14.85 Ma (see Fig. 19).

These dates of the lower boundary of the Tarkhanian Regional Stage based on nannoplankton, planktonic foraminifers, and paleomagnetic data show its correlation with the Middle Langhian of the Mediterranean. Therefore, a significant part of the Upper Maikopian should be correlated with the Lower Langhian and dated to the Middle Miocene. At the same time, paleomagnetic data show that the lithological transition from Maikopian noncalcareous clays with jarosite to carbonate facies characterized by fauna and nannoplankton is not strictly synchronous and was probably determined by bathymetry and currents. Among the studied sections, this boundary occupies the lowest position in the section of the Intsra River in western Georgia, where the entire lower part of the Tarkhanian, characterized by malacofauna (about 50 m), is negatively magnetized. This is followed by the Malyi Kamyshlak and Skelya sections of the Kerch Peninsula, where the lower boundary is marked within the reverse polarity zone, while it is in the normal polarity zone in the Ciscaucasian sections (Pshekha and Belaya rivers) (see Fig. 19).

Chokrakian Regional Stage

Stratotype: section on the eastern shore of the Lake Chokrak (Kerch Peninsula, Andrusov, 1884), where only the lower strata of the Chokrakian are exposed (with an apparent thickness of 9 m). The more complete sections closest to this stratotype are outcrops of the Bulganak anticline, the western flank of which (Malyi Kamyshlak) is proposed as a hypostratotype of the Chokrakian Regional Stage (Goncharova, 1989).

←
Fig. 4. Scheme of correlation of the Malyi Kamyshlak and Skelya sections in the Tarkhanian and lower strata of the Chokrakian regional stages of the Bulganak syncline on the Kerch Peninsula and their biotic and paleomagnetic characteristics (according to Palcu et al., 2019a with supplements).

Here, Chokrakian deposits conformably overlie the Upper Tarkhanian deposits. The Lower Chokrakian deposits are represented by the upper (greater) part of the “*Spirialis* beds” (85 m) and sandy-bioherm series with rich malacofauna (60 m). The latter is currently disturbed by landslides. Upper Chokrakian sediments are composed of clays interbedded with marls (30 m) and characterized by extremely impoverished assemblages of mollusks with *Davidaschvilia intermedia*. The boundary between the Chokrakian and Karaganian regional stages is not exposed. This outcrop, as well as the Skelya section of the southeastern flank of the anticline (Merklin, 1950; Vernigorova et al., 2012), clearly demonstrate the problems of determination of the Tarkhanian/Chokrakian boundary (Fig. 4), as opposed to most of the other sections, due to the transgressive deposition of the Chokrakian and erosion in its base (see above).

Based on mollusks, the Chokrakian Regional Stage is divided into the Lower (Zyukian) and Upper (Brykian) substages. The Lower Chokrakian is characterized by a depleted marine fauna (compared to the Tarkhanian marine fauna), in which the endemic species of the Eastern Paratethys (*Anadara bosporana*, *Aequipecten varnensis*, *Angulus fuchsi*, *Pitar laskarevi*, *Eurypocardium pseudomulticostatum*, *Acanthocardia centumpania*, *Parvicardium kubanicum*, *Cerastoderma bogachevi*, *Mactra bajarunasi*, *Ervilia praepodolica*, and *Cerithium cattleyae*) became dominant (Goncharova, 1989; Goncharova et al., 2002). The Upper Chokrakian is characterized by a sharp depletion of fauna, which is entirely endemic. The number of bivalve species decreased to six (the most common among them are *Davidaschvilia intermedia*, *Ervilia praepodolica*, and *Donax tarchanensis*); gastropods rarely occur here (Goncharova, 1989).

Based on benthic foraminifers, Bogdanowicz (1965) divided the Chokrakian into three parts. The lower ***Bolivina tarchanensis* Beds** have a limited distribution and were encountered only in troughs. The middle ***Tschokrakella caucasica* Beds** correspond to the maximum level of the Chokrakian transgression and are most widespread. The assemblages were dominated by miliolids (mainly *Chokrakella*) and nonionids. At the end of the Chokrakian, a decrease in water salinity led to the appearance of small fauna of ***Florilus* (=Nonion) parvus Beds** (Bogdanowicz, 1965; Bogdanowicz, 1971), represented by a depleted assemblage of discorbids, elphidiids, and nonionids.

The calcareous nannofossils of the Lower (Middle) Chokrakian can be quite abundant; however, the association includes several eurybiont species with a wide stratigraphic range.

The upper strata of the Lower Chokrakian are characterized by the Belomechet assemblage of mammals (Central Ciscaucasia, Belomechetskaya village), assigned by L.K. Gabuniya and O.G. Bendukidze to the MN5 zone in the Main scale, to the MN6 zone by

A.K. Agadzhanyan (*Neogenovaya sistema*, 1986), and to the upper strata of the MN5 zone—lower strata of the MN6 zone by A.V. Lopatin (Nevesskaya et al., 2004).

We consider the sections of the Belaya and Pshekha rivers in Western Ciscaucasia as the most representative reference sections for the Chokrakian (see Fig. 19); these sections were used as a basis for paleomagnetic data (Palcu et al., 2017). In Central Ciscaucasia, these are the Yaman-Dzhalga gully section, several km from Belomechetskaya settlement (upstream the Kuban River), where a rich assemblage of vertebrates was found (Neogenovaya sistema, 1986), and the section of the Bolshoy Zelenchuk River.

Correlation. According to paleomagnetic data, the base of the Chokrakian Regional Stage in the stratotype section and reference sections of Western Ciscaucasia (Belaya and Pshekha rivers) lies inside or near the top of normal polarity subchron C5Bn.1n and is therefore dated to 14.8 Ma. The boundary of the Upper and Lower Chokrakian substages is faunistically well dated in the Belaya River section in Western Ciscaucasia (to about 14.2 Ma) and lies in the upper part of chron C5ADn. The top of the regional stage was determined within chron C5ACn and is dated to 13.8–13.9 Ma (see Fig. 19). The Belomechetskaya assemblage of mammals, which characterizes the upper part of the Lower Chokrakian, belongs to the upper part of the MN5 zone—lower part of the MN6 zone, which (similarly to paleomagnetic data) helps to correlate the Chokrakian with the upper part of the Lower Badenian of the Central Paratethys and date it to the Langhian.

Karaganian Regional Stage

Lectostratotype: a section of the Uiratam area, Mangyshlak Peninsula, Kazakhstan (Andrusov, 1917a; *Stratotypes...*, 1975).

Here, the Karaganian sediments that contain a mollusk assemblage with *Davidaschvilia (Zhgentiana) gentilis*¹ transgressively overlie the Oligocene and are represented only by the Lower Karaganian (Fig. 5).

Above, there are unconformable Kartvelian (Pholadidae) beds containing an assemblage of mollusks with *Barnea*, which we (following Andrusov, 1917a and other (see below)) attribute to the Konkian Regional Stage. The latter are unconformably overlain by the Sarmatian with washed Konkian fauna.

In deeper sections, the Karaganian Regional Stage conformably overlies the Chokrakian Regional Stage, is often represented by the same facies, and is recognized only according to paleontological data: by the appearance of an extremely impoverished endemic fauna with mollusks *Davidaschvilia (Zhgentiana)* and

¹ See the discussion of the taxonomy of this species in the section “Mollusks.”

Mohrensternia and benthic foraminifers from ***Discorbis urupensis* Beds** and characteristic small-sized *Discorbis urupensis*, *Cassidulina*, *Nonion*, etc.

Based on mollusks, the deposits of the Karaganian Regional Stage are divided into two parts.

The lower part of the regional stage (Arkhashenian Beds, Zhgenti, 1991, eastern Georgia) is characterized by a sharp dominance of *D. (Zhgentiana) gentilis*. The upper part (Varna Beds, Zhgenti, 1961, northeastern Bulgaria) is characterized by the appearance of a new endemic, *Savanella andrussovi*, and sometimes by the short-term appearance of more polyhaline elements, which can also be reflected in the composition of foraminifers (see sections “Mollusks” and “Benthic Foraminifers”).

A section of the Zelensky Hill on the Taman Peninsula (Popov et al., 2016) and the Belaya River section above the village of Tulsy, for which detailed paleomagnetic data are available, are proposed as reference sections for the Karaganian Regional Stage (Palcu et al., 2017).

Correlation. According to paleomagnetic data, the base of the Karaganian Regional Stage in the reference sections of the Taman Peninsula (Zelensky Hill) and Western Ciscaucasia (Belaya and Pshekha rivers) is within normal polarity chron C5ACn and is dated to 13.8–13.9 Ma; the base of the Upper Karaganian with *Savanella andrussovi* is in the middle of chron C5ABn and is dated to about 13.5 Ma and the base of the Kartvelian beds of the Konkian Regional Stage was determined in the upper part of the same chron or within the following reversed polarity chron C5AAr and was dated to 13.3–13.4 Ma (see Fig. 19). Therefore, these data show a fairly accurate correspondence of the Karaganian deposits s.str. to the Wieliczka in the middle of the Badenian Regional Stage of the Central Paratethys (Palcu et al., 2017) and are dated to the lower part of the Seravallian of the Mediterranean.

Konkian Regional Stage

N.I. Andrusov considered the “*Venus konkensis* Beds”, described from the Zaporozhye Region in Ukraine, on the Konka River near the village of Vesylyanka, as a stratotype of the Konkian Regional Stage (Andrusov, 1917a). This section and mollusk fauna were described in detail in the classic work by N.A. Sokolov (1899; see the modern interpretation of the composition of mollusks and comments on the age of deposits in Goncharova and Golovina, 2007).

At that time, the Dnieper River, into which the Konka River flows, had not yet been backed by a dam and the left bank of the river, 2 km above the village of

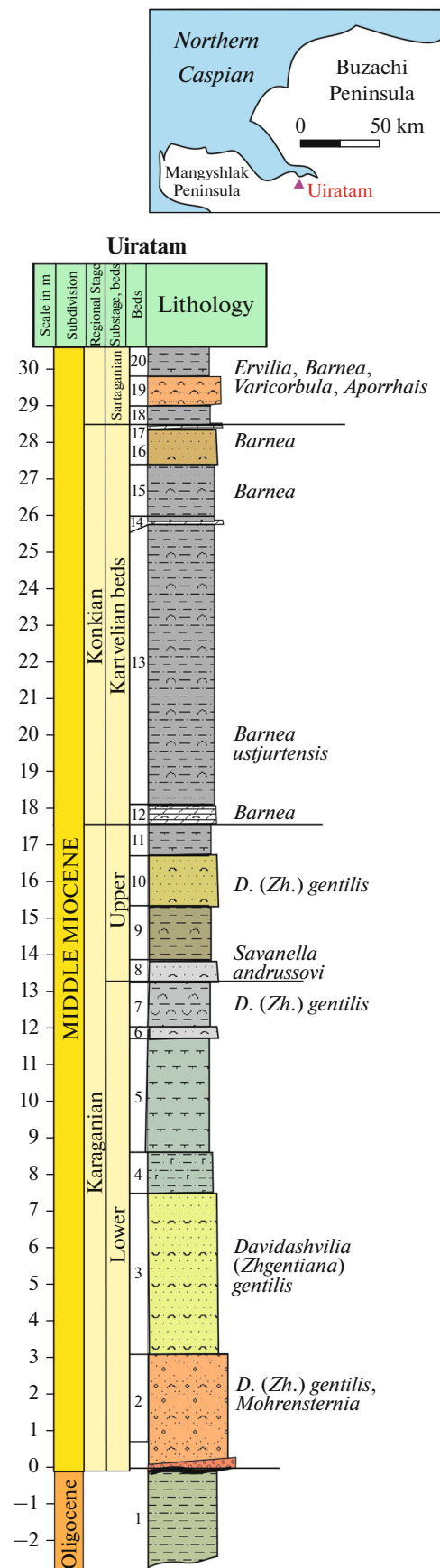


Fig. 5. Scheme of location and section of the Uiratam area in northern Mangyshlak; lectostratotype of the Karaganian Regional Stage.

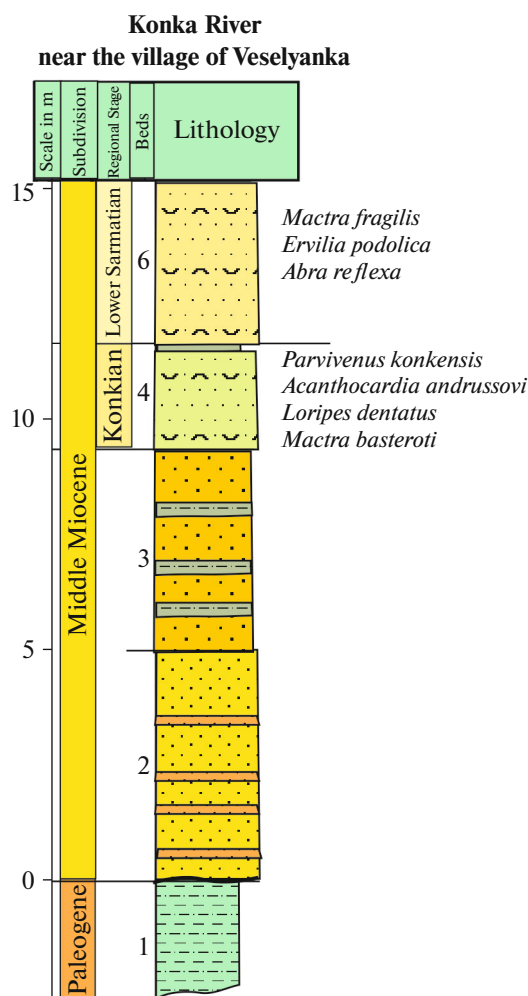


Fig. 6. Scheme of the stratotype of the Konkian Regional Stage on the Konka River near the village of Veselyanka, Ukraine. The beds are given according to Sokolov, 1899.

Veselyanka, was a 15 m cliff, the photo of which was published by Sokolov in 1899. When we visited this section in 2012, the entire slope except its upper Sarmatian part was covered with a thick deluvium (0.3–0.5 m). Nevertheless, we were able to expose the deluvium and see all the beds described by Sokolov except lower bed 1 and collect fossil mollusks and take samples for microfaunal analysis. The beds and thicknesses of this section (Fig. 6) are given according to Sokolov's data, since their boundaries remained unexposed both by us and our predecessors (Barg et al., 2005). Sokolov assigned only the deposits of Bed 4 of this outcrop to “*Venus konkensis* Beds.” However, Barg et al. (2005) reported that they also found Konkian fauna in Bed 2 (Bed 6 in their description of the section), represented mainly by mollusks and, to a certain extent, by foraminifers. We also found Konkian fauna at this level; however, we were always convinced that it might have been moved here along the slope from the overlying beds, rather than being here in situ.

The redeposition of the fauna into these beds was also described by Sokolov; therefore, we also believe that only Bed 4 belongs to the Konkian Regional Stage. Following R.L. Merklin (1953), we consider this bed as a stratotype specifically for the Veselyanka Beds recognized by Merklin. The presence of the mollusk *Acanthocardia andrussovi* is particularly indicative in Bed 4 (a species specific to this bed). In addition, we share the opinion of Goncharova and Golovina (2007) on the redeposition of the most polyhaline elements of the fauna, which are unknown in the Veselyanka beds of other localities and from Sartaganian beds and are absent in the outcrop (among mollusks, these are *Dosinia exoleta*, *Aequipecten diaphanus*, *Hadriania boeckii* (= *Murex* cf. *craticulatus* in Sokolov, according to L.B. Il'ina).

A three-member division of the Konkian Regional Stage is recognized in its more complete sections in Ciscaucasia and on the Taman Peninsula:

(1) Lower Kartvelian Beds (Davitashvili, 1930), characterized by mollusks *Barnea* and *Ervilia*, sometimes with *Davidaschvilia* (*Zhgentiana*) *gentilis* and a number of Mediterranean migrants (*Callista*, *Gafrarium*, *Clausinella*, *Eastonia*, *Alaba*, and *Hadriania* among mollusks, *Bulimina* and *Dendritina* among foraminifers, and single nannoplankton). Recall that Andrusov (1917a) assigned the Pholadidae Beds to the Konkian Bed and this opinion was shared by many authors (Merklin, 1953; Barg, 1993; Vernigorova et al., 2012; etc.). Other researchers included them in the Karaganian, which was accepted in the volume of the Neogene System (*Neogenovaya Sistema*, 1986) and approved scheme of the Neogene (*Unifitsirovannaya...*, 2004). N.M. Zhgenti (1991) proposed to consider the Kartvelian Beds as an independent regional stage with a stratotype on the Khobistskali River near the village of Mukhuri (western Georgia). This suggestion was supported by O.I. Dzhanlidze (1970) and L.B. Il'ina (2000b). There are sediments with a relatively stenohaline marine fauna of mollusks in the most complete sections at the base of the Kartvelian beds (Turkmenian beds, M.M. Sudo, 1961). A particularly rich malacofauna at this level was found by Merklin in the West Ustyurt section in the Ashchiktaipak area. The presence of diverse polyhaline fauna (including Konkian endemics *Acanthocardia andrussovi* in the Ashchiktaipak area and *Cerastoderma praeplicatum* in the section of the Belaya River) in these beds and typical Konkian microfauna and nannoplankton in the “Barnean beds” of the Belaya River (Golovina et al., 2009 and this paper) and deeper analogs of Kartvelian beds in the sections of the Taman Peninsula (Vernigorova et al., 2006; Popov et al., 2016), make it reasonable to return to the original ideas of Andrusov and consider the Kartvelian Beds as the lower subdivision of the Konkian Regional Stage;

(2) the middle part (Sartaganian Beds) (Andrusov, 1917a) contains the richest assemblages of polyhaline

mollusks (*Glycymeris*, *Arca*, *Anadara*, *Chlamys*, *Europicardium*, *Parvicardium*, *Glans*, *Callista*, *Diloma*, *Alvania*, *Onoba*, *Spiratella*, etc.) and foraminifers from ***Adelosina konkensis* and *Elphidium horridum* Beds** (Bogdanowicz, 1965), in which buliminids, peneropliids, miliolids, nonionids, elphidiids, globigerinids, etc. are common; it also contains reach assemblages of nannoplankton with the polyhaline genera *Discoaster* and *Rhabdosphaera* from the undivided NN6–NN7 zones; and

(3) the upper part (Veselyanka beds) (Merklin, 1953) with poorer euryhaline marine fauna and specific endemics.

However, levels with a richer fauna are also recorded even in these upper beds, which reflect the unstable connection of the basin with the open seas (Eberzin, 1960; Bidzinashvili, 1974; Iljina, 1993, 2000b).

The reference sections of the Konkian Regional Stage can be the section of the Zelensky Hill on the Taman Peninsula; section of the Maikopian (Podvesnaya) Gully in the basin of the Belaya River near the Tulsky settlement (see Fig. 19), and the section of the Gilyandy ravine in the northwestern part of the Ustyurt Cliff, Kazakhstan. Data on the first and second sections are most complete: phytoplankton and macro- and microfauna were studied and their paleomagnetic characteristics were obtained based on these data (Popov et al., 2016; Palcu et al., 2017).

Correlation. The richest nannofossil assemblages of the Konkian Regional Stage are correlated with the undivided assemblage of **NN6 *Discoaster exilis*–NN7 *Discoaster kugleri* zones** of Martini (1971). According to these data, the Konkian Regional Stage is correlated with the Upper Badenian (Kosovian) and part of the Serravallian.

According to the paleomagnetic data based on the obtained sequence of chrons and nannoplankton zonality, the lower boundary of the Kartvelian beds in the most fully studied section of the Zelensky Hill lies in the upper part of normal polarity chron C5ABn and is dated to 13.4 Ma (Palcu et al., 2017). The top of these beds almost completely coincides with the boundary of subchrons C5Ar.2n and C5Ar.3r and is dated to 12.9 Ma and the top of the Veselyanka beds of the Konkian lies in reversed polarity subchron C5Ar.1r and is dated to 12.65 Ma according to D. Palcu (Palcu et al., 2015) (see Fig. 19). Therefore, the Konkian Regional Stage of the Eastern Paratethys in the Mediterranean region corresponds to the middle part of the Serravallian and shows a fairly accurate correspondence of the Kartvelian, Sartaganian, and Veselyanka Beds to the Upper Badenian (Kosovian) of the Central Paratethys (Palcu et al., 2017).

Sarmatian Regional Stage

The name Sarmatian Stage was first published by E. Suess (1866), but with reference to the authorship of N.P. Barbot de Marni. The Sarmatian Regional Stage is divided into three substages (Andrussow, 1899; Simionescu, 1903): the Lower (Volhynian), Middle (Bessarabian), and Upper (Khersonian) substages, which, in turn, can be subdivided into beds in shallow-water facies based on bivalves.

The lectostratotype of the regional stage was chosen by Paramonova and Belokrys (1972) from the localities described by Barbot de Marny (1869); it includes all the three substages and is located southwest of the city of Krivoy Rog (Ukraine). The lower substage is exposed on the left bank of the Ingulets River near the village of Shirokoe, and the middle and upper substages are exposed on the right bank of the Ingulets River in the overburden of the quarry of the Ingulets Mining and Processing Plant (INGOK) (about 5 km southwest of the village of Shirokoe). All the three subdivisions are represented by shallow-water sandy-shell-detrital facies with numerous erosions (Fig. 7). Sarmatian deposits with erosion occur in the Paleogene and are also unconformably overlain by Maeotian deposits.

Lower (Volhynian) Substage. The shallow-water facies of the Lower Sarmatian are characterized by mollusks *Plicatiformes praeplicata*, *P. plicata plicata*, *Obsoletiformes lithopodolica ruthenica*, *Obsoletiformes obsoleta*, *Ervilia*, *Mactra eichwaldi*, and *Polittitapes vitaliana* and its deeper facies are characterized by the presence of *Abra*, *Mactra andrussovi*, and species of the genus *Replidacna*. Benthic foraminifers are represented by assemblage of the *Miliolinella reussi* Beds (Bogdanowicz, 1971), which are characterized by abundant miliolid forms with a low species diversity.

The middle (**Bessarabian**) Substage is characterized by flourishing of endemic fauna. The shallow-water deposits of the lower part of the substage (Novomoskovsk beds) are characterized by the presence of bivalve mollusks *Plicatiformes plicata plicatofitoni*, *Mactra vitaliana*, and *Polittitapes ponderosa* and coeval deeper deposits (“*Cryptomactra* clays”) contain *Cryptomactra pesanseris*, *Mactra urupica*, and *Inaequicostates barboti*. The rich, endemic Middle Sarmatian assemblage of foraminifers corresponds to ***Dogielina sarmatica* Beds** (Bogdanowicz, 1971).

The shallow-water facies of the upper (Dnepropetrovsk-Vasilievsky) beds are characterized by the presence of *Plicatiformes fittoni*, *Mactra fabreana*, and *Polittitapes crenelata*, different *Obsoletiformes* species, and various trochids and nassariids among gastropods. The regional shallowing of the basin and change of “*Cryptomactra* clays” to sandy facies with a characteristic Middle Sarmatian mollusk fauna including large mactras and sparsely ribbed cardiids, are dated to this period in Ciscaucasia.

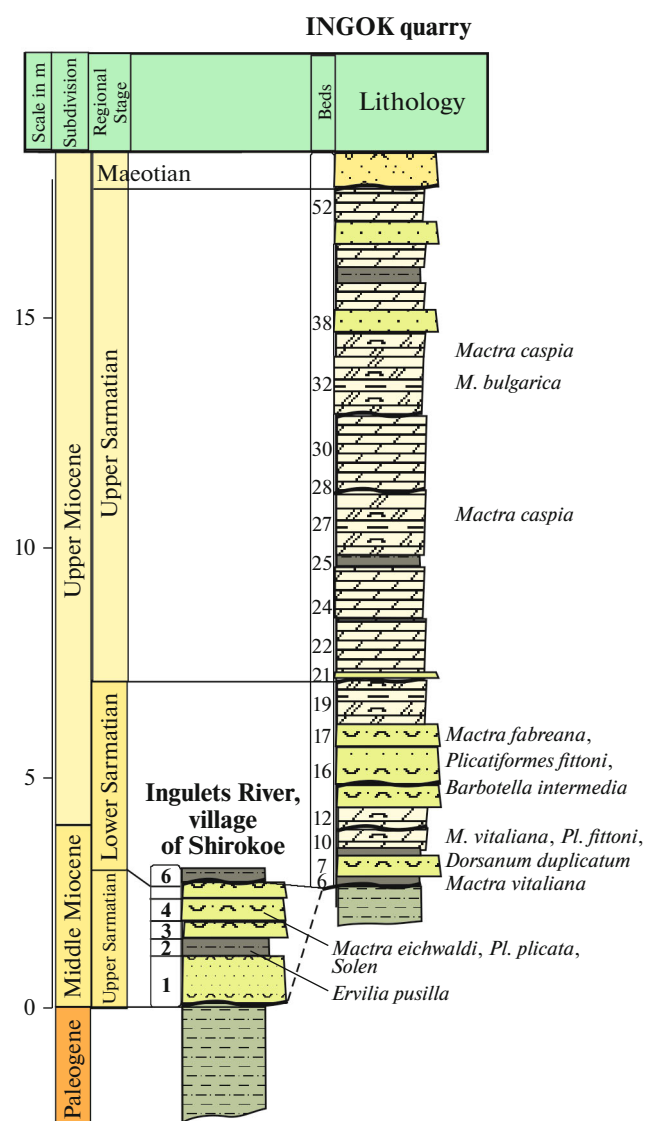


Fig. 7. Scheme of the structure of the lectostratotype of the Sarmatian Regional Stage on the Ingulets River, Ukraine (according to Paramonova and Belokrys, 1972; *Stratotypes...*, 1975).

The endemic composition of the fauna indicates a low-salinity semi-marine Sarmatian basin. However, a limited connection with the eastern Mediterranean probably existed in Transcaucasia in the Early and Middle Sarmatian, which provided access for marine phytoplankton to the southern Caspian part of the basin and enriched the benthic fauna of Transcaucasia and Iran with marine species (Kolesnikov, 1940; Popov et al., 2015). Occasional occurrence of nannoplankton are also known in the Lower–Middle Sarmatian in the Taman part of the basin (*Paleontology...*, 2016; see also the chapter “Nannoplankton”).

The upper (**Khersonian**) substage is characterized by a sharply depleted assemblage of mollusks, consisting of species of the subgenus *Mactra* (*Chersonimac-*

tra). Foraminiferal assemblages correspond to the ***Quinqueloculina consobrina* Beds** (Bogdanowicz, 1965; Bogdanowicz, 1971) and a few species of *Quinqueloculina*, *Elpidium*, *Spiroloculina*, *Sarmatella*, *Articulina*, and *Protoelphidium*. The Late Sarmatian water body was considered completely enclosed; however, the study of the diatom compositions in the sections of the Taman Peninsula (Radionova et al., 2012; Popov et al., 2016) showed that seawater ingressions with the invasion of oceanic species also continued at the end of this period.

The most complete reference section is an outcrop near Cape Panagia of the Taman Peninsula (Popov et al., 2016). The thickness of the regional stage is up to 700–750 m.

Correlation. According to paleomagnetic data, the base of the Sarmatian Regional Stage is dated at 12.65 Ma (Palcu et al., 2015, 2017). Most of the Middle Sarmatian corresponds to a normal polarity zone, which is interpreted as chron C5n. However, the position of the lower boundary of the Middle Sarmatian (Bessarabian Substage) has so far been determined only approximately at the level of about 12 Ma. The boundary between the Middle and Upper Sarmatian (Bessarabian/Khersonian) substages in the Panagia section (see Fig. 20) lies in reversed polarity chron C4Ar and is dated to 9.6 Ma (Palcu et al., 2021).

The appearance of zonal and stratigraphically important oceanic diatom species (*Thalassiosira burckliana* (LO-7.9 Ma) and *Th. grunowii* (LO-7.8 Ma) in the second half of the Upper Sarmatian and *Th. antiqua* in the later period (FO-7.7 Ma) suggests that the age of the upper strata of the Late Sarmatian is not older than 7.6–7.7 Ma (Radionova et al., 2012).

Paleomagnetic data on the age of the Sarmatian/Maeotian boundary are conflicting. Regressive events with several levels of unconformities, interrupted by pulses of sea water input, at the end of the Late Sarmatian are clearly visible even in the facies of the open basin with stable sedimentation on the southern coast of the Taman Peninsula. At the same time, the dates of the end of the regression and beginning of marine sedimentation conditions do not coincide even in the adjacent sections of the Taman Peninsula (Panagia and Popov Kamen) and fall into the intervals of normal and reversed polarity in the upper part of chron C4Ar (Pilipenko and Trubikhin, 2014; Palcu et al., 2021). There are the same problems in dating the Dacian Basin (see Fig. 20). According to these data, the age and position of this boundary in the most complete sections can be estimated at about 7.6–7.7 Ma.

Maeotian Regional Stage

The author of the stage (Andrusov, 1890) did not designate the stratotype; however, he substantiated its recognition in the sections of the Kerch Peninsula. A section near Cape Akburun on the Kerch Strait coast

to the south of the city of Kerch, near the town of Arshintsevo (*Stratotypes...*, 1975), where the Maeotian Regional Stage is represented by two substages in shallow-water facies of detrital limestones, shell rocks, and clays, was proposed as a lectostratotype (Fig. 8).

Maeotian and Lower Pontian deposits are exposed here on the northern flank of the Kamysh-Burun Syncline. The lower boundary of Maeotian deposits is defined by the appearance of euryhaline fauna of marine origin. The boundary is usually sharp and characterized by unconformity, erosion, and lithological and faunal changes, since the end of the Sarmatian corresponds to a significant fall of sea level in the Paratethys (about 200–300 m, Tugolesov et al., 1985; Popov et al., 2010). The upper boundary in the continuous series of sediments is marked by the first appearance of brackish-water cardiiids and ostracods, which are characteristic of Pontian deposits.

The Maeotian Stage is subdivided into two substages.

The Lower **Bagerovian** Substage (Karlov, 1937, Crimea) is characterized mainly by endemic mollusk species of marine Mediterranean origin genera: bivalves *Dosinia*, *Mytilaster*, *Politiitapes*, and *Abra* and gastropods *Rissoa*, *Mohrensternia*, *Potamides*, and *Bitium*. Foraminifers are also represented by an assemblage with euryhaline genera: *Quinqueloculina*, *Elphidium*, *Articulina*, *Discorbis*, etc., assigned to ***Quinqueloculina seminulum maeotica* Beds** (Bogdanowicz, 1971).

Diatoms are represented by several associations included in the *Thalassiosira maeotica* and *Cymatosira savchenkoi* zones (data of E.P. Radionova and T.M. Kozыrenko in *Paleontology...*, 2016) and are composed of both brackish-water and marine groups. The composition of the benthic fauna and phytoplankton indicates a semi-marine pattern of the Maeotian basin, and finds of oceanic zonal forms of diatoms and fairly polyhaline taxa of ostracods, planktonic and benthic foraminifers, and mollusks at some levels (Iljina, 1980; Arevadze, 1987; Popov et al., 2016) indicate short-term connections of both the Early and Late Maeotian basins with fully saline marine water bodies.

The Upper **Akmanian** Substage (recognized in the same place) is characterized by a brackish-water assemblage of malacofauna, in which marine elements are rare. There are many freshwater forms among ostracods, while the composition of foraminifers is very depleted. However, relatively polyhaline mollusks and foraminifers, as well as abundant assemblage of nannoflora, dominated by *Braarudosphaera bigelowii*, and diatoms with oceanic forms, were found among brackish-water species in some localities (Taman Peninsula, Kerch Peninsula, and western Georgia), which again indicates permanent connections with open sea waters and, probably, a sharply stratified water mass (Popov et al., 2016).

The thickness of the regional stage is up to 300–450 m (in the Taman and West Kuban troughs).

Outcrops of the Taman Peninsula are proposed as a reference section of the Maeotian Regional Stage: Popov Kamen and Zhelezny Rog; the latter differs in deeper water facies and a continuous transition to the Pontian (Popov et al., 2016).

Correlation. According to paleomagnetic data, the base of the Maeotian is distinctly diachronous and was determined by the time of filling of the regressed basin. The boundary lies in the intervals of both normal and reverse polarity and is dated from 7.65 to 7.4 Ma. The oldest dates of the beginning of the transgression were established in the deeper western part of the Dacian basin and in the Panagia section of the Taman trough, where they correspond to chron C4n.1r and are therefore dated to 7.65 Ma, which makes it possible to correlate it with the Early Maesianian according to the International Stratigraphic Chart. According to biotic and paleomagnetic data, the boundary between the Lower and Upper Maeotian substages is close to the boundary of chrons C3Ar/C3An (Filippova and Trubikhin, 2009; Palcu et al., 2019b) and is dated to 6.75 Ma and the top of the Maeotian is in the upper part of chron C3An and dated to 6.1 Ma (see Fig. 20).

Pontian Regional Stage

The stratotype section of the Pontian Regional Stage in the city of Odessa (Ukraine), analyzed in most detail by the author (Barbot de Marny, 1869), was covered by the Potemkin Stairs back in 1837. The lectostratotype (near the Lanzheron beach in Odessa (Ukraine) (*Stratotypes...*, 1975) is represented only by the Lower (Novorossian) Substage in shallow-water, calcareous–detrital facies (Fig. 8) and characterized by a highly endemic brackish-water fauna with freshwater species at the base.

Since the presence of exposure was doubtful within the limits of the city of Odessa (*Stratotypes...*, 1975), the Kamysh-Burun section to the south of the city of Kerch, which is a continuation of the Maeotian typical section and then unconformably changes into the stratotype section of the Kimmerian Regional Stage, was later proposed as a hypostratotype (Nevesskaya et al., 2004) (Fig. 8). This well-known section was repeatedly described by Andrusov (1917b), Eberzin (1947, 1967), and Nevesskaya (in Nevesskaya and Stevanovic, 1985).

The Pontian Regional Stage is subdivided into two substages.

The lower (Novorossian) Substage (Andrusov, 1923) is subdivided into beds based on the composition of bivalves. The Yevpatorian Beds (Davitashvili, 1937, Crimea) in the lower part of the Lower Pontian contain a very depleted assemblage of brackish-water mollusks of the genera *Eupatorina*, *Dreissena*, *Congerina*,



and *Theodoxus*, and the overlying, Odessian Beds (Mikhailovskii, 1909b; southern Ukraine) are characterized by the appearance of the brackish-water genera *Pseudocatillus*, *Lymnocardium*, and *Paradacna* and euryhaline marine species *Parvivenus widhalmi*. Congerians and rare *Abra tellinoides* continued from the Maeotian.

Upper Substage, *Congeria subrhomboidea* Beds.

The name *Portaferian beds*, often used for designating the lower beds of the Upper Pontian Regional Substage, was proposed for the southern part of the Pannonian Basin (Stevanovic, 1951), where the recognition of the Pontian has now been abandoned and the correlation of which with the Pontian remains unclear. Therefore, this part of the Neogene section is designated by term proposed by Andrusov, namely, the *Congeria subrhomboidea* Beds, containing various brackish-water malacofauna, similarly to the overlying Bosphorian Beds (Andrusov, 1923; Kerch and Taman peninsulas). The diversity of malacofauna is characteristic only of the shallow-water facies of the Pontian, while the relatively deep-water clayey sediments contain mainly *Paradacna* and *Valenciennius* (*Valenciennius* clay facies).

The total thickness of the regional stage is up to 450 m (in the Taman and West Kuban troughs).

The lower boundary of the regional stage, which is conformable in deep troughs, is distinctly transgressive in the marginal parts of the Eastern Paratethys, where deposits of the Novorossian Substage underlie the continental facies of the Neogene or marine sediments of the Sarmatian or Karaganian. The deposits of the end of the Lower Pontian are distinctly regressive; in most sections, this time period covers either a break or the beginning of continental sedimentation. Marine facies are preserved only within the vast western Kuban Trough. The upper boundary of the Bosphorian Beds of the Upper Pontian is also distinctly regressive even in the trough facies.

The most complete reference section of the Pontian of the Taman Peninsula is the Zhelezny Rog (Popov et al., 2016), which is characterized by paleomagnetic and cyclostratigraphic data (Filippova and Trubikhin, 2009; Vasiliev et al., 2011; Rostovtseva and Rybkina, 2014; Popov et al., 2016).

Correlation. According to paleomagnetic data, the base of the Pontian lies in the upper part of normal polarity subchron C3An.1n and is dated to 6.1 Ma and the upper boundary of the Pontian is observed at the very end of reversed polarity chron C3r and dated to 5.25 Ma. According to cyclostratigraphic data (see

Fig. 34), the base of the Bosphorian Beds is dated to 5.45 Ma and the sedimentation break at the end of the Lower Pontian under *Congeria subrhomboidea* Beds is estimated at 160 thousand years (Rostovtseva and Rybkina, 2014, 2017).

Kimmerian Regional Stage

The Kimmerian Stage was recognized by N.I. Andrusov (1908) instead of the “ore bed,” when it was revealed that it was widely distributed not only on the Kerch Peninsula but also in Kuban and the Black Sea region. Lectostratotype: a section of the western shore of the Kerch Strait near the town of Arshintsevo to the south of Kerch (*Stratotypes...*, 1975), illustrated above (Fig. 8) according to Andrusov (1917b) and A.G. Eberzin (1947). It is subdivided into two substages: the lower substage, which includes the Azovian Beds, and the upper substage, which combines the Kamysh-Burun and Panticapaeum Beds. The regional stage is incompletely represented in the stratotype: its lower part (Azovian Beds) is absent. The Kimmerian deposits are conformably overlain by barren Kuyalnikian sandy clays.

Azovian beds (Vassoevich and Eberzin, 1930) are developed along the Azov coast of the Kerch Peninsula, where they are represented by limestone-shell rocks and sands and less often by clays and characterized by mollusks of the genera *Macradacna*, *Panticaepaea*, *Stenodacna*, and *Pachydacna* s. str., which do not occur in the underlying Pontian deposits, as well as by a number of specific species originating from Pontian ones (*Paradacna deformis*, *Oraphocardium alatoplanum*, *Pseudocatillus azovicus*, *Stenodacna praeangusticostata*, etc.). Detailed paleomagnetic data were obtained for the Pontian, Kimmerian (Fig. 9), and Kuyalnikian (Semenenko and Pevzner, 1979; *Neogenovaya Sistema*, 1986) from boreholes in the Arabat Spit of the Crimean Peninsula.

Kamysh-Burun Beds (Andrussow, 1886; Crimea) correspond to the “ore bed” and contain numerous and diverse species of the same genera as those in the Azovian Beds; many of them are endemic and large in size (*Arcicardium acardo*, *Pontalmyra crassatella*, *Prosodacna macrodon*, etc.).

Panticapeanian Beds (Davitashvili, 1933; Taman Peninsula) are characterized by the disappearance of a number of species and appearance of a few new species at the same generic composition. The specific species include *Macrodacna meridionalis* and *M. maxima* and rare *Prionopleura colchica*, *P. krestovnikovi*, *Pachydacna anapensis*, and *Pontalmyra voskobojnikovi*.

←
Fig. 8. Scheme of correlation of sections of the lectostratotype of the Maeotian Regional Stage at Cape Akburun and hypostratotype of the Pontian Regional Stage and lectostratotype of the Kimmerian Regional Stage near the town of Arshintsevo, to the south of the city of Kerch, Crimea (according to Andrusov, 1917b; Eberzin, 1947, 1967; Popov et al., 1996), with the lectostratotype of the Pontian Regional Stage near the Lanzheron beach, Odessa (according to Sintsov, 1883, 1894; *Stratotypes...*, 1975, p. 300).

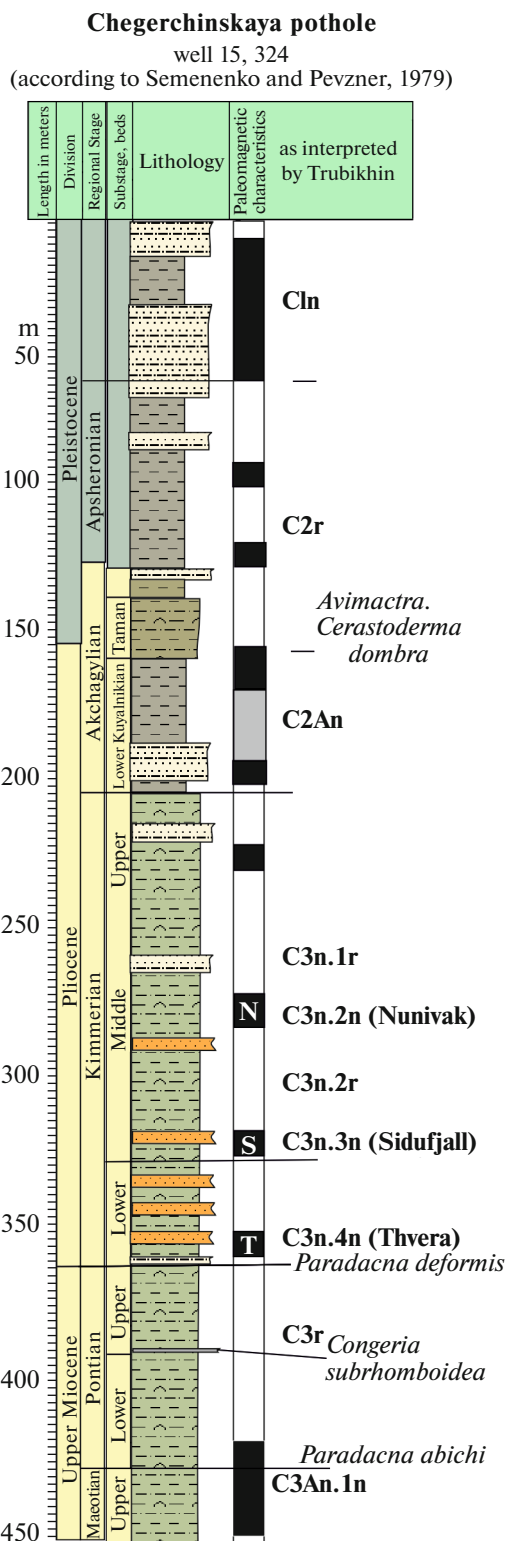


Fig. 9. Scheme of the section and paleomagnetic characteristics of the Pontian, Kimmerian, and Akchagylian regional stages of the Chegerchinskaya pothole on the Azov coast of the Kerch Peninsula (according to Semenenko and Pevzner, 1979; *Neogenovaya sistema*, 1986, Fig. 2, with interpretation by Trubikhin).

In addition to bivalves, Kimmerian deposits also contain gastropods, as well as numerous ostracods of the genera *Caspiolla*, *Bakunella*, *Caspiocypris*, etc.

The thickness of the regional stage is up to 550 m (in the West Kuban Trough).

A section on the coast of the Kerch Strait near the village of Taman is proposed as a reference section (Popov et al., 2016).

Brackish-water deposits of the Kimmerian Regional Stage have a very limited distribution and are developed only in the Taman and West Kuban troughs, where they are represented in clay facies typical of the regional stage with ferruginous sandstone beds with characteristic endemic fauna, as well as near the city of Sukhumi (Republic of Abkhazia), where ore facies are absent.

Correlation. According to paleomagnetic data, the base of the Kimmerian Regional Stage, which is understood as the base of the Azovian Beds, lies in the uppermost strata of reverse polarity chron C3r, right below subchron C3n.4n (Thvera) and is dated to 5.25 Ma, while the base of unconformity under the Azovian beds in the Zhelezny Rog section was dated to 5.2 Ma, according to cyclostratigraphic data (Rostovtseva and Rybkina, 2014, 2017). The base of the Kamysh-Burun beds of the Middle Kimmerian lies above the Thvera subchron, in reverse polarity subchron C3n.3r, and below the following normal polarity subchron C3n.3n (Sidufjall) and is dated to 4.9 Ma. The top of the Kimmerian lies at the very end of reverse polarity chron C2Ar and is therefore dated to 3.6 Ma.

Akchagylian Regional Stage

The Akchagylian was differentiated as a horizon by Andrusov (1912) without stratotype designation.

Since the deposits assigned to the Akchagylian Stage in this study were first described on the Krasnovodsk Peninsula (Andrusov, 1896, 1902) (whence the name Akchagylian comes from), the lectostratotype was chosen just in this place (section near the Ushak well, Krasnovodsk Peninsula, Turkmenistan) (*Stratotypes...*, 1975). The section was described in A. Alizade (1961), V.M. Trubikhin (1977), and G.A. Danukalova (1996, pp. 70–72).

The Akchagylian Regional Stage in the lectostratotype (Fig. 10) is represented by interbedded siltstones, clays, sands, sandstones, marls, oolitic and shelly limestones, and conglomerates. The malacofauna is impoverished in the lower part of the section: bivalves of the genera *Aktschagylia*, *Avimactra*, and *Cerastoderma* and gastropods of the genera “*Clessiniola*” and *Pirenella* were found. The middle part is characterized by the most diverse composition of mollusks; bivalves of the genera *Andrussella*, *Miricardium*, *Andrusovicardium*, and *Avicardium* were encountered here; only *Cerastoderma* and *Aktschagylia* are preserved and *Dre-*

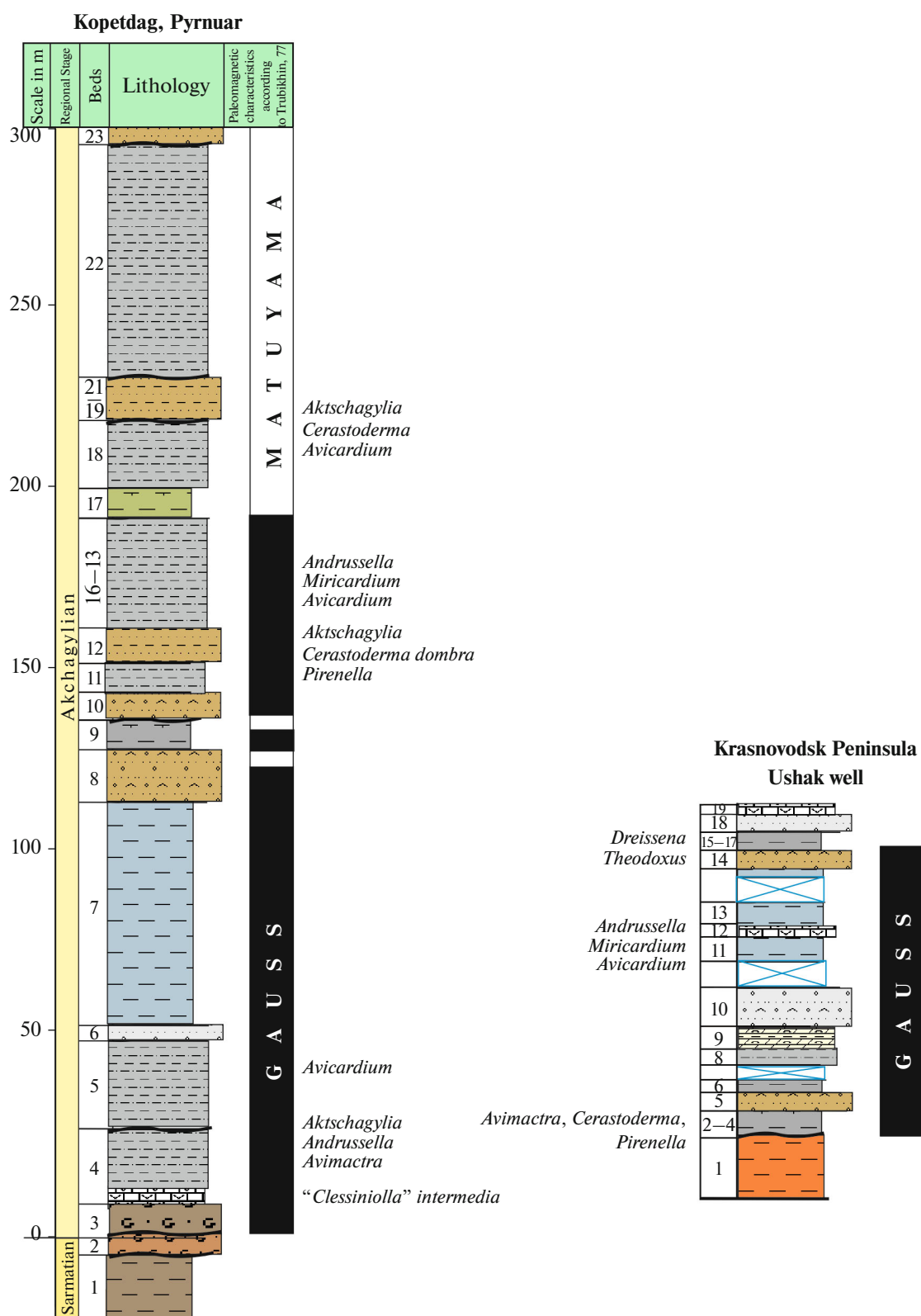


Fig. 10. Scheme of the lectostratotype of the Akchagylia Regional Stage on the Krasnovodsk Peninsula and hypostratotype on Kopetdag and their paleomagnetic characteristics (according to Trubikhin, 1977; Danukalova, 1996).

issena and *Theodoxus* appear in the uppermost strata. According to the paleomagnetic data of Trubikhin, this and other sections of the Akchagylian of the Krasnovodsk Peninsula are incomplete and represented only by the lower part of the Akchagylian, which is normally magnetized and assigned to the Gauss paleomagnetic chron. More complete sections of the Akchagylian Regional Stage in Turkmenistan are known from more eastern areas, from Greater Balkhan and Kopetdag. The most complete thick section of Kopetdag in the western part of the Pynuar Syncline was described by many researchers, including Alizade (1961) and Trubikhin (1977), who obtained its paleomagnetic characteristics (Fig. 10), and Danukalova (1996, p. 92), who proposed it as a hypostratotype.

Akchagylian deposits are also well exposed in sections of the lower part of the Kura Basin: Jeirankhechmez, Hajigabul, and Lokbatan (Richards, 2018; Van Baak et al., 2019; Lazarev et al., 2019, 2021; Hoyle et al., 2020). The thickness of the regional stage reaches 600–750 m (in the Terek–Kuma trough).

The subdivision of the Akchagylian into substages or regional beds is controversial. Fauna-based stratigraphic subdivisions that were proposed by Kolesnikov (1936, 1940) and named Ushak, Umchal, and Suprimchek Beds by Paramonova (1994) can be used for a limited number of sections and only in the southern part of the Akchagylian basin (Turkmenistan, Azerbaijan, eastern Georgia, and Dagestan), which is richest in mollusks. However, according to paleomagnetic data, they are not synchronous in different sections even here. In the northern part of the basin (the Middle Volga and Kama regions and Bashkir Cis-Urals), it is impossible to differentiate beds and substages based on faunal data due to the depletion of the malacofauna or its absence; independent local stratigraphic schemes were proposed for these regions.

According to other researchers (Alizade, 1961; Trubikhin, 1977; Danukalova, 1996, etc.), the division of the Akchagylian should be based on transgressive–regressive cycles that do not coincide with the stages of malacofauna development. In addition, some authors divide the Akchagylian into two parts, while others into three parts.

The magnetostratigraphic correlation of the Akchagylian, officially accepted in the regional stratigraphic scheme of the Neogene of Russia (*Unifitsirovannaya...*, 2004), is based on paleomagnetic data from Turkmenistan sections (Trubikhin, 1977). Here, the Akchagylian begins within a long normal chron in most of the sections, which upwards changes to a long reversed chron. This polarity change was interpreted as a Gauss/Matuyama paleomagnetic inversion (C2An–C1r). In six of the 20 sections studied by Trubikhin, one or two small reversed intervals were found within the Gauss chron and interpreted as the Kaena (2An.1r) and Mammoth (2An.2r) subchrons, which served as a basis for correlation of the lower boundary

of the Akchagylian with the base of the Gauss chron (2An.3n), dated to 3.6 Ma in the Global Paleomagnetic Time Scale (GPTS 2020) (Gradstein et al., 2020). The upper boundary of the Akchagylian was correlated with the base of the Gilsa subchron, which was dated to 1.79 Ma according to the Cox scale used at that time (Cox, 1969). Subsequently, the age of the boundary remained at the level of 1.8 Ma, despite multiple modifications of the GPTS, and is currently defined within the Olduvai subchron (C2n) (*Unifitsirovannaya...*, 2004).

Later, there were doubts about this interpretation. Estimates of sedimentation rates in sections containing reversed zones which were interpreted as Kaena and Mammoth showed that they were too short and probably represented only short excursions rather than full subchrons (Gurarii, 2015). Thus, it was proposed to interpret the data of Trubikhin (1977) on the Pynuar section in a different way (Fig. 11): G. Z. Gurarii (2015) correlated the entire normally magnetized part of the section with Chron C2An.1n. This conclusion can be indirectly confirmed by the very limited appearance of reverse intervals (in six of the 20 sections studied by Trubikhin), as well as by their different numbers (one or two) and polarities (from the reversed to the indefinite one).

The recent studies on the Kura Basin of Azerbaijan have proposed a tripartite subdivision of the Akchagylian based on the reconstruction of paleoenvironments and absolute dating (Fig. 12). The new age model based on sedimentological and magneto- and biostratigraphic data and $^{40}\text{Ar}/^{39}\text{Ar}$ -dating makes it possible to differentiate the following intervals in the Akchagylian: (1) The beginning of Akchagylian transgression with freshwater–mesohaline conditions (2.95–2.75 Ma), the lower part of subchron 2An.1n (Upper Gauss); (2) Meso-euhaline or “marine” Akchagylian (2.75–2.45 Ma), which covers the Gauss–Matuyama inversion (the upper part of subchron 2An.1n—the lower part of subchron C2r.2r); (3) Oligohaline interval (2.45–2.13 Ma), subchron C2r.2r—within subchron C2r.1n (Reunion) (Lazarev et al., 2021) (Fig. 12). According to the ideas of the co-authors from the Paleontological Institute, it is more correct to characterize the Middle Akchagylian by the term mesohaline rather than the term euhaline.

Accumulation of magneto-biostratigraphic data and data on $^{40}\text{Ar}/^{39}\text{Ar}$ dating in the Kura basin showed that most of the Gauss chron, including the Kaena and Mammoth subchrons, is located in deposits of the Productive Series (Van Baak, 2015; Van Baak et al., 2019). The beginning of the Akchagylian, which is understood as an extensive freshwater–mesohaline transgression, is observed within C2An.1n (Upper Gauss), which generally corresponds to most of the sections of Turkmenistan. The upper boundary of the Akchagylian, which was studied in detail in the Goychay and Hajigabul sections, was marked within the

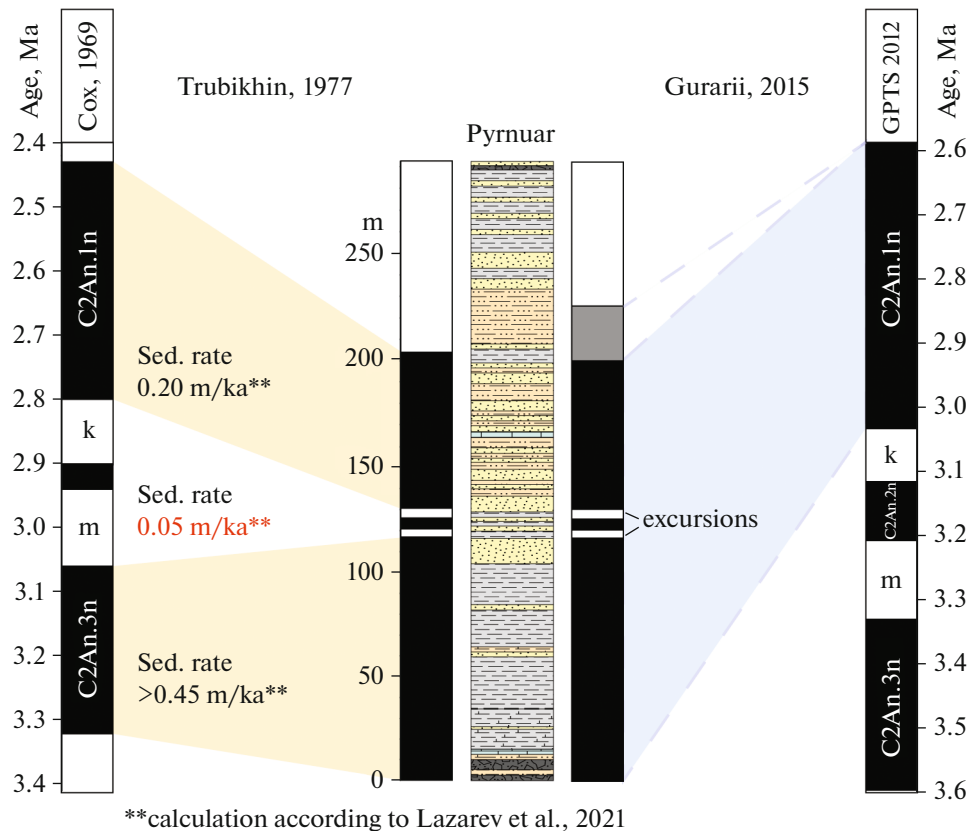


Fig. 11. Scheme of interpretation of paleomagnetic data on the Pynruar section. To the left of the section is the interpretation by Trubikhin (1977) with sedimentation rates calculated by S.Yu. Lazarev. To the right of the section is the alternative correlation proposed by G.Z. Gurarii (2015), where the base of the Akchagylian is correlated with Gauss subchron C2An.1n.

Reunion subchron (C2r.1n) with an age of 2.13 Ma based on the appearance of first Apscheronian mollusks, *Apscheronia* sp. and *Monodacna* sp. (Lazarev et al., 2019).

The authors of these studies emphasize that the faunal characteristics of these intervals can significantly differ laterally due to a high variability of sedimentation conditions and, consequently, the paleoecological conditions of the given fauna. To avoid incorrect subdivision of Akchagylian deposits on an interregional scale, it is necessary to combine dating methods (magnetostratigraphy and $^{40}\text{Ar}/^{39}\text{Ar}$ dating), methods of reconstructing depositional environments (sedimentology), and collection of data on several faunal groups reflecting different paleoecological environments (mollusks, ostracods, foraminifers, and dinocysts) (Hoyle et al., 2020; Lazarev et al., 2021).

The Akchagylian basin with fauna and phytoplankton of marine origin occupied only the Caspian part of the Eastern Paratethys and flew into the Azov Bay of the Kuyalnikian reservoir. The latter had a limited distribution, being rarely outside the modern Black Sea basin, and was occupied by depleted brackish-water fauna.

Euxinic basin. The stratigraphic analog of Akchagylian deposits of the Caspian region in the Euxinic basin are the **Kuyalnikian beds** (Sintsov, 1875; Mikhailovskii, 1909a, near the city of Odessa, Ukraine), represented by shallow-water sands, sandstones, and clays interbedded with marls. They contain a few species of bivalve mollusks of the genera *Lymnocardium*, *Prosodacna*, *Pseudocatillus*, and *Dreissena*, which were inherited from the Kimmerian, and are interbedded with sediments containing the malacofauna of Akchagylian genesis with Mactridae (*Aktschagyliya*) and rare *Cerastoderma* in areas of the Azov Sea region—Taman Peninsula.

Taman beds (Eberzin, 1931) with Akchagylian mollusks were recovered by wells on the northern coast of the Kerch Peninsula and are exposed on the Taman Peninsula near the Bugaz Estuary. The beds are represented by sands and clayey sands with Akchagylian mollusks *Aktschagyliya subcaspia* and *A. karabugasica* and rare *A. ossoskovi*, *Cerastoderma dombra*, *Raricardium* ex gr. *konjushevskii*, *Unio*, *Viviparus*, and *Melanopsis* (up to 20 m). These deposits occur on Lower Kuyalnikian sands (Fig. 9) with *Pachydacna kujalnicensis*, *Pseudocatillus subriegeli*, *P. vulgare*, and *Dreissena theodori* and freshwater mollusks (field data from

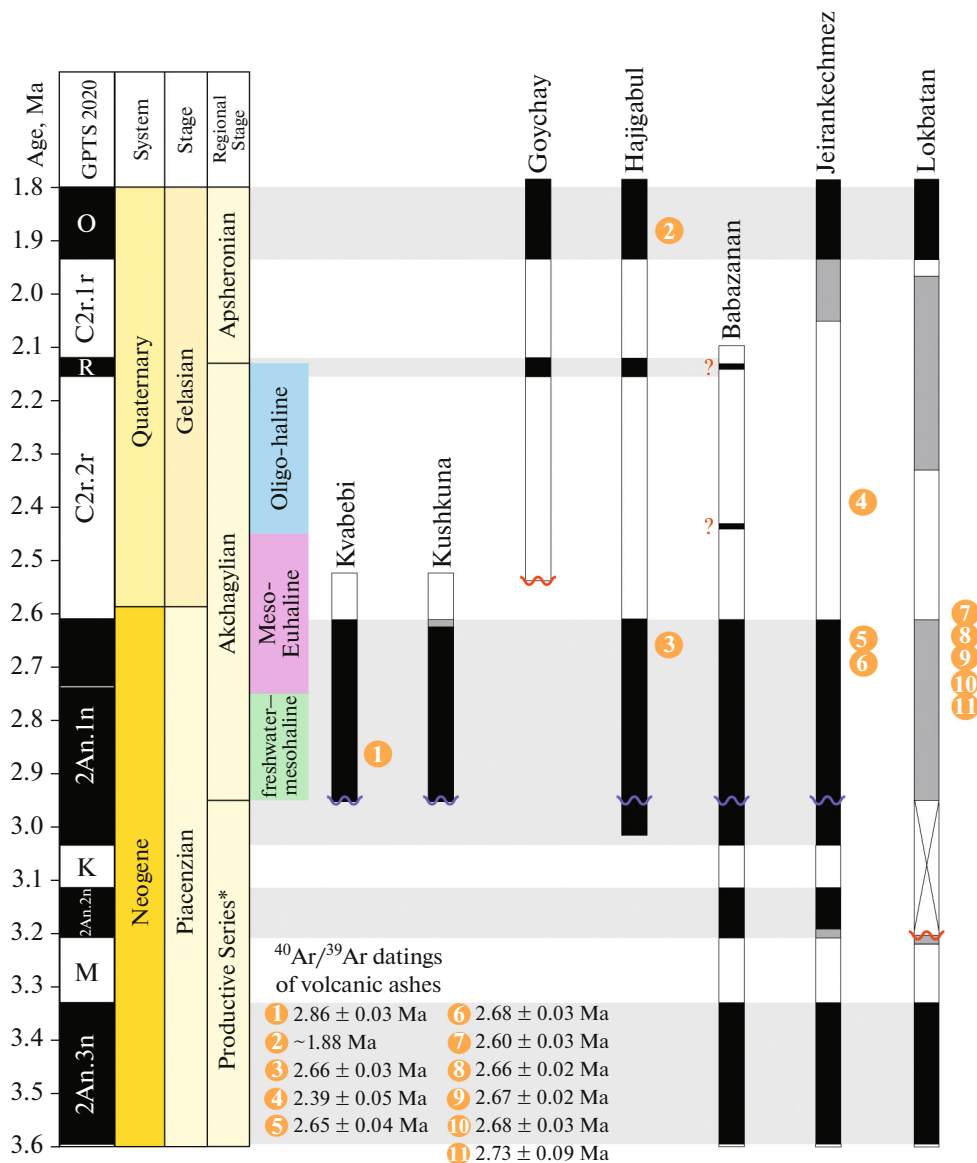


Fig. 12. Alternative age model of the Akchagylian Regional Stage based on the reconstruction of depositional environments and on the age of the Akchagylian Regional Stage according to the magnetobiostratigraphic and isotopic data from sections of the Kura depression (according to Lazarev et al., 2021, Fig. 9, with supplements).

Nevesskaya, 1974, Neogenovaya sistema, 1986) and contain the teeth of rodents of the species *Mimomys hintoni livenzovicus* in a section near the village of Veselovka (Tesakov, 2002). Therefore, the Taman beds in the sections of the Taman Peninsula are correlated with the upper part of Kuyalnikian Beds.

Since Akchagylian mollusks were also found in wells in Lower Kuyalnikian Beds (in the northern Cis-Azov region and eastern Crimea) (Semenenko, 1966, 1975) and the Kuyalnikian has the same paleomagnetic characteristics as the Akchagylian (Semenenko and Pevzner, 1979), it can generally be considered an analog of the Akchagylian of the Caspian basin (Nosovskii and Semenenko in Neogenovaya sistema,

1986, p. 141), even though the uppermost strata of the Kuyalnikian probably correspond to the lower strata of the Apsheeronian (Semenenko, 1975).

Correlation. The Akchagylian correlation, officially accepted in the regional stratigraphic scheme of the Neogene of Russia, is based on paleomagnetic data (Figs. 10, 11). The base of the Akchagylian is correlated with the base of the Gauss chron (2An.3n) dated to 3.6 Ma in GPTS-2020. The upper boundary of the Akchagylian is correlated with the base of the Gilsa Chron, which is dated to 1.8 Ma and established within Olduvai chron (C2n) (Trubikhin, 1977; Nevesskaya et al., 2004).

An alternative interpretation of the paleomagnetic data (Fig. 12) suggests that the beginning of the Akchagylian is in the lower part of subchron C2An.1n (Upper Gauss). The Upper Akchagylian includes subchron C2r.1n (Reunion) within chron C2r (Lazarev et al., 2021). According to this interpretation, the Lower Akchagylian corresponds to freshwater–mesohaline sedimentation conditions; the mesohaline middle interval (or mixomesohaline middle interval, according to Nevesskaya et al., 2005) corresponds to the “marine Akchagylian”; the Upper Akchagylian is characterized by oligohaline paleosalinity conditions (according to Lazarev et al., 2021, amended). In any case, the lower part of the Akchagylian corresponds to the Piacenzian (fully or to its upper part) and the upper part of the Akchagylian corresponds to the Gelasian, i.e., to the Upper Pliocene–lower part of the Quaternary system, as they are currently understood.

HISTORY OF SEPARATE BIOTA GROUPS

The study of the most complete sections of the Eastern Paratethys, which was started back in the 20th century, and the currently ongoing integrated studies of the reference sections of the Taman Peninsula, Ciscaucasia, and Transcaucasia make it possible to significantly refine the stratigraphic knowledge of our great predecessors about the traditional benthic groups (mollusks and foraminifers) and supplement it with new data based on studying phytoplankton, ichthyofauna, and terrestrial flora.

Calcareous Nannofossils

Calcareous nannoplankton (or calcareous nannofossils) is a formal group in which the main components are shells and shell fragments (coccoliths) of unicellular yellow-green algae (coccolithophorids) and calcareous cysts of dinoflagellates, as well as skeletal remains or fragments of other organisms no larger than 63 µm (Ovechkina, 2007).

The remains of coccolithophorids were first described by G.G. Ehrenberg in the mid-19th century (Ehrenberg, 1836), who considered them as inorganic formations. In 1954, M. Bramlette and W. Riegel (1954) proposed to use calcareous nannoplankton for stratigraphic purposes.

The deep sea drilling project has shown the importance of this group for the detailed stratigraphic subdivision of the sediments and the establishment of large scale correlations based on the rapid evolution and wide geographic distribution of calcareous nanofossils and the identity of coeval associations over vast expanses (Martini, 1971; Okada and Bukry, 1980).

History of the Study of Nannoplankton in the Neogene of the Eastern Paratethys

The introduction of new groups of microfauna and microflora (in particular, calcareous nannofossils) into biostratigraphic studies made it necessary to review the correlation of regional subdivisions of the Eastern Paratethys with Mediterranean stratotypes, as well as the paleogeographical and paleohydrological characteristics of the Miocene and Pliocene basins of the Euxinic–Caucasian region (Muzylev and Golovina, 1987; Popov et al., 2016, 2018).

The study of calcareous nannofossils in the Neogene deposits of the Eastern Paratethys was started in the second half of the 20th century. The first publication about the find of coccolithophorids was devoted to studying the Lower Sarmatian clayey series in the southeast of Ukraine (Didkovskii et al., 1968). This was followed by studies of S.I. Shumenko (1975), A.S. Andreeva-Grigorovich (Barg et al., 1975; Andreeva-Grigorovich and Nosovskii, 1976a, 1976b, 1978, 1983, 1989; Nosovskii et al., 1976; Andreeva-Grigorovich, 1977; S.A. Lyul'eva (Kulichenko et al., 1976a, 1976b; Didkovskii et al., 1981), E.M. Bogdanowicz (Nosovskii and Bogdanowicz, 1984; Bogdanowicz and Ivanova, 1997), Ts.D. Minashvili (1981, 1986), and N.G. Muzylev and Golovina (1986; 1987; Golovina et al., 1986, 1987, 1989).

Pioneer studies by Lyul'eva, which were continued in collaboration with V.N. Semenenko, deal with calcareous nannofossils from many sections and wells of the Northern Black Sea region and Ciscaucasia (Semenenko and Lyul'eva, 1978, 1982; Semenenko, 1987; Lyul'eva, 1989a, 1989b, 1990a, 1990b; 1991, 2009; Semenenko et al., 1999). A detailed paleomagnetic and paleontological study was carried out and the traditional stages of the Neogene of the Black Sea–Caspian basin, on the reference sections in the stratotype areas (on the Kerch Peninsula) in the Indol trough of Crimea, Chegerchin trough, and Taman sections, where significantly thick monofacial sediments of the Upper Neogene are developed (Semenenko and Pevzner, 1979). Semenenko (1987) was the first to attempt to directly correlate the Upper Miocene and Pliocene of the Eastern Paratethys with the Mediterranean.

Since the 1980s, the study of Neogene nannoplankton has become more systematic; many sections in the south of the former Soviet Union (Moldova, Ukraine, Northern Caucasus, Georgia, Azerbaijan, and Turkmenistan, as well as a collection of deep-sea drilling wells in the Black Sea) have been studied to substantiate the stages with nannoplankton as a reliable basis for the correlation of the regional scale of the Eastern Paratethys with the strata of the International Stratigraphic Scale (works by Andreeva-Grigorovich, Lyul'eva, Muzylev, Golovina, Minashvili, etc.).

At the present time, the study of calcareous nannofossils are an integral part of multidisciplinary studies of the most complete reference sections (Popov et al., 2016). Long-term studies have shown that the presence of nannoplankton in the Neogene deposits of the Eastern Paratethys is associated with the cyclic development of the Miocene–Pliocene basins and is an indicator of marine phases of its development; therefore, the quantitative and qualitative composition of the Miocene–Pliocene nannoflora is determined by the width of the water exchange of paleobasins. Its comparison with coeval oceanic and Mediterranean nannoplankton assemblages in the Miocene–Pliocene associations of the Eastern Paratethys often indicates the absence of index species of the zones and a small number or a single occurrence of many typical taxa. The base of the assemblage is formed by cosmopolitan and long-lived species; the development of monospecific associations is often observed. Calcareous nannofossils are very sensitive to parameters of salinity and temperature, the presence of nutrients, and amount of terrigenous drift. Variations of these characteristics lead to the depletion of assemblages, primarily due to fallout of short-lived taxa sensitive to changes in environmental conditions. It is important to note that the diversity and abundance of calcareous nannofossils can significantly vary even within the same region, which is explained by different sedimentation environments.

The peculiarity of nannoplankton associations of the Eastern Paratethys and a short duration of their development do not allow a confident direct correlation of these assemblages with the zonal subdivisions of the scales of the Mediterranean, Central Paratethys, and World Ocean. It is obvious that it is hardly possible to develop a complete nannoplankton zonal scale for the Eastern Paratethys, since assemblages are recorded only at separate levels and devoid of many index species or stratigraphically important markers. All of this does not allow one to establish the full sequence of zones and observe the principle of their coupling. In this case, the significance of calcareous nannofossils for paleogeographic and paleoenvironmental reconstructions comes to the fore and the study of nannoplankton requires the binding of the assemblages to the regional stratigraphic scheme developed mainly on the basis of mollusks, as well as the correlation of this scheme with the paleomagnetic scale (Golovina et al., 1987).

*Problems of Correlation of Stratigraphic Subdivisions
of the Miocene with Zonal Scales
Based on Nannoplankton*

Two scales based on nannoplankton—the Martini scale (Martini, 1971) and Bukry scale (Bukry, 1978) (which was later slightly modified) (Okada and Bukry, 1980)—are most widely used in the stratigraphy of Miocene deposits. The Martini scale was developed

based on studying calcareous nannofossils mainly from sections of European marine sediments, which are characterized by incompleteness, relative shallowness, and uncoupled boundaries of many Miocene strata. All of this reduced the significance of the paleontological substantiation of zones according to the Martini scale: after all, many index species of zones are absent in such sections or have a reduced stratigraphic interval compared to the oceanic sections.

The basis for the creation of the Bukry scale (Bukry, 1978) was a vast factual material of the Project of Deep Sea Drilling in the Atlantic and Pacific Oceans, which made it possible to trace the continuous development of nannoplankton assemblages throughout the Cenozoic. The zonal subdivisions of this scale have an excellent paleontological substantiation. Both scales are reliably correlated with each other and with the paleomagnetic scale and successfully used in biostratigraphic studies. Further improvement and refinement of both scales based on calcareous nannofossils followed the path of synthesis and refinement of biostratigraphic and magnetostratigraphic data (Theodoridis, 1984; Fornaciari and Rio, 1996; Fornaciari et al., 1996; Backman and Raffi, 1997; Raffi et al., 2006; 2016). Based on the study of nannoplankton in the middle and low latitudes of three oceans and Mediterranean Sea with semiquantitative analysis and detailed sampling, J. Backman et al. (2012) estimated the age of biohorizons of nannoplankton marker-species in the interval of the last 23 million years. Thirty-one biozones with an average age of about 0.74 million years during the research; the age of separate biozones varies from 0.15 to 2.20 million years (Backman et al., 2012). Biohorizons based on calcareous nannofossils were supplemented by correlation with magnetic polarity chrons in combination with an astronomically calibrated scale (Abdul Aziz et al., 2003, 2008; Agnini et al., 2014, 2017; Raffi et al., 2016).

Despite the high level of detail of the scales based on the leading planktonic groups (foraminifers and nannoplankton), the correlation of the boundaries of Miocene stages with zonal substages established by nannoplankton is still a difficult problem. It is even more difficult to subdivide marine sediments of semi-enclosed epicontinental basins. This is largely due to the uncertainty of the boundaries between the stages and subdivisions and reflects many shortcomings of their stratotypes. While considering the negative features of the stratotypes of the Miocene Stage units, V.A. Krasheninnikov noted that “the stratotypes of all Miocene stages of the Mediterranean Stratigraphic Scale, which served as a basis for the currently used International Stratigraphic Scale, are spatially separated; their relationships with the underlying and overlying stratigraphic subdivisions are not always definite

and some boundaries coincide with breaks. The identification of most of the Mediterranean stage units was based on the lithostratigraphic principle of formations, according to which the dominant factor was the lithological factor (rather than the paleontological factor), allowing the coupling of stratigraphic units” (Krashennikov et al., 2003, p. 13). The principle of priority of Miocene stratotypes of the Mediterranean used when choosing the so-called “golden nails,” i.e., the global stratotype section and point (GSSP) as close as possible to the traditional stage stratotypes established on the continents. The key events by which global stratotypes are determined are mostly biostratigraphic; however, climatic, geochemical, or paleomagnetic markers sometimes come to the fore. Below, we will briefly consider the problems of establishing some boundaries of stage units based on calcareous nannofossils data.

Oligocene/Miocene boundary. The criteria for determining the Oligocene/Miocene boundary based on calcareous nannofossils have undergone significant changes over the past half century. In the Martini scale (Martini, 1971), which was developed based on marine sediments exposed by sections on the continent, the boundary was established at the base of Zone NN1. According to H. Okada and D. Bukry (1980), whose scale is based on data from the Deep Sea Drilling Project, the Paleogene/Neogene boundary passes within subzone CN1b (i.e., in the middle subzone of Zone CN1, divided into three parts). The lower subzone CN1a and lower part of subzone CN1b are correlated with the Oligocene and the upper part of subzone CN1b (=Zone NN1) belongs to the Miocene.

The global stratotype of the Aquitanian Stage was established in the Lemme-Carrioso section (Italy) (Steininger et al., 1997) at the base of subchron C6Cn.2n (with an age of 23.04 Ma, according to Gradstein et al., 2020). However, the choice of the Lemme-Carrioso section as a global stratotype proved to be rather unsuccessful due to the depletion of the biota assemblages (in particular, calcareous nannofossils), as well as due to the absence of clear isotopic and magnetostratigraphic data, which hinders the accuracy of global correlation and indicates the necessity for replacing the GSSP. The possibility of transition to a new stratotype, possibly in the continuous section of one of the ODP wells, is currently discussed (Miller and Wright, 2017; Gradstein et al., 2020).

In oceanic sections, the main marker species to Oligocene/Miocene boundary are representatives of the genus *Sphenolithus*. The last occurrence (TOP) of the short-lived species *Sphenolithus delphix* (23.06 Ma) is recognized as the closest event to the Oligocene/Miocene boundary and successfully used to determine the base of the Aquitanian Stage in oceanic sediments (Raffi, 1999; Shackleton et al., 1999, 2000; Backman et al., 2012).

To determine the Paleogene/Neogene boundary based on calcareous nannofossils in the Central Paratethys is even more difficult. The absence of many oceanic species makes it necessary to search for additional characteristic markers (Lehotayova, 1985; Marunteanu, 1999; Holcová, 2001, 2005; Chira, 2004; Rögl and Nagymarosy, 2004; Melinte-Dobrinescu and Brustur, 2008; Garecka, 2012).

Miocene/Pliocene boundary. The GSSP of the Zanclean (the base of which corresponds to the Miocene/Pliocene boundary) in the Eraclea Minoa section (Sicily, Italy) was established at the base of the marl Trubi Formation and corresponds to the recovery of open marine conditions in the Mediterranean Sea after the Messinian salinity crisis (GTS 2020). The choice of criteria for determining the Miocene/Pliocene boundary based on calcareous nannofossils data is a subject of discussion. Sequences of the appearance of species of the genera *Amaurolithus* and *Ceratolithus* are considered the most important criteria; however, their reliability and levels of biohorizons are constantly discussed and refined (Cita and Gartner, 1973; Rio et al., 1984; Raffi et al., 2006; 2016; Di Stefano and Sturiale, 2010; Backman et al., 2012; Lancis et al., 2015).

Three biohorizons were proposed as the most accurate and reliable markers of the GSSP global stratotype point of the Messinian/Zanclean boundary:

(1) some researchers consider the appearance of *Ceratolithus acutus* (5.36 Ma according to Backman et al., 2012) closest to the Zanclean base (Lourens et al., 2004). However, other researchers note that *C. acutus* sporadically occurs in the Mediterranean and cannot be used for biostratigraphic correlation (Di Stefano and Sturiale, 2010; Stoica et al., 2016). In addition, identifications of *C. acutus* may be erroneous due to the secondary calcification or fragmentary dissolution of other species (Lancis et al., 2015);

(2) the disappearance of *Triquetrorhabdulus rugosus* is recorded somewhat later (5.23 Ma according to Backman et al., 2012) and is well traced in the Mediterranean and equatorial regions of the Atlantic (Backman and Raffi, 1997; Agnini et al., 2017). At the same time, a detailed study of Miocene/Pliocene boundary deposits in the wells of the Ocean Drilling Project (ODP, wells 969B and 975B) and in sections of Central Italy (Cava Serredi, Tuscany, and Montepetra well, Marche region) confirmed that the last occurrence of *T. rugosus* was unreliable for biostratigraphic correlation (Di Stefano and Sturiale, 2010);

(3) the disappearance of *Discoaster quinqueramus* is recorded slightly below the Zanclean boundary, at around 5.53 Ma (Backman et al., 2012) and serves as an excellent marker in open ocean sections; however, it cannot be used in the Mediterranean due to the Messinian salinity crisis (Agnini et al., 2017).

Thus, the findings of *Ceratolithus acutus* by the standard method may be unsuccessful, since only a non-

standard approach is possible—single findings can be found when processing a large amount of sediment and viewing a significant number of preparations from one sample. *C. acutus* has been found in many key locations in the Mediterranean using a non-standard research approach (Popescu et al., 2006, 2009, 2010, 2016). However, resampling of the same sections did not confirm these results (Grothe et al., 2014, 2018; Van Baak et al., 2015a, 2017; Stoica et al., 2016; Golovina et al., 2019; Krijgsman et al., 2020).

In the Eastern Paratethys, *C. acutus* have been recorded in the Dacian basin (Snel et al., 2006) and Kimmerian of the Euxinic basin (Lyul'eva, 1990; Semenenko and Lyul'eva, 2006). In our material, *C. acutus* is absent and we support the view that there is a high probability of misidentifications of *Ceratolithus* species due to the secondary calcification or fragmentary dissolution of other species (Golovina et al., 2019).

Calcareous Nannofossils of the Neogene of the Eastern Paratethys

Caucasian Regional Stage

The stratotype of the Caucasian Regional Stage was established on the Kuban River below the city of Cherkessk, where the Alkun Formation, Zelenchuk Formation with Septarian Beds at the base, and lower half of the Karadzhhalga Formation are assigned to this regional stage. Among these subdivisions, nannoplankton was found only in weakly calcareous clays of the Alkun Formation (Andreeva-Grigorovich and Gruzman, 1989).

Andreeva-Grigorovich studied calcareous nannofossils from the Novopokrovskaya-4 well, the reference well for the Caucasian stage. According to her data (Andreeva-Grigorovich and Gruzman, 1989), no zonal species of nannoplankton were found in the Alkunian Horizon of the Caucasian Regional Stage; most of the species have an Oligocene–Miocene distribution range and correspond to the undivided association of Late Oligocene *Sphenolithus distenthus* (NP24)—*S. ciperoensis* (NP25) zones in the Martini scale (Martini, 1971).

The Lower Miocene index species of the *Triquetrorhabdulus carinatus* zone (NN1) according to the Martini scale (Martini, 1971) was first established by Krhovsky (Akhmetiev et al., 1995) in a section along the Belaya River; later, the presence of *T. carinatus* was recorded in the Alkunian Horizon of the Karamurzinsky section exposed along the Kuban River (Filippova et al., 2010).

In the stratotype area of Lower Miocene deposits (eastern Georgia, between the city of Gori and Mlashe-khevi gully) the transitional Upper Oligocene/Lower Miocene beds corresponding to the *Sphenolithus ciperoensis* (NP25)—*Triquetrorhabdulus carinatus* (NN1) Zones were deposited in the weakly car-

bonate facies of the Lower Uplistsikhe Subformation (Minashvili, 1992; Ananiashvili and Minashvili, 2000; Minashvili and Ananiashvili, 2017). The species *Sphenolithus ciperoensis* no longer occurs at the base of the Upper Uplistsikhe Subformation, which can be interpreted as a transition to the *Triquetrorhabdulus carinatus* zone (NN1) of the Neogene base.

Based on integrated biostratigraphic studies of deposits of the Alkunian Horizon in a series of Ciscaucasian sections (the Kuban, Alkunka, Belaya, Fiagdon, and Mairamadag rivers) made it possible to establish the presence of calcareous nannofossils and identify ***Cyclicargolithus floridanus* Beds** in the carbonate interbeds of the middle and upper parts of Alkunian Horizon.

The lower boundary of the beds is determined in the most carbonate part of the Alkunian Horizon by the appearance of a small-numbered autochthonous calcareous nannofossils, including *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Coronocyclus nitescens*, *Reticulofenestra* sp., and *Pontosphaera multipora*. The association then increases owing to the abundance of *Cyclicargolithus floridanus*. The general list includes *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Coronocyclus nitescens*, *Cyclicargolithus abisectus*, *Cyclicargolithus floridanus*, *Discoaster deflandrei*, *Helicosphaera euphratis*, *Helicosphaera* sp., *Reticulofenestra dictyoda*, *Reticulofenestra* cf. *haqi*, *Reticulofenestra* sp., *Sphenolithus conicus*, *Sphenolithus* sp., *Syracosphaera* sp., *Thoracosphaera* sp., *Triquetrorhabdulus carinatus*, *Tr. milowii*, *Umbilicosphaera* sp., *Pontosphaera multipora*, *Pontosphaera* sp., and *Pyrocyclus* sp. The dominant cosmopolitan species *C. floridanus* is characterized by a wide geographical distribution (approximately from 70° N to 70°–80° S); the maximum flowering and high abundance of the species are characteristic of the Late Oligocene–Early Miocene (Auer et al., 2014). In the upper part of the beds, the assemblage becomes depleted again and the top of the beds is determined by the disappearance of calcareous nannofossils.

In the stratotype area of the Alkunian Horizon (Prokopov, 1937a; Dmitrieva et al., 1959; Kovalenko et al., 1977), *Cyclicargolithus floridanus* Beds was identified in the part of the section exposed along the Alkunka stream (a tributary of the Assa River) near the highway between the villages of Nizhny Alkun and Muzhichi (Golovina, in press). In the upper part of the section, dark gray thin-layered, slightly calcareous clays contain abundant *Cyclicargolithus floridanus* and frequent *Pontosphaera multipora*. More rare species are *Coronocyclus nitescens*, *Helicosphaera euphratis*, *Helicosphaera* sp., *Discoaster deflandrei*, *Reticulofenestra dictyoda*, *Sphenolithus* sp., *Triquetrorhabdulus* sp., and *Thoracosphaera* sp.

In the stratotype section of the Caucasian Regional Stage on the Kuban River, with *Cyclicargolithus floridanus* Beds on the Kuban River were established in

weakly calcareous clays of the Alkunian Horizon (bed 2, specimens 7/20 and 8/20; bed 3, specimen 3/20; see Fig. 2). The nannoplankton assemblage includes abundant *Cyclicargolithus floridanus*, fragments of *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Coronocyclus nitescens*, *Cyclicargolithus abisectus*, *Discoaster deflandrei*, *Helicosphaera euphratis*, *Helicosphaera* sp., *Reticulofenestra* sp., and *Sphenolithus* sp., and frequent *Thoracosphaera* sp., *Triquetrorhabdulus* sp., *Pontosphaera multipora*, and *Pontosphaera* sp.

In the section of the Alkunian Horizon along the Belaya River (opposite the Fyuntv stream and along its channel), a peculiar association is correlated with the transition interval from the Oligocene to the Miocene or possibly with the basal part of the Miocene. Following Krhovsky (Krhovsky et al., 1995), we confirm single finds of the index species of zone NN1, *Triquetrorhabdulus carinatus*, in this area. The absence of typical elements of Oligocene nannoflora, probably indicates the beginning of the Miocene. At the same time, it is quite possible that the absence of Oligocene species might be due to local bionomic features.

Correlation. The lower boundary of the Caucasian was assumed to be isochronous with the base of Zone N4 (Blow) of the Aquitanian Stage (Nosovskii and Bogdanowicz, 1980; Nosovskii, 1998). Discussions about the boundaries and range of the first Miocene unit were intensified due to the fact that “there were no clear criteria for establishing the age analogs of the lowermost part of this stage (the Alkunian Horizon) in many sections of the south of the Soviet Union ...” (Nosovskii, cited by Vernigorova and Ryabokon, 2018). According to a few finds *Triquetrorhabdulus carinatus* (Karamurzinsky section and section along the Belaya River), the Alkunian Horizon are correlated with interval NP25–NN1 zones, since *T. carinatus* appears in the middle of zone NP25, and even the acme of this species is confined to the upper part of the Oligocene (Backman et al., 2012). However, the presence of this index species in *Cyclicargolithus floridanus* Beds together with *Triquetrorhabdulus milowii* (Karamurzinsky section) gives grounds to correlate the nannoflora assemblage with the Lower Miocene interval of zone NN1 and correlate the Alkunian Horizon with the lower part of the Aquitanian. Calcareous nannofossils data on the Neogene age, at least in the upper part of the Alkunian, are confirmed by the results of the study of dinocysts (Filippova et al., 2010, 2015; Beluzhenko et al., 2018).

The data of Minashvili on the section between Gori and Uplistsikhe in Kartli (Minashvili and Ananiashvili, 2017) suggest that the weakly carbonate level, characterized by finds of *T. carinatus*, can be traced in Georgia, at the base of the Upper Uplistsikhe Formation.

Central Paratethys. In the Central Paratethys, the determination of the Paleogene/Neogene boundary in

the absence of many oceanic species of nannoplankton makes it necessary to search for additional characteristic markers (Lehotayova, 1985; Marunteanu, 1999; Holcová, 2001, 2005, 2017; Chira, 2004; Rögl and Nagymarosy, 2004; Melinte-Dobrinescu and Brustur, 2008; Garecka, 2012). In Ciscarpathian sections, the Oligocene/Miocene boundary is defined in the “upper part of the roughly rhythmic flysch of the Lower Krosno Subformation based on the distribution of foraminifers, calcareous nannofossils, and dinocysts and is marked by the appearance of associations with *Sphenolithus belemnus*. In the Menilithic section, it is established along the base of the upper Menilithic Subformation based on the distribution of planktonic groups” (Andreeva-Grigorovich and Gruzman, 1989, p. 92–93). Along with a huge number of redeposited Cretaceous and Paleogene species, the association of the *Triquetrorhabdulus carinatus* zone (NN1), including *T. carinatus*, *Cyclococcolithus floridanus*, and *Sphenolithus moriformis*, is present in the terrigenous part of the Lower Vorotyshcha Subformation along the section of the Prut River (Andreeva-Grigorovich and Stupnitskii, 1976b). The *Discoaster druggii* zone (NN2) of the Lower Miocene is determined in the upper part of Menilithic Beds exposed on the Prut River near the town of Delyatyn (Andreeva-Grigorovich et al., 2008).

In the southern part of the Slovak Basin, the Oligocene–Miocene boundary was determined in the uppermost part of the Lucenec Formation based on the disappearance (rare occurrence) of *Helicosphaera recta* and *Dictyococcites bisectus* and appearance of *Helicosphaera carteri* in the association (Ozdinova and Sotak, 2014).

In Romania, the boundary between the Oligocene and Miocene in the western and northern parts of the Transylvanian basin was determined in Vima, Vinetisu, and Podu Morii deposits; the base of the *Triquetrorhabdulus carinatus* zone (NN1) was recognized by the first occurrence (FO) of *Helicosphaera mediterranea* (Marunteanu, 1992; Chira, 2004). In the northwestern part of Romania and in the eastern Carpathians, the Oligocene–Miocene boundary is defined within zone NN1 and is close to the first occurrence (FO) of *Sphenolithus capricornutus* (Melinte-Dobrinescu and Brustur, 2008).

Sakaraulian Regional Stage

Lower Miocene deposits in the sections of the stratotype area of the Kartli Depression in Georgia are represented by coarse-grained sandstones and sandy siltstones, in which nannoplankton was not established during our studies. In Ciscaucasia, Sakaraulian analogs are represented by noncalcareous deposits of the Upper Maikopian Group and also unsuitable for studying the calcareous nannofossils.

Calcareous nannofossils was found in analogs of Upper Maikopian deposits in northern Iran (Mazandaran province) (Popov et al., 2015), where *Triquetrorhabdulus challengerii* and *Sphenolithus conicus* were found along with an assemblage of bivalves common with the Sakaraulian of Georgia. *T. challengerii* has a narrow stratigraphic distribution within zones NN1–NN2 of the Lower Miocene; in the Central Paratethys, it was found in the Upper Miocene part of the Egerian Regional Stage of the Transcarpathian trough and in the Lower Miocene deposits of the frontal zone of the Ukrainian Outer Carpathians (Andreeva-Grigorovich et al., 2008).

Kozakhurian Regional Stage

Our long-term studies did not reveal calcareous nannofossils neither in the coarse terrigenous facies of the stratotype area of the Kartli depression nor in non-calcareous clays in the Upper Maikopian Group and Ritsa Formation of Ciscaucasia.

Correlation. According to the position in the section and presence of endemic mollusks, the Kozakhurian Regional Stage is correlated with the Upper Ottnangian, Karpatian, and lower part of the Badenian in the Central Paratethys and with the upper half of the Burdigalian and lower strata of the Langhian in the Mediterranean (Gradstein et al., 2020). This stratigraphic interval corresponds to the *Sphenolithus belemnus* zone (NN3) and most of the *Helicosphaera ampliapertura* zone (NN4).

Central Paratethys. In southeastern Ciscarpathians (Ukraine), the nannoplankton assemblage of the *Sphenolithus belemnus* zone (NN3) was established in the upper part of the Dobrotiv deposits (section of the Lukovets River and a series of wells) and includes the index species *S. belemnus*, *S. moriformis*, *Discolithina multipora*, *Helicopontosphaera* (= *Helicosphaera*) cf. *kamptneri*, and *Coccolithus* ex gr. *pelagicus* (Andreeva-Grigorovich and Stupnitskii, 1976b). The nannoplankton assemblage of zone NN3 and presumably lower part of zone NN4 was established in the Vorotyscha formation, in sections along the Prut River, near the Delyatyn settlement (Zarechye section) and village of Lanchyn (Andreeva-Grigorovich et al., 2008). The assemblage of the zone NN4, including *Cyclococcolithus leptoporus*, *Helicopontosphaera* (= *Helicosphaera*) *ampliapertura*, *H. kamptneri* (= *H. carteri*), and *Coccolithus* ex gr. *pelagicus*, was established in Stebnik deposits in wells and sections along the Lukovets, Prut, and Bystritsa-Nadvoryanskaya rivers (Andreeva-Grigorovich and Stupnitskii, 1976b) and in the Stebnik Formation of the Lanchyn section (Andreeva-Grigorovich et al., 2008). In the northeastern part of the Vienna Basin (Slovakia), the assemblage of zones NN3 and NN4 was established in a series of wells in Ottnangian and Karpatian deposits (Andreeva-Grigorovich and Halászová, 2000a). The lower boundary of the Karpatian is within

zone NN4 in the interval from the last appearance data (LAD) of *Sphenolithus belemnus* to the LAD of *Helicosphaera ampliapertura*. The first occurrence (FO) of *Sphenolithus heteromorphus* coincides with the base of zone NN4. The Karpatian/Badenian boundary also passes in the NN4 zone without any significant changes in the calcareous nannofossils (Rögl et al., 2007).

Tarkhanian Regional Stage

Tarkhanian associations of nannoplankton are rich and well studied. They were studied in the stratotype at Cape Tarkhan (Andreyeva-Grigorovich and Savvitskaya, 2000b) and in the hypostratotype on the Azov coast in the section of the Bulganak Bay on the Kerch Peninsula (Barg et al., 1975; Nosovskii et al., 1976; Nosovskii and Bogdanowicz, 1984; Muzylev and Golovina, 1987; Minashvili, 1986; Ivanova et al., 1998; Andreyeva-Grigorovich and Savvitskaya, 2000b; Krasheninnikov et al., 2003; Golovina et al., 2004; Minashvili and Ananiashvili, 2013), and in sections and wells of the Alma Depression on the Crimean Peninsula (Ivanova et al., 1998; Barg and Ivanova, 2000).

In Ciscaucasia, calcareous nannofossils were studied in sections along the Kuban River (Yaman Dzhalga gully) and along the Belaya, Pshekha, Bolshoy Zelenchuk, and Urup rivers (Golovina in Krasheninnikov et al., 2003). In Dagestan, calcareous nannofossils were studied in a section along the Rubaschai River (Krasheninnikov et al., 2003). In western Georgia, calcareous nannofossils were studied in a section along the Chanistskali River near the village of Dzhal, along the Ontkole River and Bardnala Stream, a tributary of the Tskhenistskhali River (Minashvili, 1981; 1986; Muzylev and Golovina, 1987). The sections studied in Azerbaijan are the Adzhiveli section (southern Kobystan) (Muzylev and Golovina, 1987) and section along the Sumgayit River near the village of Perekishkyul (Popov et al., 2008); and the section studied in Turkmenistan is the Geokoba section, western Kopetdag (Muzylev and Golovina, 1987).

The Tarkhanian deposits of Crimea were initially correlated to zone NN4 based on single specimens of *Helicosphaera* cf. *ampliapertura* (Barg et al., 1975). Later, Andreeva-Grigorovich made sure that these finds were wrong: “The joint review of the material by Muzylev and Andreeva-Grigorovich revealed that these finds belonged to poorly preserved *H. carteri* rather than to the species *Helicosphaera ampliapertura*, and the Tarkhanian deposits were assigned to zone NN5 in the next publication, based on the description of the neostratotype (Nosovskii et al., 1976)” (Andreeva-Grigorovich, 2005, p. 31). Further studies confirmed these data (Minashvili, 1981, 1986; Muzylev and Golovina, 1987; Andreyeva-Grigorovich and Savvitskaya, 2000b; Krasheninnikov et al., 2003; Golovina et al., 2004; Minashvili and Ananiashvili, 2013; Palcu et al., 2017). At the same time, references

to the correlation of the Tarkhanian nannoplankton assemblage with the *Helicosphaera ampliaperta* zone (NN4) continue to occur in the works of other researchers (Nosovskii and Bogdanowicz, 1984; Ivanova et al., 1998; Barg and Ivanova, 2000; Nosovskii, 2001; Nosovskii and Ivanova, 2005; Barg, 2008; Barg et al., 2012). Following Andreeva-Grigorovich (2005), we also disagree with the correlation of Tarkhanian to Zone NN4. Multiple sampling of the Tarkhanian sections by domestic and foreign specialists based on calcareous nannofossils (in particular, the Tarkhanian hypostratotype was studied by K. Müller jointly with Muzylev and Golovina in 1980 (unpublished data) did not confirm the presence *Helicosphaera ampliaperta* to the Tarkhanian.

The Tarkhanian of Crimea, Northern Ciscaucasia, western Georgia, Dagestan, and Azerbaijan contain a representative and uniform association correlated with the *Sphenolithus heteromorphus* assemblage (NN5) (Muzylev and Golovina, 1987; Krasheninnikov et al., 2003; Palcu et al., 2017). Below, we provide a brief description of the Tarkhanian divisions, taking into account our own and literary data.

Lower Tarkhanian (Kuvinian/Kamyshlak Beds). In the stratotype section near Cape Tarkhan, calcareous nannofossils represented by few species occurred in the very top of the Kamyshlak Beds in a thin (5 cm thick) interbed of gray calcareous clays (Andreyeva-Grigorovich and Savvitskaya, 2000b). The same assemblage was found in the Kamyshlak Beds of the Malyi Kamyshlak hypostratotype: *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Rhabdosphaera sicca*, *Helicosphaera carteri*, *Sphenolithus heteromorphus*, *Coronocylus nitescens*, and *Sphenolithus moriformis* (Andreyeva-Grigorovich and Savvitskaya, 2000b). Our studies also confirm the presence of this nannoplankton assemblage in the very top of Kamyshlak Beds in the hypostratotype; however, this level was not found in coeval deposits near Cape Kop Takil (Kerch Peninsula) (Golovina et al., 2004). The Kamyshlak deposits of the Kerch Peninsula were formed under deep water conditions, in which anoxic conditions, unsuitable for benthic life and the existence of nannofossils, were probably still preserved (Goncharova, 1989).

In the shallower sections of Ciscaucasia (Bolshoy Zelenchuk River, Yaman Dzhalga gully, and Belaya River), the first finds of calcareous nannofossils are recorded in the Maikopian-like clays of Kuvinian. Under field conditions, the lower boundary of Kuvinian Beds is marked during sampling of the transition from the Maikopian to the Tarkhanian based on the reaction on adding HCl (which is initially very weak and then becomes significant) with the appearance of abundant calcareous nannofossils, foraminifers, and mollusks. The Kuvinian Beds in Ciscaucasian sections (the stratotype of Kuvinian Beds along the Bolshoy Zelenchuk River; Belaya River) contain: *Braarudosphaera bigelowii*, *Calcidiscus* aff. *macintyreii*, *Cocco-*

lithus pelagicus, *Cyclicargolithus floridanus*, *Helicosphaera carteri*, *H. mediterranea*, *H. intermedia*, *H. waltrans*, *Helicosphaera* sp., *Reticulofenestra pseudoumbilicus*, *Rhabdosphaera sicca*, *R. pannonica*, *Rhabdosphaera* sp., *Pontosphaera* sp., *Sphenolithus heteromorphus*, and *S. moriformis* and fragments of *Thoracosphaera* sp. (Krasheninnikov et al., 2003; Golovina's data on field collections in 2019).

The cooccurrence of *Sphenolithus heteromorphus* and *Helicosphaera waltrans* in the association is an important argument for comparing this assemblage with the *Sphenolithus heteromorphus* association of zone NN5. *Helicosphaera waltrans* is a short-lived species used to subdivide the Middle Miocene in the Mediterranean (Theodoridis, 1984; Fornaciari et al., 1996), Central Paratethys (Rögl et al., 2002; Švábenická, 2002; Ćorić and Rögl, 2004; Ćorić and Švábenická, 2004; Bartol, 2009), and Eastern Paratethys (Andreyeva-Grigorovich and Savvitskaya, 2000b). The biohorizon with *H. waltrans* was described in Italy within zone NN5 (Theodoridis, 1984) and corresponds to the transgressive phase of the Lower Badenian (Ćorić et al., 2007).

According to Minashvili, the first representatives of calcareous nannofossils appear in the sections of the Megrelian and Racha-Lechkhumi synclines in Georgia simultaneously with the benthic Lower Tarkhanian macro- and microfauna in conformable sediments in the Rzehakia (oncophoric) layers of the Kozakhurian. The general assemblage includes *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *C. leptoporus*, *Pontosphaera multiposa*, *Helicopontosphaera kamptneri* (= *Helicosphaera carteri*), *Braarudosphaera bigelovi*, *Rhabdosphaera sicca*, *Coronocylus nitescens*, *Sphenolithus heteromorphus*, *S. moriformis*, and *Discoaster variabilis* and corresponds to the lower part of zone NN5 (Minashvili and Ananiashvili, 2013).

Middle Tarkhanian ("Tarkhanian marl", Terek Beds). The Terek Beds of Ciscaucasia (the sections along the Kuban River: Yaman Dzhalga gully, village of Sadovoe, and village of Ust Nevinka; Bolshoy Zelenchuk, Pshekha, and Urup rivers] and in Georgia and northern Azerbaijan (village of Perekishkyul) are characterized by richness calcareous nannofossils. The assemblage is composed by *Coccolithus pelagicus* and frequent *Braarudosphaera bigelowii*, *Coronocylus nitescens*, *C. neogamaton*, *Cyclococcolithus leptoporus*, *Discolitina multipora*, *Helicosphaera carteri*, *H. mediterranea*, *H. intermedia*, *H. waltrans*, *Lithastromation perdurum*, *Rhabdosphaera sicca*, *Reticulofenestra* sp., *R. pseudoumbilicus*, *R. minuta*, *Sphenolithus heteromorphus*, and *S. moriformis*. In all studied sections, this level contains the richest and most diverse nannoplankton association and corresponds to the most seaward conditions of the Tarkhanian paleobasin.

Upper Tarkhanian [Yurakivka (Argun) Beds]. The pattern of distribution of calcareous nannofossils clearly reflects changes in biotic and abiotic condi-

tions in the Late Tarkhanian. In the hypostratotype, a fairly representative assemblage with *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Reticulofenestra pseudumbilicus*, *Sphenolithus* sp., *Helicosphaera carteri*, *Pontosphaera multipora*, *Perfocalcinella fusiformis*, *Thoracosphaera* sp., *Discoaster exilis* (the only find at the base of spiralis clays) continues to exist in a small interval of the lower part of spiralis clays (about 3–4 m) overlying the Tarkhanian marl. This assemblage then sharply decreases and the nannoplankton is rapidly depleted (Muzylev and Golovina, 1987; Krasheninnikov et al., 2003; this paper). Such changes in the composition of calcareous nannofossils in the Upper Tarkhanian deposits of the hypostratotype were noted by all researchers (Nosovskii et al., 1976; Andreyeva-Grigorovich and Savitskaya, 2000b; Krasheninnikov et al., 2003, etc.). The same pattern is observed in the sections of Ciscaucasia and western Georgia (Muzylev and Golovina, 1987; Krasheninnikov et al., 2003). The exception is the Tarkhanian section along the Pshekh River, where there is a subaqueous slumping zone with a mixed assemblage and high abundance of redeposited species almost immediately above calcareous clays (an analog of Tarkhanian marl) (Palcu et al., 2017).

Correlation. Debates about the position of the lower boundary of the Tarkhanian and its range are based mainly on the idea of the presence of nannoplankton of zone NN4 in the sections of the Bulganak anticline and Alma depression of Crimea (Ivanova et al., 1998; Barg and Ivanova, 2000; Nosovskii and Ivanova, 2005). In our opinion, this point of view is insufficiently justified, since it is based on the material that does not have images of stratigraphically important species of calcareous nannofossils and the lists are represented by mixed species of different stratigraphic age (Ivanova et al., 1998).

Following Andreeva-Grigorovich et al., we correlate the Tarkhanian with the lower part of the *Sphenolithus heteromorphus* zone (NN5) based on the cooccurrence of the species *Sphenolithus heteromorphus* and *Helicosphaera waltrans* (in the absence of *H. ampliaperta*) (Andreeva-Grigorovich and Savitskaya, 2000b; Krasheninnikov et al., 2003; Golovina et al., 2004; Andreyeva-Grigorovich, 2005). Comparison with the lower part of the *Sphenolithus heteromorphus* zone (NN5) shows a correlation of the Tarkhanian with the upper half of the Langhian–lower strata of the Seravallian and, consequently, a decisive renewal of the upper strata of the Maikopian Group, since the transition from the Maikopian to the Tarkhanian in Crimean and Ciscaucasian sections is conformable and continuous (Palcu et al., 2017).

L. Švabenická (2002) and S. Ćorić et al. (2007) believe that the first occurrence (FO) of *H. waltrans* is diachronous in the eastern and western parts of the Central Paratethys and in the Mediterranean. Accordingly, any correlation based on the first occurrence of

this species should be considered with caution. Only the first constant occurrence (FCO) of *H. waltrans*, as well as its last constant presence (LCO), are recognized as a reliable stratigraphic marker (Di Stefano et al., 2008; Bartol, 2009). The stratigraphic range of this interval is determined from 15.476 Ma (FCO) to 14.357 Ma (LCO) (Abdul Aziz et al., 2008). In our material, the constant occurrence of *H. waltrans* together with *Sphenolithus heteromorphus* is observed in the Lower and Middle Tarkhanian.

Central Paratethys. According to calcareous nannofossils data, the correlation of Lower Badenian deposits varies in different parts of the Central Paratethys (Andreyeva-Grigorovich and Halášová, 2000a; Švabenická, 2002; Kováč et al., 2007; Piller et al., 2007; Rögl et al., 2007). In Volhyn-Podolia (Ukraine), an abundant and diverse assemblage of nannoplankton of zone NN4 with *Sphenolithus heteromorphus* but still with the presence of *Helicosphaera ampliaperta* was established in *Lentipecten denudatum* Beds at the base of the Early Badenian in the section near the village of Lany (Ivano-Frankivsk Region) and in wells (the villages of Bukovka and Kulikovka, Chernivtsi Region) (Lyul'eva and Prisyazhnyuk, 1992; Prisyazhnyuk et al., 1997). In the sections of the Carpathian region (Slovakia and Ukraine), the lower boundary of the Badenian stage is transgressive and marked by the appearance of *S. heteromorphus* without *Helicosphaera ampliaperta* (which is dated to about 15.1–15.0 Ma) (Andreeva-Grigorovich et al., 2007).

In northern Bosnia, the Lower Badenian deposits are assigned to zone NN5 (Jerković and Ćorić, 2006). In Romania, the Lower and Middle Badenian (Moravian and Velichka) are correlated with the interval of the *Sphenolithus heteromorphus* and *Discoaster exilis* zones (NN5–NN6) (Chira and Vulc, 2003).

In Austria (Styrian basin), basal (Badenian) deposits (Wagna and Retznei sections) were correlated with zones NN4 and NN5, respectively (Rögl et al., 2002, 2007; Hohenegger et al., 2009a, 2009b); however, it has now been proved that the Wagna section cannot be used as a boundary stratotype, since it has no continuous transition from the Karpatian to the Badenian (Hohenegger et al., 2014).

According to the results of deep drilling, a long break (more than 1 million years) between the Karpatian and Lower Badenian Grund formation was established in the Alpine–Carpathian trough (Molasse basin) (Ćorić and Rögl, 2004). The deposits of the Grund Formation are characterized by a rich and diverse nannoplankton of zone NN5 with *Sphenolithus heteromorphus*, *Helicosphaera waltrans*, and *H. walbersdorfensis*, abundant *Reticulofenestra minuta*, and rare *Coccolithus pelagicus* (Ćorić and Švabenická, 2004). In the stratotype area of Grund formation development (the town of Grund near Hollabrunn, Austria), Grund deposits are characterized by an assemblage of zone NN5 with a constant occurrence

of *Helicosphaera waltrans*, a rare occurrence of *H. walbersdorfensis*, and a relatively abundant occurrence of *H. carteri* (Ćorić and Rögl, 2004). A similar assemblage of zone NN5 was established from the Muhlbach locality (Gaiendorf Formation, Austria) (Ćorić, 2003).

The Early Badenian deposits of the Lavanttal Basin (Austria) in the marine part of the Mühldorf Formation are characterized by a rich association of nannoplankton with *Reticulofenestra gelida*, *R. minuta*, *R. haqii*, *R. pseudoumbilicus*, *Helicosphaera carteri*, *H. walbersdorfensis*, *H. wallichi*, *Discoaster adaman-teus*, *D. musicus*, *D. exilis*, and *D. variabilis* together with *Sphenolithus heteromorphus* and *Helicosphaera waltrans*. In the absence of *Helicosphaera ampiaperta*, the assemblage is correlated with the lower part of zone NN5 (the upper strata of the Early Badenian 14.91–14.74 Ma) (Reichenbacher et al., 2007).

Therefore, according to our calcareous nannofossils data, the Tarkhanian deposits are confidently correlated with the second half of the Lower Badenian of the Central Paratethys and, accordingly, with the upper part of the Langhian of the Mediterranean.

Chokrakian Regional Stage

Nannoplankton was not studied in the Chokrakian stratotype (the eastern shore of Lake Chokrak, Kerch Peninsula). In the Chokrakian hypostratotype (Malyi Kamyshlak area), nannoplankton was indicated by many researchers (Barg et al., 1975; Nosovskii et al., 1976; Minashvili, 1981, 1986; Nosovskii and Bogdanowicz, 1984; Muzylev and Golovina, 1987; Minashvili, 1992; Bogdanovich, 1998; Andreyeva-Grigorovich and Savitskaya, 2000b; Krashennnikov et al., 2003; Minashvili and Ananiashvili, 2013).

The results of our studies replicate the previously obtained data on the distribution of calcareous nannofossils in the hypostratotype: a fairly abundant association of nannoplankton continues to exist in a small interval (about 3–4 m) in the clayey series above the deposits of the Middle Tarkhanian (“Tarkhanian marl”), even though its taxonomic diversity decreases and the assemblage is then sharply depleted to several eurybiont species of wide stratigraphic distribution: *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, and *Reticulofenestra pseudoumbilicus*. Slight fluctuations in the abundance and preservation of this meager assemblage can be observed higher up the section.

A similar distribution of nannoplankton is typical for relatively deep-water deposits of the Upper Tarkhanian–Lower Chokrakian interval and can also be observed in the lower strata of the Yaman Dzhalga gully section (on the right bank of the Kuban River). Nannoplankton associations in the Chokrakian sections of western Georgia were studied in detail (Dzhgali, Sachino, Khorshi, Badzhi, Goris, Tsageri,

Chkumi, and other sections) (Minashvili, 1983, 1986; Muzylev and Golovina, 1987; Minashvili and Ananiashvili, 2013). The general list includes *Coccolithus pelagicus*, *Braarudosphaera bigelowii*, *Helicopontsphaera campneri*, *Rhabdosphaera sicca*, *Coronocylus nite-scens*, *Cyclococcolithus leptoporus*, *C. neogammation*, *Lithastromation perdurum*, *Pontosphaera discopora*, *Discolitina multipora*, and *Perforocalcinella fusiformis* (Minashvili and Ananiashvili, 2013). According to Minashvili, the index species *Sphenolithus heteromorphus* “disappears in sections of spirialis clays throughout Georgia together with the Tarkhanian index species of mollusks and foraminifers, while a new species, *Perforocalcinella fusiformis*, appears in the nannoplankton assemblage (its stratigraphic distribution range in Georgia coincides with the range of the Chokrakian Regional Stage)” (Minashvili and Ananiashvili, 2013, p. 156).

The species *P. fusiformis* does not belong to fossil coccolithophorids; it is actually a skeletal element of ascidian spicules (Phylum: Chordata, Class: Ascidiacea of the sub-phylum Tunicata, also known as Urochordata). Ascidiaceans are exclusively marine forms that live in the sublittoral zone down to depths of 200 m, mainly in rocky areas of the seabed. Therefore, the mass development of *Perforocalcinella fusiformis* can serve as a marker of bionomic conditions of the marine basin (Golovina, 2008; Popov et al., 2016). Consequently, nannoplankton assemblages clearly mark the change in the water exchange regime at the Tarkhanian/Chokrakian boundary and characterize stable, relatively shallow marine water conditions throughout the Early Chokrakian in the sections of Georgia (Late Chokrakian deposits were not recognized by Georgian researchers and were probably included in the Karaganian).

Correlation. The Chokrakian nannoflora in the Eastern Paratethys are very impoverished and cannot be correlated by their composition with the assemblages of any zonal subdivisions of the nannoplankton scale. The presence or disappearance of calcareous nannofossils species are associated exclusively with the paleobionomic conditions of the Chokrakian basin.

In the Central Paratethys, the nannoplankton assemblages of zone NN5 were described from many localities of the Lower Badenian (Mărunțeanu, 1992; Mărunțeanu and Chira, 1998; Chira, 1999; Chira and Malacu, 2008; Chira and Mărunțeanu, 2000; Mărunțeanu et al., 2000; Ćorić and Hohenegger, 2008; Andreyeva-Grigorovich et al., 2008); however, it is unclear which part of this zone should be correlated with the Chokrakian.

Karaganian Regional Stage

Nannoplankton was not studied in the Karaganian lectostratotype (section of the Uiratam area, Mangyshlak Peninsula). The scarce calcareous nan-

nofossils was identified from Karaganian deposits in Borehole 6 on the Golitsyn Uplift, Black Sea (Kulichenko et al., 1976b).

In western Georgia, the study of the Dzhgali section revealed a very impoverished assemblage with single *Coccolithus pelagicus*, *Reticulofenestra pseudumbilicus*, and *Braarudosphaera bigelowii* was found in the upper part of Karaganian deposits or in the lower strata of Konkian deposits (Muzylev and Golovina, 1987). This interval may correspond both to the upper strata of the Arkhashenian Beds or to Varna Beds or belong to the Kartvelian Beds of the Konkian.

On the Taman Peninsula, calcareous nannofossils were not found in the deep-water facies of Karaganian deposits (the core of the fold near the Zelensky Hill), as well as in the section along the Pshekha River (Krashennnikov et al., 2003; Popov et al., 2016).

Konkian Regional Stage

The integrated study of the stratotype on the Konka River near the village of Veselyanka revealed single *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Reticulofenestra pseudumbilicus*, and *Discoaster* cf. *deflandrei* in the uppermost part of the section (Barg et al., 2005).

In southern Ukraine, an assemblage of undivided zones NN6–NN7 was established in Sartagan Beds (well 468 near the village of Malaya Belozerk, Zaporozhye region) (Andreeva-Grigorovich and Nosovskii, 1976). Lyul'eva found small *Reticulofenestra pseudumbilicus*, *Helicosphaera carteri*, *Braarudosphaera bigelowii*, *Rhabdosphaera procera*, *Rhabdosphaera* cf. *poculi*, *Coccolithus pelagicus*, etc., in well 158 (Berdiansk graben, southern slope of the Azov Uplift). One or two calcareous nannofossils species are quantitatively developed in the upper part of Konkian and in Lower Sarmatian at a simultaneous general depletion of the species composition of the assemblage, which is associated with the development of anomalous salinity in the basin (Kulichenko et al., 1976a).

In western Georgia, Konkian were studied in sections along the Chkhoushi River and near the village of Dzhgali are characterized by the presence of *Coccolithus pelagicus*, *Coronocyclus nitescens*, *Cyclococcolithus floridanus*, *Rhabdosphaera sicca*, *Reticulofenestra pseudumbilicus*, *Braarudosphaera bigelowii*, and *Cyclococcolithus macintyreii* (Minashvili, 1986; Muzylev and Golovina, 1987). Minashvili (1986) notes a mass development of *Helicosphaera carteri* in the upper strata of the Konkian Regional Stage (the interfluvium of the Khuru–Ochkhauri rivers).

An assemblage with *Coccolithus pelagicus*, *Cyclococcolithus floridanus*, *Reticulofenestra pseudumbilicus*, *Helicosphaera carteri*, *Reticulofenestra gelida*, and *Reticulofenestra minuta* was established in western Kazakhstan (the Mangyshlak Peninsula, Karagaily

section). The species *Calcidiscus leptoporus*, *Helicosphaera wallichii*, *Perforocalcinella fusiformis*, *Rhabdosphaera* sp., *Sphenolithus moriformis*, *Thoracosphaera heimii*, and *Thoracosphaera saxea* occur sporadically. The absence of *Sphenolithus heteromorphus* in the presence of *Cyclococcolithus floridanus* indicates the interval of the zone NN6, the age of which is determined as Konkian and correlated with the Kosovian (Late Badenian) of the Central Paratethys (Bratishko et al., 2015). In an additional sample studied by Golovina, an assemblage with a monodominant association of *Reticulofenestra pseudumbilicus* (>7 µm) together with abundant *Braarudosphaera bigelowii* and rare *Rhabdosphaera sicca*, *Cyclococcolithus floridanus*, and *Helicosphaera carteri*, was identified from this section. This assemblage corresponds to the upper subdivision (*Reticulofenestra pseudumbilicus* Beds, established in the Konkian deposits of the Zelensky anticline section, Cape Panagia (Taman Peninsula) (Golovina in Popov et al., 2016).

In Turkmenistan, the study of the Upper Chokrakian–Konkian deposits (Diodzhi section) revealed single *Coccolithus pelagicus* and *Reticulofenestra pseudumbilicus* only in tentatively Konkian deposits (Golovina et al., 1989).

Konkian were studied most completely and comprehensively on the Taman Peninsula, in the section of the Zelensky anticline. This section was proposed as the main reference section of the Konkian Regional Stage, since Konkian are exposed here in a continuous sequence with a monoclinical occurrence from the Upper Chokrakian to the Maeotian, which makes it possible to trace the coupling of the boundaries of several regional stages (Golovina et al., 2004; Popov et al., 2016; Vernigorova et al., 2017). Nannoplankton was studied here by Muzylev and Golovina (1987) and later by Golovina based on collections of Popov and Zastrozhnov (1998); since 2000, it has been studied several times in the course of integrated biostratigraphic and paleomagnetic studies (Golovina et al., 2004; Vernigorova et al., 2012; Popov et al., 2016). The detailed layer-by-layer sampling of the continuous sequence of Karaganian–Konkian–Sarmatian made it possible to trace the pattern of changes in nannoplankton assemblages during the Konkian (Fig. 13).

The quantitative and qualitative variations of the nannoflora assemblage make it possible to identify three stages of development of the basin (subdivisions *a*, *b*, and *c*), corresponding to the successive phases of the development of marine transgression in the Konkian (Golovina, 2019). The base of the beds is determined by the cooccurrence of nannoflora and microfauna index species for the Konkian. This level is correlated with the base of Kartvelian Beds (Vernigorova et al., 2017). Within the lower part of the beds (subdivision *a*, Fig. 13), there is an association including *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Cricololithus jonesi*, *Reticulofenestra pseudumbilicus*, *Rhabdos-*

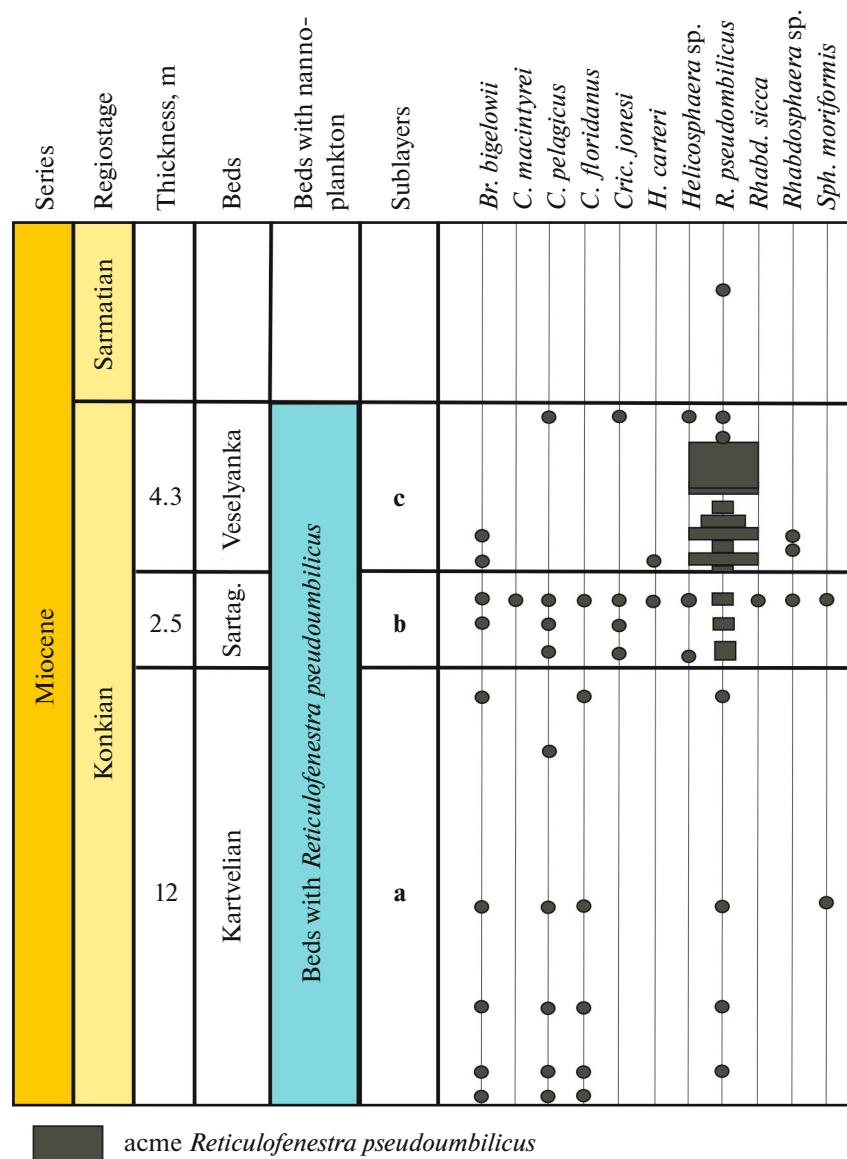


Fig. 13. Scheme of distribution of nannoplankton species and foraminifer genera in the Konkian beds of the Zelensky Hill section.

phaera poculii, *R. pannonica*, *R. sicca*, *Sphenolithus moriformis*, *Discoaster* sp., *Helicosphaera carteri*, *Helicosphaera* sp., *Sphenolithus* sp., and *Thoracosphaera* sp. (Popov et al., 2016).

In the middle part of the beds (subdivision *b*), *R. pseudoumbilicus* becomes increasingly dominant. The abundant nannoplankton becomes a rock-forming component and forms thin interbeds of laminated light clays. The benthic microfauna was characterized here by the richest species diversity (Vernigorova et al., 2017).

The upper part of the beds (subdivision *c*) corresponds to the epibole of the index species in *Reticulofenestra pseudoumbilicus* Beds. The marker bed (up to 1.7 m thick) is composed of exceptionally well preserved calcareous nannofossils, represented mainly by

a monospecies *R. pseudoumbilicus* with rare *B. bigelowii*, *Rhabdosphaera poculii*, and *Rhabdosphaera* sp. The top of beds is determined by the completion of the development of the monotype *R. pseudoumbilicus* and correlated with the boundary of the Konkian and Sarmatian regional stages (Popov et al., 2016; Palcu et al., 2017).

The subdivisions of *Reticulofenestra pseudoumbilicus* Beds (*a*, *b*, and *c*) in the Zelensky anticline section (Fig. 13) correspond to certain stages in the development of the Konkian basin and may probably be correlated with the Kartvelian, Sartagan, and Veselyanka beds; however, they cannot be considered Veselyanka beds. Since, the micropaleontological and nannofloral characteristics are currently absent in the stratotypes of the Kartvelian, Sartagan and Veselyanka Beds

the subdivisions of (*a*, *b*, *c*) do not have the right to be called these Beds. The relatively deep-water deposits of the Zelensky anticline section contain few mollusks; therefore, the demarcation of Konkian deposits is based here solely on micropaleontological data.

Correlation. The *R. pseudumbilicus* Beds that we recognized are traced in the Konkian of Ciscaucasian sections [Belaya (Chumnaya Gully), Pshekha, Fars, and Bolshoy Zelenchuk rivers] and western Kazakhstan (Krashennnikov et al., 2003; Vernigorova et al., 2006; Bratishko et al., 2015; Golovina, 2019) and their richest assemblage is correlated with the undivided assemblage of zones NN6 with *Discoaster exilis*—NN7 (with *Discoaster kugleri*) (Golovina and Vernigorova, 2011). The presence of *Rhabdosphaera poculii* and *R. pannonica* is an important additional biomarker for the correlation, since it was previously believed that these species were present only in the Central Paratethys (Chira, 1999). According to these data, the Konkian Regional Stage is correlated with the Upper Badenian (Kosovian) and corresponds to part of the Serravallian.

Central Paratethys. In Ciscarpathia (town of Kosov, Ukraine), the nannoplankton assemblage from the upper part of the formation in the stratotype section of the Kosov Formation along the Rybnitsa River and in wells 18 (Zabolotov area) is correlated with the undivided association of zones NN6–NN7 (Andreva-Grigorovich and Nosovskii, 1976a). A similar assemblage was established in the saliferous deposits of the Cis-Carpathian Trough (Wieliczka, Bokhno, and Poland) and Kalush (Ukraine) (Andreyeva-Grigorovich et al., 2003). The typical association is represented by *Calcidiscus leptoporus*, *C. macintyreii* (>10 µm), *C. premacintyreii*, *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Coronocyclus nitescens*, *Discoaster exilis*, *D. variabilis*, *Helicosphaera carteri*, *H. walbersdorfensis*, *Pontosphaera multipora*, *Reticulofenestra pseudumbilicus* (>7 µm), *R. minuta*, *Sphenolithus abies*, *Syracosphaera pulchra*, *Triquetrorhabdulus rioi*, *T. rugosus*, and *Umbilulicosphaera* (Andreva-Grigorovich et al., 2008).

In the interfluvium of the Dniester and Prut (Moldova) rivers, calcareous nannofossils from Badenian (Podolsk and Chernivtsi formations) was studied from well sections (Drepkaushy well 11; Korneshty well 15; and Balaneshty well 16). The general Badenian assemblage is quite diverse in these sections and includes more than 20 species, including *Discoaster exilis*, *D. variabilis*, *Sphenolithus heteromorphus*, *Rhabdosphaera sicca*, *Calcidiscus macintyreii*, etc. Based on the occurrence of *S. heteromorphus*, the Podolsk formation is assigned to zone NN 5 and the Chernivtsi formation corresponds to the interval of undivided zones NN5–NN6 (Golovina et al., 1986). In Romania, an assemblage of zone NN6 was established in the Upper

Badenian (Kosovian) (Mărunţeanu et al., 1998a; Chira, 1999).

Sarmatian Regional Stage

Calcareous nannofossils were not studied in the Sarmatian lectostratotype (the village of Shirokoe on the left bank of the Ingulets River, Ukraine). In the hypostratotype (the village of Veselyanka in the Skotovataya gully, Ukraine), nannoplankton was not found in Sarmatian deposits. The Sarmatian calcareous nannofossils are poorer than the Konkian ones and represented by a limited set of eurybiont species. The levels with calcareous nannofossils have a discontinuous local distribution both with respect to the area and with respect to the intervals of the section of Sarmatian deposits.

Lower Sarmatian. In the western part of the Kerch Peninsula, an assemblage with *Coccolithus pelagicus*, *C. miopelagicus*, *Reticulofenestra haqii*, *Cyclicargolithus floridanus*, *Sphenolithus abies*, *S. neoabies*, *S. moriformis*, *Syracosphaera pulchra*, *Rhabdosphaera pannonica*, *Braarudosphaera bigelowi*, *Discolithina* spp., *Helicosphaera* spp., and *Dictyococcites* sp. and single *Discoaster deflandrei*, *D. ex gr. brouweri*, and *D. kugleri* was established in wells (villages of Lenino, Ilyichevo, and Astanino) in the basal beds of the Lower Sarmatian. At some levels of the Lower Sarmatian, monospecific *Coccolithus pelagicus* and small *Reticulofenestra haqii* and *Braarudosphaera bigelowi* are developed at different levels of concentration (from insignificant to moderate level) (Lyul'eva, 2009).

Calcareous nannofossils in the upper part of the Lower Sarmatian on the southern slope of the Ukrainian Shield (Obitochny and Berdyansk grabens) and in Prisivashye (Genicheskaya area, Arabat Spit, and Biryuchy Island), on the Black Sea shelf (Golitsyn, Selsky, Schmidt, and Ilyichevsk uplifts) are characterized by a low general diversity with a predominant development of *Calcidiscus leptoporus* s.l. (Didkovskii et al., 1968; Kulichenko et al., 1976b; Lyul'eva, 1990b, 2009).

In sections of the Taman Peninsula, we studied calcareous nannofossils in the Sarmatian deposits of the Zhelezny Rog, Popov Kamen, and Taman sections and in a section of Cape Panagia, which is proposed as a reference section of the Sarmatian Regional Stage for the south of Russia (Popov et al., 2016). The lower boundary of the Sarmatian was established in a section along the top of *Reticulofenestra pseudumbilicus* Beds, which cover Konkian. The superabundant development of the monodominant association of *Reticulofenestra pseudumbilicus* forms a thick (up to 120 cm) layer of laminated calcareous clays composed of coccoliths and whole coccospheres almost without terrigenous admixture. The lower part of the Lower Sarmatian deposits contains rare *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Sphenolithus moriformis*, and

Lacunolithus menneri. A monodominant association of small species of the genus *Syracosphaera* is particularly abundant in the upper part of the Lower Sarmatian and lower strata of the Middle Sarmatian.

Calcidiscus macintyreii, *Cyclicargolithus floridanus*, and *Reticulofenestra pseudoumbilicus* occur quite often in the upper part of the Lower Sarmatian deposits of Crimea (Zbruch beds); *Coccolithus pelagicus* and *Reticulofenestra pseudoumbilicus* were encountered in the lower part of the Middle Sarmatian (Novomoskovsk beds); calcareous nannofossils are absent in the Upper Sarmatian (Ivanova and Bogdanowicz, 2004).

In Volhynia–Podolia, the Kuzhora and Zbruch beds are characterized by calcareous nannofossils with different degrees of occurrence, periodically dominated by large *Reticulofenestra pseudoumbilicus*, *Coccolithus pelagicus*, and *Calcidiscus leptoporus* s.l. and the endemic *Dictyococcites compactus*. In addition, single *Discoaster variabilis*, *D. exilis*, *D. adamanteus*, *D. deflandrei*, *D. extensus*, *D. aulakos*, *D. gr. brouweri*, and *D. kugleri* were also recorded (Lyl'eva, 2009).

In the Ciscarpathians (Chernivtsi Region), the Lower Sarmatian (Kuzhora Beds) is dominated by *Coccolithus pelagicus*, *Dictyococcites minutus*, and *Cyclicargolithus floridanus*, along with *Reticulofenestra haqii* and *Helicosphaera carteri* (Lyl'eva, 2009).

In the Prut region of Moldova, calcareous nannofossils were studied from boreholes near the villages of Drepkautsy, Balaneshty, and Korneshty (Golovina et al., 1986; Muzylev and Golovina, 1987). The upper part of the Lower Sarmatian and lower part of the Middle Sarmatian contain abundant calcareous nannofossils. The species *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Reticulofenestra pseudoumbilicus*, *Sphenolithus moriformis*, *Cyclicargolithus floridanus*, and *Helicosphaera carteri* are always present. Other species were recorded sporadically: *Calcidiscus macintyreii*, *Discoaster exilis*, *Coronocyclus nitescens*, *Pontosphaera multipora*, *Rhabdosphaera sicca*, etc. Outbreaks of *Reticulofenestra pseudoumbilicus* in the lower part of the Lower Sarmatian and *Calcidiscus macintyreii* in the upper part of the Lower Sarmatian (Drepkautsy Borehole) indicate changes in the biogenic conditions of the Sarmatian basin (Muzylev and Golovina, 1987).

Less diverse associations were established in the Lower–Middle Sarmatian of western Georgia (Chkhoushi section): *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Reticulofenestra pseudoumbilicus*, *Sphenolithus moriformis* (Muzylev and Golovina, 1987). According to Minashvili (1983), in addition to the above-listed species, other species were also recorded: *Rhabdosphaera sicca* and mass development of *Cyclicargolithus floridanus* (in the Lower Sarmatian) and *Rh. clavigera*, *Discoaster variabilis*, and *Catinaster* cf. *coalitus* (in the Middle Sarmatian); this indicates

episodes of a wider marine communication in this part of the basin in the Sarmatian time.

An impoverished calcareous nannofossils from the lower strata of the Lower Sarmatian with *Coccolithus pelagicus*, *Reticulofenestra pseudoumbilicus*, and *Cyclococcolithus rotulus* was established by Andreeva-Grigorievich in the Tyub-Karaganian section (Mangyshlak) section (*Neogenovaya sistema*, 1986, p. 147).

In Turkmenistan (Diodzhi section), *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Braarudosphaera bigelowii*, and *Calcidiscus leptoporus* were identified in the lower part of Lower Sarmatian. A similar assemblage is present in the Lower–Middle Sarmatian of the Archman section. The study of the diatom formation (Sarmatian–Maeotian–Pontian; section Adzhiveli 2) revealed single *Coccolithus pelagicus* in the interval corresponding to the Sarmatian (Golovina et al., 1989).

In the Caspian part of Iran, sandstones of the Lower Sarmatian in the Babol and Talar rivers contain *Coccolithus pelagicus*, *Helicosphaera carteri*, *Sphenolithus* sp., *Reticulofenestra* sp., *Calcidiscus leptoporus*, *Discoaster deflandrei*, and *Coccolithus miopelagicus* (Popov et al., 2015).

Middle Sarmatian. In the Middle Sarmatian deposits of the Alma depression of Crimea, calcareous nannofossils are represented by several species: *Perfocalcinella* ex gr. *fusiformis* and *Thoracosphaera* spp. and small *Syracosphaera didkovskyi*, *Noelaerhabdus bozsnovicae*, and *Noelaerhabdus* sp. (Lyl'eva, 2009).

In the sections of the Taman Peninsula, a rapid development of small *Syracosphaera* spp. is recorded in the sediments of the upper strata of the Lower Sarmatian and lower strata of the Middle Sarmatian of the Panagia section. Rare *Pontosphaera* sp., *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, and *Rhabdosphaera* sp. were recorded after the completion of the acme of small *Syracosphaera*. Rare finds of *C. pelagicus* and *Reticulofenestra* sp. were recorded in the upper strata of the Middle Sarmatian; in Upper Sarmatian, single finds are recorded only in some specimens.

A calcareous nannofossils with *Calcidiscus leptoporus* s.l. (including *C. macintyreii*), *Reticulofenestra pseudoumbilicus*, *Coccolithus pelagicus*, *Braarudosphaera bigelowii*, *Perfocalcinella* ex gr. *fusiformis*, and *Geminilithella rotula* was established in the Middle Sarmatian of the eastern Cis-Azov Region (Novomoskovsk beds, the basin of the Gruzinsky Elanchik River). The association includes *Catinaster calyculus*, a marker species for zone NN8 (Lyl'eva, 2009).

An assemblage with *Coccolithus pelagicus* and *Cyclococcolithus leptoporus* (= *Calcidiscus leptoporus*), *Cyclococcolithus macintyreii* (= *Calcidiscus macintyreii*), *Helicopontosphaera carteri* (= *Helicosphaera carteri*), *Reticulofenestra pseudoumbilicus*, *Rhabdosphaera sicca*, *R. clavigera*, and *Catinaster* cf. *coalitus* was found in the Middle Sarmatian of Georgia. Based on the last

find, the association is correlated with the *Catinaster coalitus* zone (NN8) (Minashvili, 1986).

A depleted assemblage was found in the Middle Sarmatian deposits of the Mikhailovka quarry (the valley of the Yuzhny Bug River near the village of Mikhailovka, Ukraine) (Prisyazhnyuk et al., 2006).

Upper Sarmatian. In the Upper Sarmatian clays of the eastern part of the Kerch Peninsula, there are sporadic finds of eurybiont species of calcareous nannofossils. A strongly impoverished calcareous nannofossils were also found in the lower part of the Upper Sarmatian (Eldari section along the Iori River) (Muzylev and Golovina, 1987).

Calcareous nannofossils were not found in the Upper Sarmatian from the Zhelezny Rog, Taman, and Popov Kamen sections. From the middle of the Middle Sarmatian, the sedimentation regime changes in the sections of the Taman Peninsula, and siliceous microorganisms become dominant in plankton associations and form the leading group in the Late Sarmatian time.

Correlation. The richest and most diverse associations are confined to the Lower Sarmatian and lower strata of the Middle Sarmatian; however, they are depleted and contain very few stratigraphically important species. The materials of Lyul'eva (2009) and Minashvili (1986) recorded single (literally one to two specimens) finds of such species: the index species *Discoaster kugleri* (zone NN7) in the Lower Sarmatian of the Kerch Peninsula and Volhynia-Podolia, index species *Catinaster calyculus* (zone NN9) in the upper strata of the Lower Sarmatian and in the Middle Sarmatian of southern Ukraine, and *Catinaster cf. coalitus* (zone NN 8) in the Middle Sarmatian of Georgia. However, these rare, unique finds (along with the general depletion of the Sarmatian nannoflora) do not make it possible to clearly determine criteria for the correlation with zonal nannoplankton assemblages. Our observations support the opinion of Lyul'eva "that it is difficult or impossible to clearly identify nannoplankton zones in most of the specific sections of the Sarmatian based on standard criteria; accordingly, the position of the Sarmatian in the nannoplankton zonal scale should be considered debatable" (Lyul'eva, 2009, p. 328).

In the Central Paratethys, the lower strata of the Sarmatian (Volhynian) in the Romanian part of the eastern Carpathians are assigned to zone NN7, the lower strata of zone NN8, the Middle Sarmatian (Bessarabia) to the upper strata of zone NN8 and to zone NN9, and the Upper Sarmatian, presumably, to the upper strata of NN9–lower strata of NN10 (Mărunțeanu et al., 1998b).

Sarmatian nannoplankton assemblages including zonal species of zones NN8–NN9, NN10, and ?NN11 were established in suprasaliferous deposits of the Precarpathian Trough (Gazdzicka, 1994; Wojcik and Jugowiec, 1998). The association of zone NN9

was determined in Slovakia (East Slovak Depression) (Andreyeva-Grigorovich et al., 2003). In Transcarpathia, the presence of stratigraphically important *Catinaster mexicanus* and discoasters from the *Discoaster bellus* group, together with the index species *Catinaster coalitus* (zone NN8), was recorded in the Middle Sarmatian (Almash Formation, Khust section) (Lyulyeva, 2009). In Croatia, the Sarmatian s. str./Pannonian boundary is established within zone NN8 (Galović, 2010, 2017).

The identification of these zonal nannoplankton assemblages in isolated sections of different formations of the Central Paratethys does not yet make it possible to directly correlate them with certain subdivisions of the Sarmatian of the Eastern Paratethys.

Maeotian Regional Stage

The Maeotian stratotype (the western shore of the Kerch Strait near the town of Arshintsevo) is represented by shallow water deposits and can hardly be used for studying calcareous nannofossils. Deeper deposits are exposed in the Popov Kamen, Panagia, and Zhelezny Rog reference sections (Taman Peninsula). Calcareous nannofossils from Maeotian of Crimea, the Taman Peninsula, and other regions has been studied by many researchers (Semenenko and Lyul'eva, 1978, 1982; Kalinichenko and Pronin, 1985; Semenenko, 1987; Pronin and Kalinichenko, 1988; Lyul'eva, 1990a, 1993; Bogdanowicz and Ivanova, 1997; Golovina in Popov et al., 2016).

In the stratotype area of development of Pontian (Odessa, Bolshoy Fontan station 16), a nannoflora assemblage, represented by eurybiont species, such as *Coccolithus pelagicus*, *Calcidiscus leptoporus*, *C. macintyreii*, and *Reticulofenestra pseudoumbilicus*, was identified in Maeotian underlying the Pontian (Pronin and Kalinichenko, 1988). On the shelf of the north-western part of the Black Sea (Borehole 6, Golitsyn Uplift), Maeotian also contain an impoverished assemblage (Kulichenko et al., 1976b).

The presence of an impoverished calcareous nannofossils, but with zonal species, is recorded in the Lower Maeotian of Crimea on the Ak-Manai Isthmus (Borehole 501, the village of Frontovoe, Kerch Peninsula) (Bogdanowicz and Ivanova, 1997). *Catinaster calyculus* was recorded in Maeotian deposits of the Alma depression (Ivanova and Bogdanowicz, 2004).

A more diverse calcareous nannofossils were recorded from the Maeotian of the Taman Peninsula (Semenenko and Lyul'eva, 1978, 1982; Semenenko, 1987; Lyul'eva, 1990a).

We studied calcareous nannofossils in sections of the Taman Peninsula from 1997 in combination with lithobiostratigraphic and magnetostratigraphic research (Radionova and Golovina, 2004; Radionova and Golovina, 2011; Popov et al., 2016). Our data are based on studying calcareous nannofossils in the

Lower and Upper Maeotian both in the Popov Kamen reference section and in the Panagia and Zhelezny Rog sections associated with the Popov Kamen section (Popov et al., 2016).

Lower Maeotian. In bryozoan limestone blocks, abundant ascidian spicules were found at the base of the Maeotian (Popov Kamen and Taman sections), which indicates the shallowness of the biohermal facies. The overlying deposits of the Lower Maeotian are represented mainly by diatomaceous clays. Under conditions of the predominant development of diatoms, calcareous nannofossils finds are recorded only in separate narrow intervals and include *Braarudosphaera bigelowii*, *Calcidiscus leptoporus*, *Calciosolenia* sp., *Coccolithus pelagicus*, and *Reticulofenestra minutula* and rare *Reticulofenestra pseudumbilicus*, *Helicosphaera* sp., *Rhabdosphaera sicca*, *Rhabdosphaera* sp., and *Syracosphaera* sp. The presence of *Isolithus semenko* and *Isolithus* sp. and numerous morphotypes of the genus *Lacunolithus* is also recorded. Representatives of the genus *Lacunolithus* were first described by Lyul'eva (1989b) from the Zhelezny Rog section of the Taman Peninsula. The range of distribution of the type species, *Lacunolithus menneri*, is limited to the Maeotian; however, according to the description by Lyul'eva, the species is most characteristic of deposits from the Lower Maeotian.

Upper Maeotian. In deposits of the Upper Maeotian, the pattern of the nannoflora assemblage changes significantly. Representatives of the genus *Perfocalcinella* become abundant here; they represent microscopic skeletal elements of ascidians, rather than planktonic organisms. It is possible that representatives of the genus *Micrascidites* are also the skeletal remains of ascidians. According to our observations, the high abundance of *Perfocalcinella* and *Micrascidites* is a characteristic feature of the lower part of the Upper Maeotian of the Crimea and Taman Peninsula, which indicates shallow, but undeniably marine conditions. Fusiform forms with a longitudinal crest along the long axis are especially numerous; there are also "druses" or "intergrowths" of "spindles" (Golovina, 2008; Popov et al., 2016).

A diverse and abundant nannoflora, dominated by *Braarudosphaera bigelowii* and very small (1 to 3 µm) *Acanthoica* sp. and *Syracosphaera* spp., appears in the upper part of the Upper Maeotian. Single specimens of *Discoaster intercalaris* and *Discoaster* sp. were found in the Popov Kamen section. The level with this peculiar calcareous nannofossils is well observed in all Maeotian parts of the sections of the Taman Peninsula (Fig. 14); however, it is most fully represented in the Zhelezny Rog section, where a continuous sequence of Maeotian and Pontian is revealed. This interval is only partially represented in shallower sections (Popov Kamen and Taman). The monospecific *Braarudosphaera bigelowii*, alternating with the monospecific association of diatoms, suggests that the sediments

were formed in the frontal zone of interaction between marine and brackish water masses at a high trophic content of the basin.

The combined analysis of the distribution of diatoms and nannoflora made it possible to reveal the features of the formation of these peculiar deposits corresponding to different stages of marine transgression and substantiate the identification of an auxiliary biostratigraphic subdivision (***Braarudosphaera bigelowii* Beds**) and propose the Zhelezny Rog section as a stratotype for this biohorizon (Radionova and Golovina, 2011; Popov et al., 2016; Golovina, 2019).

With respect to the pattern of distribution of calcareous nannofossils, the beds in the Zhelezny Rog section are divided into three parts: **a**, **b**, and **c**; each of them characterizes a certain stage of development of marine transgression (Fig. 14). The biohorizon Unit **a** is characterized by a more abundant and richer calcareous nannofossils; it corresponds to the beginning of the new marine stage in the upper strata of the Maeotian. The lower boundary of the beds is established in the upper part of the Upper Maeotian based on the appearance of calcareous nannofossils dominated by *Braarudosphaera bigelowii*, frequent *Syracosphaera pulchra* and *S.* sp., less frequent *Coccolithus pelagicus*, and single *Discoaster* sp., *D. intercalaris*, and *Lithostromation perdurum*, *Reticulofenestra* spp., *Rhabdosphaera* sp., and *Thoracosphaera* sp., together with marine diatom species (Radionova and Golovina, 2011).

The middle part of the biohorizon of *Braarudosphaera bigelowii* Beds (Unit **b**) corresponds to the second stage of transgression. This stage is characterized by periodic outbreaks of rapid development of monoton taxon diatom and coccolithophorid communities, as well as by the formation of thick laminated diatomite interbeds, in which thin calcareous interbeds composed of a *B. bigelowii* monoton taxon assemblage alternate with siliceous interbeds formed from a monoton taxon *Actinocyclus octonarius* assemblage (Radionova and Golovina, 2011; Popov et al., 2016).

The upper part of the biohorizon, Unit **c**, corresponds to the final stage of marine transgression. A deterioration of the communication with the open sea basin is recorded by a sharp depletion of the calcareous nannofossils and by the presence of freshwater diatom species (Radionova and Golovina, 2011). The lower boundary of subdivision **c** is close to the Maeotian boundary (Pontian), which is determined by the appearance of the mollusk *Paradacna abichi* and organic-walled phytoplankton species *Galeacysta etrusca*, probably of Pannonian origin (Fig. 14). The upper boundary of *Braarudosphaera bigelowii* Beds is established by the disappearance of calcareous nannofossils in the Lower Pontian, directly above diatomite N. *B. bigelowii* Beds in the Zhelezny Rog section are readily recognized by lithology (a distinct diatomite

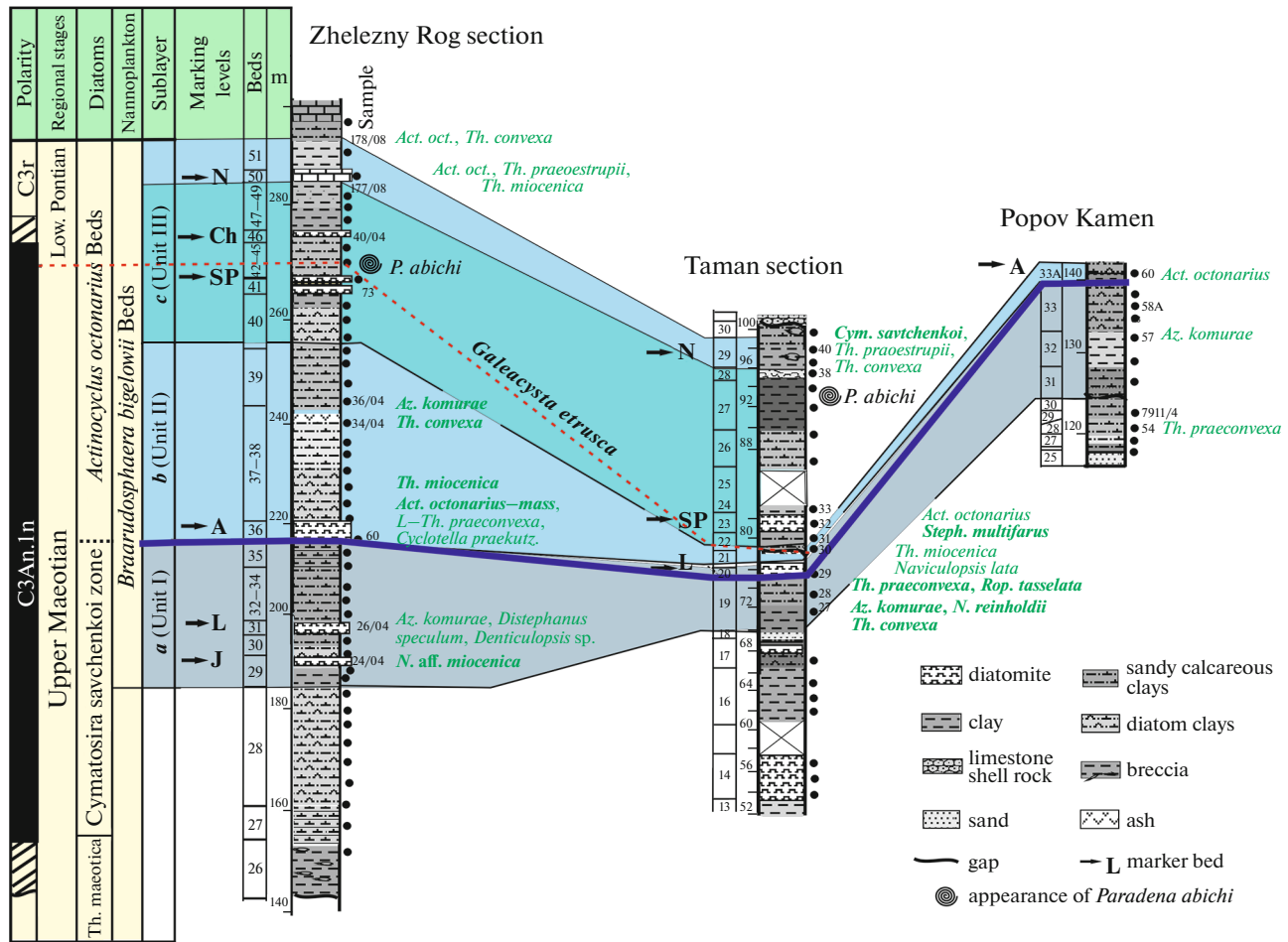


Fig. 14. Scheme of correlation of sections of the Upper Miocene of Taman with rich assemblages of diatoms and with the nannoplankton of *Braarudosphaera bigelowii* Beds in the Upper Maeotian–Lower Pontian (according to Radionova and Golovina, 2011).

series of varying thickness, corresponding to the interval from diatomite L to diatomite N).

Correlation. In the Maeotian of the Kerch Peninsula (well 15, Chegerchinskaya Trough), the uppermost part of the Maeotian is correlated with the interval of zone NN10 with *Discoaster neohamatus* (*D. neorectus* Subzone) based on finds of *Discoaster neohamatus* and *D. neorectus* (Semenenko and Lyul'eva, 1982). Later, an association of the *Discoaster neohamatus* Zone (zone NN10) was also established in the Maeotian of the Panagia section (Taman Peninsula) (Semenenko, 1987). Analysis of the assemblage shows that this correlation is not entirely correct, since the zonal index species *D. neohamatus* was not found in Taman and the list includes species with open nomenclature and different stratigraphic ranges. The uppermost strata of the Maeotian are correlated with the Tortonian/Messinian boundary based on the presence of nannoplankton of zone NN11a and finds of *Globigerinoides obliqua extremus*, which were recorded

at the Maeotian/Pontian boundary (Semenenko, 1987; Semenenko and Lyul'eva, 1982).

Following Semenenko and Lyul'eva, Bogdanowicz and Ivanova (1997) also correlate the Crimean Maeotian with the Tortonian by correlating the lower part of the Bagerian substage with the *Discoaster hamatus* zone (NN9) and upper part of this substage and Akmanaian Substage with the interval of the *Discoaster neohamatus* zone (NN10) (*D. bellus* Subzone) based on the presence of index species of these subdivisions together with stratigraphically important species (Ivanova and Bogdanowicz, 2004). In our opinion, the autochthony of these assemblages is unreliable. Tables depicting the stratigraphically important species *Discoaster neohamatus*, *D. hamatus*, *Catinaster coalithus*, and *C. calyculus* are absent and the accompanying assemblage is represented by a few eurybiont species with a wide range, including redeposited Paleogene discoasters. The appearance of *Lithostromation perdurum* in the uppermost strata of the Akmanaian Substage, noted by the authors as an additional

marker of NN10–NN11 zones, is insignificant, since *L. perdurum* has a very wide stratigraphic range (from the Paleogene (Lutetian) to the Pleistocene) and is rather an ecological indicator.

Lyul'eva established the *Lacunolithus menneri* Zone in Maeotian, the stratotype of which are “Maeotian of the Taman Peninsula (to the west of Cape Panagia). The zone is recognized in the Maeotian of the Kerch–Taman region and in western Georgia (Galidzga River)” (Lyul'eva, 1989a, p. 13).

Unfortunately, there are no more clear criteria for identifying this zone and its position in sections. The *Lacunolithus menneri* is proposed as an index species for the Maeotian and *Isolithus semenenko* as an index species for the Pontian (Lyul'eva, 1989a); however, in the Pannonian deposits of the Szák Formation (northwestern Hungary), both species occur together (Cziczter et al., 2008). In our material, *Lacunolithus menneri* is represented in different morphotypes in the Lower Maeotian of the Popov Kamen section (Golovina, 2008; Popov et al., 2016).

The high abundance of *Braarudosphaera bigelowii* together with several calcareous nannofossils, which was previously recorded in the Zhelezny Rog section in the Upper Maeotian (Semenenko, 1987), is also confirmed in our studies. This interval was studied in more detail, including the identification of an auxiliary biostratigraphic unit, namely, *Braarudosphaera bigelowii* Beds (Popov et al., 2016).

In the Zhelezny Rog section, sparse calcareous nannofossils were initially recorded at the contact between the Maeotian and Pontian (Semenenko and Lyul'eva, 1978); in further works, *Amaurolithus primus* and *A. delicatus* are recorded in this interval as markers of the upper part of standard zone NN11 with *Discoaster quinqueramus* (Semenenko and Lyul'eva, 2006). In our material, these finds in the Zhelezny Rog section were not confirmed.

According to the results of our research, calcareous nannofossils in the Lower Maeotian in the sections of the Taman Peninsula occurs in narrow carbonate interbeds in the diatomaceous clay series. The assemblage is relatively diverse, which indicates marine conditions; however, it does not contain stratigraphically important species.

In the upper Maeotian, several eurybiont species occur discretely and the *Braarudosphaera bigelowii* biohorizon was established only in the upper strata of the Maeotian, where it can be recognized in all reference sections of the Taman Peninsula (Zhelezny Rog, Taman, Panagia, and Popov Kamen). The presence of *Discoaster intercalaris* suggests that the association corresponds to part of the stratigraphic range of *D. intercalaris*, which covers the interval of zones CN9A–CN10A (upper strata of the Tortonian–Messinian) (Okada and Bukry, 1980). Based on the finds of index-species for oceanic diatom zones, the formation of *Braarudosphaera bigelowii* Beds is estimated

from 6.3 to 5.9 Ma and correlated with the Messinian (Radionova and Golovina, 2011; Radionova et al., 2012; Golovina et al., 2019). In the Dacian Basin (Romania), assemblages of the zone NN11b with *Discoaster quinqueramus* are established in the Upper Maeotian and in transitional Maeotian/Pontian deposits (Mărunțeanu et al., 1998b; Snel et al., 2006).

Pontian Regional Stage

In the stratotype area for the Pontian near the city of Odessa (Ukraine) (Novorossiysk Substage), calcareous nannofossils were established in the most basal beds of the Pontian and represented by very rare finds (Kalinichenko and Pronin, 1985; Pronin and Kalinichenko, 1988). Calcareous nannofossils were not found in shallow-water deposits of the Pontian hypostratotype (Kamysh-Burun section in the town of Arshintsevo, Kerch Peninsula) (*Stratotypes...*, 1975).

In the Northern Black Sea region (the village of Vinogradovka), only a few eurybiont species with a wide stratigraphic range were found in Pontian (Prisyazhnyuk et al., 1994). A monodominant cold-water species, *Dictyococcites “perplexus”* (= *antarcticus*), was recorded in the Lower Pontian of southwestern Crimea (the village of Lyubimovka, mouth of the Belbek River), along with abundant *Perforacalcinella* ex gr. *fusiformis* (Semenenko et al., 1999; Pevzner et al., 2004).

A calcareous nannofossils with numerous *Isolithus semenenko* was established in Pontian of the Taman Peninsula (Zhelezny Rog) (Lyul'eva, 1989). An assemblage with *Coccolithus pelagicus* *Calcidiscus macintyreii*, *Helicosphaera carteri*, *Amaurolithus primus*, *Scafolithus fossilis*, *Triquetrorhabdulus rugosus*, and *Scyphosphaera* sp. was found in Pontian of the central part of the West Kuban Trough (borehole SG-12000, data of Lyul'eva in *Geology...*, 1991).

The boundary deposits of the Upper Maeotian and Lower Pontian at Cape Zhelezny Rog were studied from the collections of M.A. Pevzner, I.S. Chumakov, N.Yu. Filippova, etc., and according to our own collections (1985–1990; 2000–2014). Detailed studies of the sequence of Maeotian–Pontian–Kimmerian in the Zhelezny Rog section (Taman Peninsula) were supplemented by studying this sequence in deep-water deposits of the Black Sea (Hole 380A DSDP) (Radionova and Golovina, 2011; *Paleontology...*, 2016; Golovina et al., 2019). The combined study of calcareous nannofossils and diatoms in the Zhelezny Rog section and in Hole 380A showed the same sequence of ecological events and facies replacement (Fig. 15) and recognized the following beds:

- (1) the Lower Maeotian with depleted marine phytoplankton associations (7.8–6.7 Ma according to paleomagnetic data);
- (2) breccia and Beds with nonmarine diatom flora of the *Coscinodiscus jambori* zone (6.6–6.3 Ma);

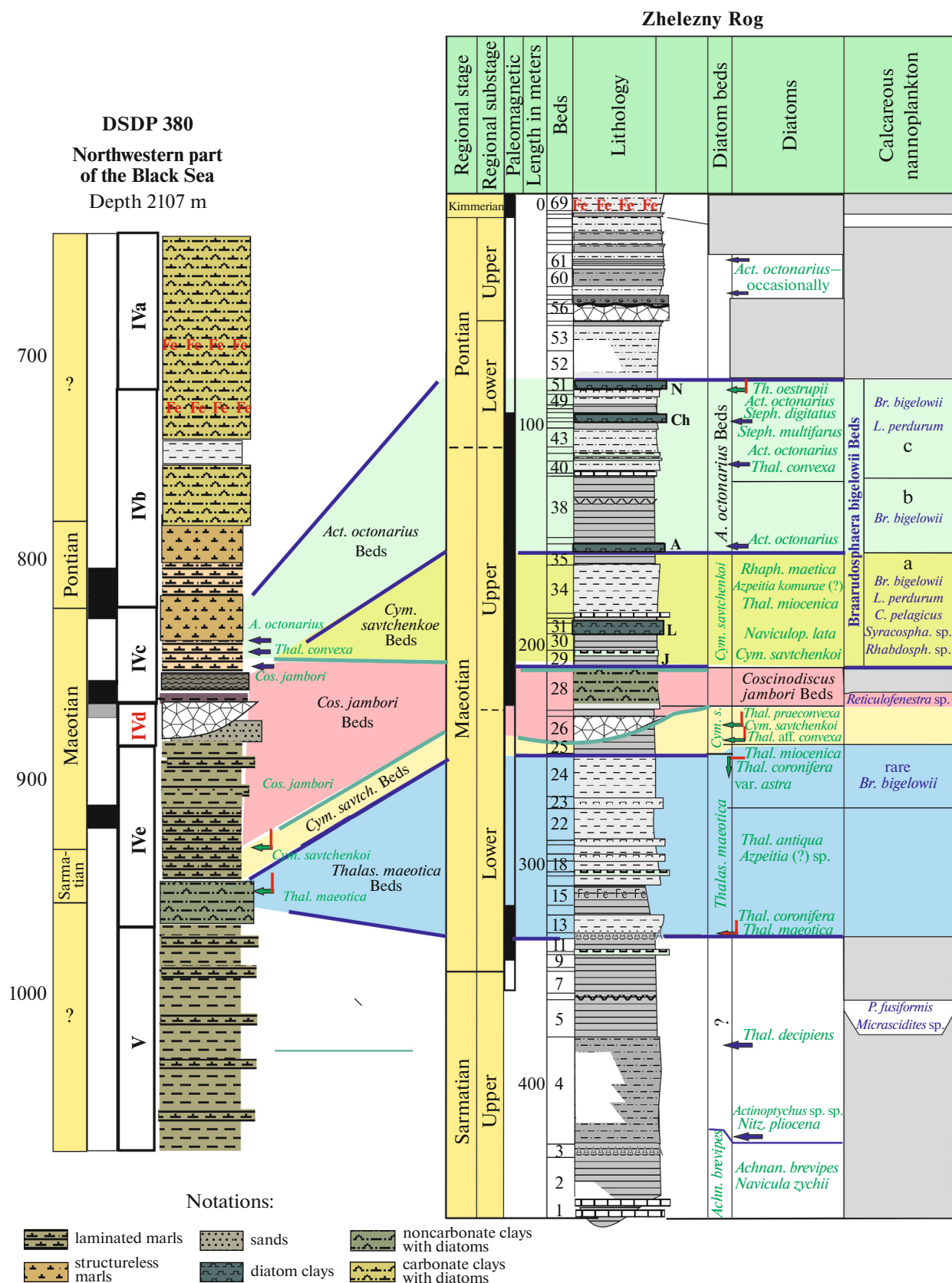


Fig. 15. Scheme of correlation between the Zhelezny Rog section and DSDP 380 Hole based on nannoplankton and diatoms (according to Golovina et al., 2019, with supplements).

(3) Beds with marine phytoplankton of *Braarudosphaera bigelowii* Beds, subdivisions *a* and *c*, which are dated to the Late Maeotian (6.3–6.1 Ma) according to the benthic fauna and paleomagnetic data;

(4) interbedding of Beds with of marine phytoplankton *Braarudosphaera bigelowii*, Unit *c*, and interbeds with brackish-water–freshwater diatoms (6.1–5.9 Ma), dated as Early Pontian based on benthic fauna and dinocysts.

We consider the formation of breccia as the result of slope slumping during the lowering of the level of the Euxinic basin at the beginning of the Late Maeotian. Bed (3) with nonmarine flora (brackish-water and freshwater diatoms of the *Coscinodiscus jambori* zone) was formed in a closed basin that was not connected with the Mediterranean. This connection was recovered at the turn of the Maeotian–Pontian, followed by the appearance of nannoplankton and oceanic diatom flora. Based on benthic fauna and dinocysts, the connection with the brackish-water Aegean and/or Pannonian basin, from which highly endemic Pontian fauna came, is dated as the beginning of the Early Pontian. However, the characteristic features of calcareous nannofossils and diatoms show a simultaneous connection with a more saline sea basin at that time. The connection was constant at the beginning of this transgression; however, it became discontinuous very soon and took on the character of separate pulses. The final disconnection with the Mediterranean Sea in the Zhelezny Rog section is recorded by the disappearance of nannoplankton and marine diatom species directly above diatomite N (the top of *Braarudosphaera bigelowii* Beds) (Radionova and Golovina, 2011; Golovina et al., 2019). According to Rostovtseva, the geological age of the level with diatomite N is estimated at 5.88 Ma (Rostovtseva and Rybkina, 2014; see Fig. 34).

Correlation. In our opinion, the correlation of the depleted assemblages of Pontian nannoflora, as well as the Maeotian of the Eastern Paratethys, with the zonal divisions of the oceanic scale should be recognized as insufficiently substantiated.

In the Dacian Basin, an assemblage of zone NN11b with *Amaurolithus delicatus*, *A. primus*, *Discoaster quinqueramus*, and *Trithorabdulus rugosus* was established in Pontian in the Portaferian–Bosphorian (Badislava section). The deposits of the Upper Pontian and Lower Dacian (Valya Vatsi section) contain a nannoplankton assemblage of zone NN12 with *Amaurolithus tricorniculatus* and *Ceratolithus acutus* (data of Mărunțeanu in Snel et al., 2006). However, one should keep in mind the discrepancy between the range of the Pontian in the Euxinic and Dacian basins.

Based on the presence of *Ceratolithus acutus*, an impoverished association correlated with NN12 was established in the Aegean region in the northern part of the Aegina Island (Saronic Gulf, Greece) in the Souvala 2 section in the Houmnicon Formation, cor-

related with the Pontian with respect to common endemic mollusk genera and species (Rögl, 1991).

Kimmerian Regional Stage

The Kimmerian lectostratotype is unsuitable for studying calcareous nannofossils due to its shallow water conditions, as well as due to the incompleteness of the section (it does not have the basal part of the Kimmerian, i.e., Azov beds).

Calcareous nannofossils from the Kimmerian deposits of the Kerch–Taman region was studied in the Zhelezny Rog section (Semenenko and Lyul'eva, 1982; Muzylev and Golovina, 1987; Lyul'eva, 1990a; Popov et al., 2016), in the Chegerchinskaya Depression of the Indol Trough (Kerch Peninsula, Arabat Spit), from the Lower Kimmerian of the Galidzga River (Abkhazia), and from the Ambra River (Georgia), as well as from Dacian (town of Reni, lower reaches of the Danube River, Ukraine) (Semenenko and Lyul'eva, 1982, 2006; Lyul'eva, 1990a). Calcareous nannofossils from deep-water sediments of the Black Sea was studied using the holes of the Deep Sea Drilling Project (DSDP) (Holes 379, 380, and 380A, Leg 42-A); however, no stratigraphically significant nannoplankton assemblages were found in the Pliocene interval (Muzylev and Golovina, 1987; Golovina et al., 2019).

A rich and diverse assemblage, including *Amaurolithus amplificus*, *A. primus*, *A. delicatus*, *A. tricorniculatus* (= *Ceratolithus tricorniculatus*), *Ceratolithus acutus*, *Sphenolithus neoabies*, *Helicopontosphaera* (= *Helicosphaera*) sp., *Reticulofenestra pseudoumbilicus*, *Scyphosphaera globulosa*, *S. lagena*, *Coccolithus pelagicus*, *Discoaster brouweri*, *D. variabilis*, *D. icarus*, *D. quinqueramus*, etc., was established in a series of well sections in the Lower Kimmerian of the Indol Trough (Chegerchinskaya Depression, Kerch Peninsula) (Semenenko and Lyul'eva, 1982, 2006; Semenenko, 1987; Lyul'eva, 1990a). Long-term attempts to find this level of presence of *Ceratolithus acutus* in the zone of transition from the Azov to the Kamysht-Burun beds of the Kimmerian in Cape Zhelezny Rog proved to be unsuccessful (Muzylev and Golovina, 1987; Popov et al., 2016).

In the Azov Beds of the Kimmerian, we established a monoassociation *Isolithus semenenko* in the Taman section (Popov et al., 2016). This species was first described by Lyul'eva (1989a) from the Pontian of the Zhelezny Rog section; later, she also designated the stratotype of the *Isolithus semenenko* Zone in the same section, which was characterized by the presence of the index species together with a very diverse calcareous nannofossils. Lyul'eva pointed out that there was also a monotype flora *Isolithus semenenko* Luljewa, 1989 and that the zone was traced in the Pontian of the Kerch–Taman zone and Black Sea coast of the Caucasus (near the town of Gudauta). Unfortunately, the

geological reference of the proposed zone and criteria for its identification were not given by the author. Lyul'eva proposed to use the appearance of endemic *Lacunolithus menneri* as an index species for the Lower Maeotian and *Isolithus semenenko* as a species-index for Pontian. However, the co-occurrence of these species was later established in Pannonian deposits of Hungary (Cziczter et al., 2008). A mass distribution of *Isolithus semenenko* was recorded in the Upper Sarmatian (s. str.) and Pannonian of Croatia (Čorić, 2005; Galović, 2010, 2017), Slovakia (Vlček et al., 2020), and Romania (Chira and Vulc, 2003; Chira and Malacu, 2008). The presence of *Isolithus semenenko* and its mass distribution are considered a sign of shallow water conditions with increased inflow of river waters (Galović, 2017).

Correlation. The Lower Kimmerian (Azov Beds) is correlated with zone NN11 (which corresponds to the Messinian) based on presence zonal markers (*Amaurolithus delicatus*, *Amaurolithus tricorniculatus*, *Ceratolithus acutus*, and *Ceratolithus rugosus*). The Middle Kimmerian and Upper Kimmerian are correlated with the interval of zones NN11–NN13 (which corresponds to the Zanclean and, possibly, Piacenzian) (Semenenko and Lyul'eva, 1978, 1982; Semenenko, 1987; Lyul'eva, 1990a). The presence of almost all main zonal markers of the Late Miocene–Pliocene along with the extensive calcareous nannofossils (according to Lyul'eva, the total list includes about 40 species) assumes open-sea basin conditions in the Kimmerian time.

Further studies of calcareous nannofossils did not confirm the presence of these rich and diverse nannoplankton assemblages in the DSDP Holes of the Black Sea (Shumenko and Ushakova, 1980; Muzylev and Golovina, 1987; Golovina et al., 2019); however, they showed that the distribution of calcareous nannofossils was much more wider than that established during the initial study by S. Percival (Percival, 1978). Therefore, finds of zonal species from the Kimmerian of the Euxinic Basin have not yet been confirmed. At the same time, in the western areas of the Eastern Paratethys (Romania), the assemblage of zone NN12 with the index species *Ceratolithus acutus*, *Amaurolithus delicatus*, and *A. tricorniculatus* is marked in the Upper Pontian and Lower Dacian (Snel et al., 2006). In our opinion, the still insufficient level of study of the Kimmerian calcareous nannofossils leaves the question of the nature of its assemblages open. At the same time, if “ceratoliths occur extremely rarely (from single to two–three specimens) and their search requires a non-standard review” (Lyul'eva, 1990a), these features reduce the possibility of reproducibility of the results in further studies based on the standard method of studying calcareous nannofossils.

Akchagylian Regional Stage/Kuyalnikian

Calcareous nannofossils were not studied in the Akchagylian lectostratotype (section near the Ushak well on the Krasnovodsk Peninsula, Turkmenistan) and reference section on the left bank of the Sulak River near the village of Bavyugay, Dagestan (Neveskaya et al., 2004). Studies were carried out in the Taman beds of the Kuyalnikian in the Azov part of Ukraine, in Western Georgia, and in Akchagylian of Azerbaijan and Turkmenistan (Semenenko and Lyul'eva, 1982; Muzylev and Golovina, 1987; Golovina et al., 1989) and the Volga–Ural region (Kalmykia and the Saratov Left Bank area) (Musatov, 1990; Staroverov et al., 2000).

A similar assemblage with *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Coccolithus* cf. *doronicoides*, *Cyclococcolithus leptoporus*, *Discoaster brouweri*, *D. pentaradiatus*, *Discolithia japonica*, *Reticulofenestra pseudoumbilicus*, *Sphenolithus abies*, *S. neoabies*, *Scyphosphaera* sp., *Pseudoemiliania* cf. *lacunosa*, and *Thoracosphaera* sp. (? *phacotus* sp.) was established in Tamanian of the Kerch Peninsula (wells in the Chegerechinskaya Depression of the Indol Trough) and in sections of the Akchagylian of Azerbaijan (Yasamal Valley, Duzdag Range, Karadag) (Semenenko, 1987).

During the study of the Upper Akchagylian–Lower Apsheronian in the Duzdag and Bozdag sections (Azerbaijan), Muzylev and Golovina (1987) revealed an assemblage with rare finds (single in some intervals) of *Helicosphaera* aff. *carteri*, *Calcidiscus* aff. *leptoporus*, and *Pseudoemiliania* aff. *lacunosa* and fragments of *Braarudosphaera bigelowii*, along with a large number of redeposited species. A more diverse calcareous nannofossils were established in the section of the Yasamal valley (Apsheron Peninsula, Azerbaijan), where mainly *Braarudosphaera bigelowii* together with *Helicosphaera* sp., small *Reticulofenestra* spp., small *Syracosphaera* spp., *Coccolithus pelagicus*, and very rare *Calcidiscus* aff. *leptoporus*, aff. *Pseudoemiliania* were found (data of Golovina on joint collections with A.E. Dodonov, 1980).

An even poorer assemblage of nannoplankton with *Braarudosphaera bigelowii* occurs in the boundary interval between the Lower Kuyalnikian and Taman Beds, correlated with the Upper Akchagylian (section of the shore of the Bugaz Estuary near the village of Veselovka, Taman Peninsula) (Muzylev et al., 1986). A large number of calcareous cysts of the genus *Thoracosphaera* is recorded in Kuyalnikian deposits of eastern Crimea and near Odessa (Semenenko, 1987).

In western Georgia (Guria, the village of Tsikhisperdi), an impoverished assemblage with *Coccolithus pelagicus*, *Sphenolithus* sp., and *Reticulofenestra* cf. *pseudoumbilicus* was found in Kuyalnikian deposits (Semenenko and Lyul'eva, 1978; Semenenko, 1987).

In Turkmenistan, a monotype *Braarudosphaera bigelowii* (Golovina et al., 1989) was established in Akchagylian deposits (Porsayman section, southern

slope of the Malyi Balkhan Range); the development of this association was then recorded in the Akchagylia of Kalmykia and the Saratov trans-Volga region (Musatov, 1990; Staroverov et al., 2000). The epibole of *Braarudosphaera bigelowii* is also observed in deep-water deposits of the Akchagylia in the Caspian Sea (DRV Borehole, Apsheron threshold, identifications by Golovina).

Correlation. According to Lyul'eva and Semenenko (Semenenko, 1987), calcareous nannofossils from sections of the Taman beds of the Kerch and Taman peninsulas and Akchagylia of Azerbaijan are correlated with the association of undivided zones NN17 with *Discoaster pentaradiatus*/NN18 with *Discoaster brouweri*, based on the rare, almost single occurrence of two index species of these zones. However, the composition of nannoplankton includes several species of the genus *Sphenolithus* together with *Reticulofenestra pseudumbilicus*. The biohorizon of the last occurrence of *Reticulofenestra pseudumbilicus* is dated to about 3.82 Ma (Raffi et al., 2006). In this case, this assemblage (taking into account its autochthony) rather corresponds to the interval of undivided zones NN14/NN15 (the upper part of the Zanclean), which is beyond the limits of the possible age of the Akchagylia according to paleomagnetic data.

In further studies, we failed to confirm the presence of zonal nannoplankton species in the Akchagylia (Muzylev and Golovina, 1987; Golovina et al., 1989). The study of nannoplankton with the integrated palynological, biostratigraphic, and sedimentological research of the Productive Series (Late Miocene–Pliocene) in the sections of the Karmakinskaya and Yasamal valleys (Azerbaijan) also did not reveal autochthonous nannoplankton assemblages (Richards, 2018).

The horizon with the monotype *Braarudosphaera bigelowii*, which was traced in sections from Turkmenistan to the Saratov trans-Volga region, can be considered a regional event marker of the maximum of Akchagylia transgression (Golovina et al., 1989; Musatov, 1990; Staroverov et al., 2000). According to Trubikhin (1977), *Braarudosphaera bigelowii* Beds in the Akchagylia of the Porsayman section have reversed polarity and occur somewhat higher than the boundary between the Gauss and Matuyama zones (Golovina et al., 1986). In Kalmyk sections, beds with monotaxonic nannoplankton are confined to the upper part of the Urda Formation, which is located at the boundary of Gauss and Matuyama orthozones in the regional paleomagnetic scale (Staroverov and Zhidovinov, 2002). The Gauss–Matuyama boundary is dated as 2.58 Ma, which corresponds to the Piacenzian/Gelasian boundary and to the currently accepted Neogene–Quaternary boundary (GTS 2020), being within the Akchagylia Regional Stage.

Results

The possibilities of biostratigraphy based on calcareous nannofossils are significantly limited in the Eastern Paratethys compared to the Central Paratethys and Mediterranean; the levels with calcareous nannofossils can be considered as an indicator of periods of marine events (communications between the epicontinental seas and World Ocean) and as a tool for paleoecological and paleogeographic reconstructions. The pattern of distribution of calcareous nannofossils clearly reflects changes in the biotic and abiotic conditions of Miocene basins; the abundance and diversity of its associations is controlled by parameters of salinity, temperature, depth, and nutrient availability and the amount of terrigenous admixture. Even a change in one of these factors may influence the abundance and structure of the nannoflora assemblage. The reduction of taxonomic diversity under stress conditions leads to the development of monodominant assemblages, which are very typical of the Miocene of the Eastern Paratethys.

Although the basins of the Eastern Paratethys were connected with the World Ocean for a significant part of the Neogene time, their bionomic conditions were very rarely close to normal marine conditions. Most of the Miocene associations are represented mainly by taxa with a wide stratigraphic range. The only exceptions are richer Early Miocene, Tarkhanian, and Konian nannoplankton assemblages.

Almost all regional stage subdivisions are currently characterized by calcareous nannofossils, even though the degree of their study differs. Studies of calcareous nannofossils in the Eastern Paratethys are complicated by problems of the taxonomic identification of species both due to their poor preservation and due to a large number of redeposited species, often modified by secondary processes (encrusting or dissolution), as well as due to a low abundance of coccoliths in coarse terrigenous sediment. Comparison of data from different authors is complicated by different study methods and lack of images of stratigraphically important species and their exact geological reference. Differences in the correlation of some regional stage subdivisions can be eliminated by studying problematic sections using a unified research methodology and publishing paleontological plates.

Based on the accumulated results of the study of calcareous nannofossils in the Eastern Paratethys, it should be noted that it is necessary to be very careful about single finds of “oceanic” species of nannoplankton if they are not accompanied by a sufficiently representative assemblage of related species and are combined with increased redeposition of older forms. It is known that short-lived species are the most valuable for stratigraphy, being extremely selective to aquatic environmental factors. Such species are at the top of ecological pyramids, and the shortness of their stratigraphic range is an indicator of short-term stabil-

ity of bionomic conditions of the basin. In our opinion, the “uniqueness” of finds of marker species and index species in the Miocene of the Eastern Paratethys can be really significant only if it is combined with a sufficiently representative accompanying calcareous nannofossils and correlated with data on other groups of marine phytoplankton.

The reproducibility of data and results is one of the fundamental principles of scientific research and it is impossible to consider data reliable if the results cannot be confirmed by further studies. Therefore, the correlation of the depleted assemblages of the Maeotian, Pontian, and Kimmerian nannoflora in the Eastern Paratethys with the zonal subdivisions of the oceanic scale should probably be recognized as insufficiently substantiated. It should be carried out taking into account data on other groups of calcareous, siliceous, and organic-walled plankton.

Organic-Walled Phytoplankton of the Lower and Middle Miocene

The organic-walled phytoplankton of the Paratethys Neogene began to be studied only 40 years ago. The foundation was laid by A.S. Andreeva-Grigorovich (Grigorovich and Veselov, 1971; Grigorovich, 1975). Later, the study of Neogene dinocysts was continued by N.I. Zaporozhets and N.Yu. Filippova, who described assemblages from different intervals of the Paratethys Neogene.

It should be noted that, despite the rather lengthy study of the Lower and Middle Miocene, zonal biostratons were proposed and described in detail only for the boundary Oligocene–Miocene interval (Andreeva-Grigorovich, 1980, 2004; Zaporozhets, 1999; Semenenko et al., 2009; Andreeva-Grigorovich et al., 2011; Zaporozhets and Akhmetiev, 2017). For the Ukraine territory, it is proposed to select the *Chiropteridium galea* Zone (DP14), which corresponds to nannoplankton zones NP23–NP25 of the Oligocene, above which an Early Miocene assemblage with a high concentration of *Deflandrea* is established. A *Chiropteridium partispinatum* Zone (D16) was established in the sections of the south of the European part of Russia; this zone corresponds to the Late Rupelian–Chattian and has two subzones (*Rhombodinium draco* (DP16a, at the level of nannoplankton zones NP23–NP24) and *Deflandrea spinulosa* (D16 b, at the level of zone NP25)), as well as a *Labyrinthodinium truncatum* Zone (D17, in the transitional interval of zones NP25–NN1 and zone NN1) in the lower strata of the Aquitanian. Other zonal biostratons based on dinocysts were not proposed for the Lower and Middle Miocene Eastern Paratethys.

Oligocene–Miocene boundary. Despite the well-known isolation of the Maikopian basin from the Mediterranean, the replacement of assemblages of organic-walled phytoplankton (dinoflagellate cysts) in

the boundary interval from the Oligocene to the Miocene generally had a similar scenario. As in the Lemme section (Piedmont, Italy) (Steininger et al., 1997), which was chosen as a GSSP of the lower boundary of the Neogene, two main levels of this change can also be recognized in the Paratethys sections. The first level, which is confined to the Paleogene and Neogene boundary in the Lemme section, coincides with the succession of nannoplankton assemblages of NP25/NN1 zones. At this level, the genus of dinocyst *Chiropteridium*, which plays the main role in the Chattian, disappears in this and other sections of Italy and northern Germany. An interval of mass development of *Deflandrea* (epibole) was recognized higher in the section. It covers the first half of the Aquitanian. The complete disappearance of dinocysts *Deflandrea* corresponds to the second turn, which is somewhat lower than the LAD of *Globorotalia kugleri* in the Lemme section.

Unlike the Mediterranean sections, the epibole of *Deflandrea* in the Northern Caucasus partially overlaps the interval where the Late Oligocene genus *Chiropteridium* is still fairly widespread and the boundary between the Oligocene and Miocene passes within the epibole.

Andreeva-Grigorovich was the first to study the boundary interval between the Oligocene and Miocene in the reference section of the Caucasian Regional Stage in the Novopokrovskaya-4 Borehole near the town of Tikhoretsk and proposed three local zones based on dinocysts (Andreeva-Grigorovich, 1980). The further re-examination made it possible to refine the zonal subdivision of the section (Akhmetiev and Zaporozhets, 1996). According to the data of the latter authors, the cooccurrence of *Chiropteridium partispinatum* and massive *Deflandrea* (epibole) in the Novopokrovskaya-4 section was established in the undivided Alkun and Zelenchuk formations. This dominance of representatives of the genus *Deflandrea* in the Early Caucasian can be explained by desalination, which was also assumed here based on the assemblage of benthic foraminifers (Nosovskii and Bogdanowicz, 1980). The boundary with the Miocene in the Novopokrovskaya-4 well was marked in the middle part of the Karadzhalga Formation (Andreeva-Grigorovich, 1980; Akhmetiev and Zaporozhets, 1996).

In the section along the Belaya River, the Oligocene and Miocene boundary, where the NP25 nannoplankton assemblage is replaced by the transitional NP25–NN1 assemblage (according to the data of Ya. Krkhovskii (Akhmetiev et al., 1995), which were also later confirmed by Golovina), was linked to the replacement of dinocyst zones D16/D17 of Western Europe (Zaporozhets and Akhmetiev, 2017). According to N.Yu. Filippova, it was convincingly shown that this level was confined to the Alkunian Horizon in other sections of Ciscaucasia and the Northern Caucasus and is located within the *Deflandrea phosphorit-*

ica var. *spinulosa* Beds based on dinocysts (Beluzhenko et al., 2018).

Dinocysts of the boundary beds of the Oligocene–Miocene were also studied in the Kentykche section on the northwestern coast of the Aral Sea (Akhmetiev and Zaporozhets, 1996). They originate from a variegated clay member with *Lenticorbula helmerseni*, which overlies loose sandstones with *Cerastoderma prigorovski*. The basal bed of the member is a thin marl bed overfilled with *Hydrobia*. Dinoflagellate cysts was found in green clays 0.4 m above this bed. The assemblage is 80% represented by species of *Homotryblum*, which indicates the development of coastal-marine environments with incomplete salinity.

Caucasian regional stage. In the stratotype of the Caucasian (a section of the Kuban River near the city of Cherkessk), the Alkunian Horizon and lower strata of the Septarian beds of the Zelenchuk Formation were assigned by G.N. Aleksandrova to *Deflandrea spinulosa* Beds by dinocysts (Aleksandrova et al., in press). The phytoplankton assemblage in these beds is characterized by a relatively high taxonomic diversity. The high abundance of *Apteodinium* indicates the development of marginal marine conditions and the high proportion of the peridinoid genus *Deflandrea* and prasinophytes in the upper part of the beds shows highly productive conditions during the formation of the Alkunian Horizon and lower part of the Septarian beds. The last constant abundant occurrence of *Deflandrea spinulosa* is confined to the top of the beds.

Sumatradinium spp. beds were established in the rest of the Zelenchuk Formation—lower part of the Karadzhhalga Formation in the same section. The cooccurrence of *Cousteaudinium aubryae* and *Sumatradinium soucouyantiae* in the absence of *Chiropteridium* makes it possible to correlate the assemblage of beds containing *Sumatradinium* spp. with the ***Cousteaudinium aubryae* (DN2) dinocyst Zone** according to the de Verteuil and Norris scale (1996), date them to the upper part of the Aquitanian—lower part of the Burdigalian (about 22.2–19.1 Ma) (de Verteuil, 1997), and correlate them with the NN2 nannoplankton zone.

The characteristic features of the dinocyst assemblage from the upper part of the Caucasian Regional Stage (Zelenchuk Formation—lower part of the Karadzhhalga Formation) in the section on the Kuban River are a high taxonomic diversity of the dinocyst assemblage and the presence of *Sumatradinium soucouyantiae*, *S. druggii*, *Sumatradinium* sp., *Thalassiphora pelagica*, and ex gr. *Bigantedinium*. This indicates the development of normal marine, warm-water paleoenvironments close to subtropical ones. A similar assemblage of dinocysts was found in sections of northern Azerbaijan in the upper part of member A2 according to V.V. Weber (data of Zaporozhets in Popov et al., 2008).

The study of dinocysts in Ciscaucasia show that *Deflandrea* in the sections disappear in a short interval in the middle part of the Karadzhhalga Formation. This boundary was recorded not only in the Novopokrovskaya-4 section and along the Kuban River, but also in the ultradeep Kuban Borehole (SG-12000). In the section of the Novopokrovskaya-4 well, it roughly coincides with the replacement of *Uvigerinella californica* Beds by *Caucasinella* (= *Neobulimina*) *elongata* Beds (according to Bogdanowicz) based on foraminifers. In SG-12000, the distribution of *Deflandrea spinulosa* is limited to a depth of 3660 m. The absence of representatives of the genus *Chiropteridium* in the lower 300 m interval (3957–3660 m) indicates that deposits older than the Lower Aquitanian ones were not exposed by the well.

Therefore, the correlation of the Northern Caucasian sections with the Lemme-Carrioso stratotype section, as well as the data on nannoplankton, clearly show that the Oligocene–Miocene boundary in the Eastern Paratethys is in the lower strata of the Caucasian Regional Stage, within the Alkunian Horizon. However, based on practical grounds, E.V. Beluzhenko, Filippova, and L.A. Golovina (Filippova et al., 2015; Beluzhenko et al., 2018) propose to mark this boundary at the base of the Alkunian Formation and date the entire Caucasian Regional Stage to the Early Miocene.

Sakaraulian regional stage. The beginning of the Sakaraulian period is characterized by a sharp significant depletion of Neogene dinocyst assemblages. Most of the taxa recorded in the Caucasian Regional Stage are absent in the Sakaraulian Regional Stage.

Most of the studied sections of the Sakaraulian Regional Stage in the Northern Caucasus are dominated by different *Spiniferites* species. In the Nadarbazevi section, located in the stratotype region of the Sakaraulian Regional Stage, dinocysts were studied only in the upper part of the regional stage. The assemblage is quantitatively and taxonomically extremely poor; 11 taxa were represented by single specimens, which is most likely due to high sedimentation rates and a strong terrigenous drift from the adjacent land. The cooccurrence of *Cousteaudinium aubryae*, *Trinovantedinium harpagonium*, and *Lingulodinium multivirgatum* makes it possible to date this part of the Sakaraulian to the Burdigalian.

In the most extensively studied section along the Kuban River, the middle part of the Karadzhhalga Formation (correlated with the lower part of the Sakaraulian Regional Stage) is also characterized by an extremely low species diversity. At this level, the appearance of *Polysphaeridium zoharyi* and last occurrence of *Cousteaudinium aubryae* were established; brown spherical shells close to the protoperidinioid genus *Bigantedinium*, as well as to the *Habibacysta*–*Filispheera* group, *Tectatodinium pellitum*, and *Lejeunecysta* sp., prevail; other taxa are represented by

few number. The high proportion of *Bigantedinium* suggests the persistence of highly productive warm-water paleoenvironments (Zonneveld et al., 2013). *Spiniferites* spp., *Hetelaaulacacysta campanula*, *H. leptalea*, *Batiacasphaera sphaerica*, and *Operculodinium* sp. play a significant role in the upper strata of the Karadzhhalga and Olginskaya formations (correlated with most of the Sakaraulian Regional Stage), which is characteristic of this stratigraphic level. Prasinophytes and reworked palynomorphs (Eocene–Oligocene dinocysts and Late-Jurassic–Early-Cretaceous pollen and spores) are constantly present. These data make it possible to reconstruct the restricted marine communications of the paleobasin and intraneritic conditions with low salinity.

In northern Azerbaijan, a dinocyst assemblage low species diversity similar to the Kuban one was established in the upper part of the Sakaraulian Regional Stage at the level of member A3 according to Weber (1935) in the Perkyushkyul-1 section along the Sumgait River (data of Zaporozhets in Popov et al., 2008).

In some intervals of age analogs of the Karadzhhalga Formation in the Kerch region of Crimea, the Sakaraulian phytoplankton assemblage becomes monotaxonic and begins to be formed by *Leiosphaeridia* (from small to large individuals) (which indicates a possible oxygen deficiency in marine waters) and accompanying *Apteodinium maculatum*, *Selenopemphix nephroides*, *Lejeunecysta paratenella*, and *L. globosa*. Single specimens contain *Lingulodinium*, *Hystrichosphaeropsis*, *Tuberculodinium*, *Dapsilodinium*, *Homotryblium*, etc.

Kozakhurian regional stage. In the stratotype sections of the Kozakhurian Regional Stage in Georgia, dinocysts were studied in the lower and middle parts of the regional stage in the Kvakhvrel and Nadarbazevi sections, where they are represented by a taxonomically poor, but purely marine assemblage, which contains taxa of a predominantly wide stratigraphic range. As in the Sakaraulian time, dinocysts are encountered in small quantities in samples; the assemblage is characterized by the constant involvement of redeposited Paleogene taxa and single prasinophytes. The poor composition is primarily due to facial causes.

In the section along the Kuban River is, the regional stage is characterized by an increase in the number of dinocysts in the spectra during the development of the lower part of the Ritsa Formation (correlated with the basal beds of the Kozakhurian). The dominant species are *Spiniferites* spp., *Operculodinium* spp., *Cleistosphaeridium placacanthum*–*ancyreum* group, *Heteraulacacysta campanula*, *Heteraulacacysta leptalea*, and *Batiacasphaera* spp. The overlying greater part of the Ritsa Formation is dominated by different species of *Batiacasphaera*: *B. micropapillata*, *B. sphaerica*, and *B. baculata*; this part is characterized by the constant occurrence of various prasinophytes and freshwater

algae (*Pediastrum*, *Ovoidites*, *Sigmopolis*, *Schizosporis*, *Zygnemataceae*, *Leiosphaeridia*, *Tasmanites*, and *Botryococcus*) and a significant number of reworked Mesozoic–Paleogene dinoflagellate cysts and spores of Paleozoic and Jurassic–Early-Cretaceous spores and pollen. A similar assemblage was established in sections of northern Azerbaijan in Units b and c according to Weber (correlated with the Kozakhurian), which are dated to the Burdigalian (Popov et al., 2008).

N.I. Zaporozhets studied organic-walled phytoplankton in samples from the Alagol Formation of the northern (Azov) coast of the Kerch Peninsula, from the section part immediately underlying the Tarkhanian–Chokrakian part without unconformity. Samples are characterized by an exceptionally high saturation with palynomorphs; among them, the content of organic-walled phytoplankton is 10 to 30%.

The thickness of the Upper Maikopian deposits in the base of the section exposed in the core of the Bulganak Anticline is about 70 m. The lower strata in the dinocyst assemblage are dominated by *Batiacasphaera* (*B. micropapillata*, *B. sphaerica*, and *B. baculata*); other taxa were represented by single specimens. There are many redeposited Cretaceous and Paleogene taxa. Prasinophytes are represented by *Cymatosphaera* and *Pediastrum*. *Spiniferites* (including *S. bentorii*, *S. ramosus*, and *S. mirabilis*) are dominant higher in the section; the proportion of *Achomosphaera*, *Sumatradinium*, *Operculodinium*, *Hystrichosphaeropsis*, and *Systematophora* is noticeable here; other taxa (about 20 taxa) were represented by single specimens, which indicates marine sedimentation environments and open communications with neighboring basins. The spore–pollen spectra from this level indicate warm climate conditions, a progressive retreat of the sea, and the colonization of the free plains by pigweeds, cereals, and Ephedra.

In Ciscaucasia, the predominance of different species of *Batiacasphaera* in the dinocyst assemblage from the middle (greater) part of the Ritsa Formation and its analogs indicates limited communications between the paleobasin and ocean, as well as colder marine conditions of the formation in the middle of the Kozakhurian time than at its beginning and end. The significant diversity of prasinophytes and green algae that was established at this level, as well as the large number of redeposited taxa, indicate a strong drift from the adjacent land and a possible significant stratification of waters.

Tarkhanian regional stage. The transitional interval from Maikopian deposits and Tarkhanian interval were studied in the SG-12000 well and in the section along the Belaya River in Ciscaucasia and section of the Bulganak Bay (Malyi Kamyslak area) in eastern Crimea, where there are no signs of a significant sedimentation break.

The boundary between Maikopian and Tarkhanian deposits in SG-12000 is marked in the depth interval of 3170–3200 m (according to the unpublished results of additional study of foraminifers by T.N. Pinchuk) and dinocysts were studied in samples taken from depths of 3158 and 3141 m. In the lower sample, phytoplankton is up to 10% of the total composition of the palynospectrum, with the dominance of *Spiniferites ramosus*, *Lejeunecysta* (*L. hyalina*, *L. globosa*, *Lejeunecysta* sp.), *Selenopemphix* (*S. armata*, *S. nephroides*, and *S. selenoides*), which are accompanied by *Cleistosphaeridium*. Other taxa include *Dapsilodinium pseudocolligerum*, *Achomosphaera*, *Operculodinium*, and *Apteodinium*, as well as the prasinophytes *Pterospermella* and *Tasmanites*. In the upper sample, the diversity of dinocysts and their total number decrease to 3%. There are *Homotryblum* and *Lingulodinium*, which were not found in the sample from the depth of 3158 m.

In the section along the Kuban River, *Labyrinthodinium truncatum* Beds were established in the lower part of the Tarkhanian Regional Stage (below the “Tarkhanian Marl”) (Aleksandrova et al., in press). The dinocyst assemblage is characterized by the mass cooccurrence of *Cribroperidinium tenuitabulatum* and the *Cleistosphaeridium placacanthum*–*ancyreum* group; in addition to the index species, *Spiniferites* spp., *Operculodinium eirikianum*, *Operculodinium centrocarpum*, and *Polysphaeridium zoharyi* are also frequent; among species that are not numerous but constantly present are *Lingulodinium macherophorum*, the *Habibacysta*–*Filisphaera* group, and *Tectatodinium pellitum*, and ex gr. *Bigantodinium*.

The organic-walled phytoplankton of the Tarkhanian was studied in the section along the Belaya River (2 km upstream from the mouth of the Semikolennyi brook) in samples taken under and above the marl interbed with *Lentipeecten denudatus*. In Tarkhanian beds underlying marl, the variety of dinocysts in situ and their total number are up to 3%; redeposited taxa of the Paleogene (*Deflandrea*, *Chiropteridium*, *Charlesdowniea*, *Wilsonidium*, etc.), undoubtedly, prevail. The diversity of dinocyst assemblages increases (up to 60 taxa) with the development of the Tarkhanian basin.

On the whole, the Tarkhanian period is characterized by a great diversity and dominance of *Operculodinium* species; *Spiniferites* and *Impagidinium* occur frequently, while the number of other taxa is subordinate: *Tuberculodinium vancampoe*, *Caligodinium pycnum*, *Lingulodinium machaerophorum*, *Hystriosphaeopsis obscura*, *Distatodinium*, *Tectatodinium psilatium*, *Lejeunecysta oliva*, *L. sabrina*, *L. paratenella*, etc.

The mass occurrence of *Cleistosphaeridium placacanthum* and *Cribroperidinium tenuitabulatum*, established at the beginning of the Tarkhanian, indicates the development of transgression and recovery of normal marine neritic paleoenvironments and warming

conditions; this is also evidenced by the frequent occurrence of *Operculodinium eirikianum*, *O. centrocarpum*, *Polysphaeridium zoharyi*, and ex gr. *Bigantodinium* (Louwye et al., 2007, 2010). The latter probably corresponds to warming, which reaches the peak value in the boundary interval between the Burdigalian and Langhian.

The high diversity of dinocysts and high abundance of warm-water species make it possible to reconstruct open-sea warm-water environments in most of the Tarkhanian period, which ends in regression.

Chokrakian regional stage. The Chokrakian phytoplankton assemblage was studied in a section of the Bulganak Bay on the Kerch Peninsula (Malyi Kamyshlak area). Calcareous clays occurring in the top of “*Spirialis* Beds” have an impoverished phytoplankton composition. The dinocyst assemblage is represented by 15 taxa, dominated by *Spiniferites* (several species) and *Chytroeisphaeridia*.

In Chokrakian clays overlying the first bioherm limestones, the spectrum of dinoflagellate cysts is enriched and includes up to three dozen species. Thin-walled *Hystriochokolpoma*, poorly *Spiniferites*, various *Batiacasphaera*, and *Horologinella* were encountered. At this level, the role of *Spiniferites* spp. (*S. mirabilis*, *S. ramosus*, and *S. bentorii*) and *Operculodinium* (including *O. placitum*) is more prominent, while the contribution of *Cribroperidinium* sp., *Lejeunecysta* sp., *Systematophora* sp., *Labyrinthodinium truncatum*, *Nematosphaeropsis labyrinthus*, and *Batiacasphaera baculata* is low. The significant reduction in the number of open-sea taxa indicates the beginning of desalination of the Eastern Paratethys and strengthening of its isolation from the ocean.

In the section of the Kuban ultradeep borehole (SG-12000, 2900 m), the diversity of phytoplankton is significantly lower in the middle of the Chokrakian: here, single specimens contain no more than six to seven species, among which the constant species is *Spiniferites sagittarius* Sütő-Szentai, 1990. Communications with the open sea were presumably still preserved at that time (albeit very limited), since *Hystriosphaeopsis obscura*, *Impagidinium*, and *Trinovantedinium* are sometimes encountered. At a higher level (at a depth of 2880 m), phytoplankton (8% of all palynomorphs) becomes more diverse (up to 25 species). Along with taxa that have adapted to living in the desalinated environment, more and more taxa that are characteristic of full-saline basins (*Operculodinium*, *Impagidinium*, *Lingulodinium*, *Melitasphaeridium*, etc.) appear here.

The regression at the end of the Chokrakian was reflected in the composition of the dinocysts assemblage and, although it did not quantitatively decrease (12% in samples from the depths of 2865 and 2854 m), it is taxonomically poor and includes representatives of three genera in equal proportions: *Selenopemphix* (including *S. nephroides*), *Spiniferites*, and

Lejeunecysta (including *L. hyalina*). Single specimens contain *Batiacasphaera baculata* and ?*Lingulodinium*.

Karaganian regional stage. The closure of the Karaganian basin and its even greater desalination than that of the Chokrakian basin was reflected in the phytoplankton composition. In the section of the Kuban ultradeep well (SG-12000, depth 2798 m), it is 12% of total palynomorphs. As in the terminal Chokrakian, dinocysts of the Early Karaganian are represented by only three genera: *Selenopemphix*, *Spiniferites* (*S. elongatus*), and *Lejeunecysta*. Species of the genus *Selenopemphix* are dominant; other taxa were represented by single specimens. In the Late Karaganian (SG-12000, depth 2768 m), the phytoplankton assemblage becomes essentially monotonous as a result of the progressive desalination of the basin and is represented by underdeveloped *Spiniferites*, including *S. bentorii*. They are sometimes accompanied by single specimens of *Tectatodinium* and *Batiacasphaera* (SG-12000, depth 2725 m). The depletion of the assemblage is also observed in the top of the Karaganian (SG-12000, depth 2643 m), where only *Spiniferites*, *Selenopemphix*, and *Lejeunecysta* were represented by single specimens.

Konkian regional stage. The phytoplankton of Konkian deposits was studied using samples from the SG-12000 core, as well as from the section of Zelensky Hill on the Taman Peninsula. In the first half of the Konkian (SG-12000, depths of 2633 and 2623 m), the phytoplankton diversity increases to 20 species, which indicates some recovery of normal marine paleoenvironments and communications between the basin and ocean. At the same time, the presence of a large number of prasinophytes (large *Leiosphaeridia*, as well as *Cymatiosphaera*) may indicate the stratification of waters and their reduced aeration and hydrogen sulfide contamination, in particular, in the bottom beds. Among dinocysts, *Systematophora*, *Aptodinium* cf., *A. vescu*, and *Sumatradinium* are most common. Single specimens contain *Cleistosphaeridium*, *Impagidinium*, *Lingulodinium machaerophorum*, *Spiniferites* (including *S. ramosus* and *S. elongatus*), *Achomosphaera*, *Lejeunecysta*, *Selenopemphix*, *Hystrichosphaeropsis*, *Homotryblium*, and *Batiacasphaera baculata*. At the boundary between the Konkian and Sarmatian regional stages in the SG-12000 section, the main background of the assemblage is formed by *Operculodinium* and *Systematophora*, which indicates warming and active hydrodynamics at that time.

The dinocysts assemblage from the Lower Konkian of the Zelensky Hill section also includes over 20 species dominated by *Spiniferites* (including *S. mirabilis*), *Operculodinium* (including *O. microtrianum*), *Selenopemphix*, *Lejeunecysta*, *Lingulodinium*, *Labyrinthodinium truncatum*, *Distatodinium paradoxum*, *Trinovantedinium*, *Systematophora*, *Dapsilidinium pastielsii*, *Melitasphaeridium choanophorum*, *Impagidinium velorum*, and *Homotryblium tenuispinosum*. Prasinophytes

and acritarchs are almost absent except *Cyclopsella vieta*. The middle part of the Konkian in this section is almost completely devoid of phytoplankton and saturated with amorphous organic matter. Phytoplankton appears again in the upper part of the section, which suggests the recovery of communications between the Konkian basin and open sea. *Lejeunecysta beninensis* and *Spiniferites* begin to play a noticeable role in the assemblage in this interval. The recorded taxa included cf. *fromea*, *Tectatodinium*, *Batiacasphaera*, *Lingulodinium*, *Cometodinium*, *Sumatradinium*, *Selenopemphix*, *Hystrichosphaeropsis*, and other taxa were recorded.

Conclusions

The content of organic-walled phytoplankton in the deposits of the Upper Maikopian and Tarkhanian–Konkian regional stages of the Eastern Paratethys varies from 1 to 12% of the total number of palynomorphs and its species diversity varies widely (from one–two to 60 species), depending on the temperature and the salinity of the basin. The situation closest to normal salinity conditions existed in the Caucasian and Late Kozakhurian times and persisted in the Tarkhanian; it was also periodically observed in the Konkian time.

The composition of the dominant taxa changed over time, depending on the hydrology of the basin. In the Late Maikopian (Aquitania–Burdigalian), the leading taxa were *Deflandrea spinulosa* (Caucasian Regional Stage), *Spiniferites*, *Heteraulacacysta*, the *Selenopemphix*–*Lejeunecysta* group (Sakaraulian), *Batiacasphaera* (most of the Kozakhurian), and *Cleistosphaeridium* and *Spiniferites* (in the lower and terminal parts of the Kozakhurian). The abundance of *Leiosphaeridia* and *Cymatiosphaera* in some intervals of the Upper Maikopian section at a simultaneous reduction of dinocysts is probably evidence of oxygen deficiency in the waters. The Tarkhanian was dominated by warm-water species of *Operculodinium*, which were accompanied by a taxonomically diverse dinocyst assemblage characterizing significant warming. The dominance of *Batiacasphaera* and *Hystrichokolpoma* in the second half of the Early Chokrakian indicates that the paleoenvironments that are similar to Kozakhurian conditions and reflect cooling and limited sea communications, which led to the development of desalinated paleoenvironments at the end of the Chokrakian and Early Karaganian, where *Selenopemphix*, *Lejeunecysta*, and *Spiniferites* were dominant. The Late Karaganian, or Kartvelian, is marked by a new flourishing of *Spiniferites*. In addition to *Spiniferites*, the role of *Operculodinium* and *Systematophora* increased in the Konkian, as the marine conditions recovered. Detailed data on the microphytoplankton assemblages from the sections of the Sarmatian–Kimmerian regional stages of the Taman

Peninsula that were studied by Filippova are given in (Popov et al., 2016).

Benthic Foraminifers

Overview of the Study of Neogene Foraminifera

The first data on Miocene benthic foraminifers are given in E. Eichwald "Paleontology of Russia"; F. Carrer studied foraminifers from the Miocene deposits of Stavropol; Carrer and I.F. Sintsov described several species from Sarmatian deposits in the vicinity of Kishinev (Moldova). In the 1930s micropaleontological studies related to oil and gas exploration were started.

In the 20th century, Maikopian foraminifers of the Northern Caucasus and Ciscaucasia were studied by A.K. Bogdanowicz and A.N. Fedorov (1932), N.N. Subbotina (1936), Bogdanowicz (1947, 1960a, 1961, 1965), and Ter-Grigor'yants (1961, 1964) and later by E.M. Bugrova (2006a, 2006b), and other. The Western Ciscaucasia and Central Ciscaucasia were stratigraphically divided based on foraminifers by Krasheninnikov (1958a, 1958b, 1960), Bogdanowicz (1961, 1965, 1986), and Ter-Grigor'yants (1961, 1964), who recognized zones and Beds with microfauna in Neogene sediments. Foraminiferal beds proposed in the Bogdanowicz biostratigraphic schemes (Bogdanowicz, 1965; 1971; Neogenovaya sistema, 1986) are still relevant today. The foraminiferal assemblages identified by these authors can be traced in the Eastern Ciscaucasia, Crimea, Black Sea region, Azerbaijan, Georgia, and other regions. These studies were continued by publications of Pinchuk (2006, 2011) and Bugrova (2006a, 2006b).

In Neogene sediments from the south of Ukraine, benthic foraminifers were studied by Didkovskii (1962, 1964, 1966), Didkovskii and Satanovskaya (1970), Konenkova (1984, 1989, 1994a, 1994b, with Bogdanowicz), Vernigorova (2008, 2009, 2014, 2015; Vernigorova and Ryabokon', 2018), and Ivanova et al. (1998, 1999, 2004, 2014). Assemblages from the Miocene deposits of Georgia are reported in the works of Dzhanlidze (1953, 1970), Maisuradze (1971, 1980; Maisuradze et al., 2004), and Koiava (2006). In Azerbaijan, the fauna of foraminifers was studied by Pobedina et al. (1956) and Pronina (1959).

The monograph by Bogdanowicz (1952) "Miliolids and Peneroplids" is devoted to foraminifer systematics. The work of Voloshinova and Dain (1952) provides data on Meso-Cenozoic nonionids, cassidulinids, and chilostomelids and considers issues of their systematics. Reference books on foraminifers were published by Pobedina et al. (1956) and Didkovskii and Satanovskaya (1970). These works give the synonymy of foraminifers from the Miocene sediments of Azerbaijan and Ukraine, as well as their stratigraphic and geographical distribution. The work of Papp and Schmid (1985) "Fossil foraminifers of the Vienna Ter-

tiary Basin" presents the results of revision of the collection of d'Orbigny (1846). The work of Cicha et al. (1998) "Oligocene–Miocene foraminifers of the Central Paratethys" is an atlas that summarizes the data of long-term studies by 28 scientists from 13 countries. Their work deals with the issues of sedimentology, stratigraphy, and paleontology of the Central Paratethys from Bavaria to the Black Sea; about 600 main foraminifer species were described and grouped according to the systematics of Loeblich and Tappan (1987).

Caucasian Regional Stage

In Ciscaucasian sections, the species composition of plankton and benthos has been fairly completely studied in the Miocene part of the Maikopian (Table 1). The common species for sediments of the entire Caucasian Regional Stage are: *Spiroplectammina caucasica*, *Haplophragmoides* ex gr. *kjurendagensis*, *Nodosaria calomorphia*, *Porosononion dendriculus*, *Elphidium onerosum*, *Bolivina goudkoffi*, *B.* ex gr. *floridana*, *B.* ex gr. *plicatella*, *Uvigerinella californica*, *Virgulinea eaquele*, *V.* aff. *neobuliminiformis*, and *Fursenkoina schreibersiana*, which occur in almost all areas of the Eastern Paratethys (Bogdanowicz, 1986).

The Early Caucasian basin is characterized by a relatively rich marine assemblage of foraminifers (about 27 genera and over 70 species), including a wide development of the genera *Virgulinea*, *Uvigerinella*, *Bolivina*, *Porosononion*, and *Cibicides*. Representatives of the genera *Haplophragmoides* and *Spiroplectammina* were less common; planktonic genera *Globigerina* and *Sphaeroidina* are represented by single specimens. The presence of numerous polyhaline migrant species (*Virgulinea* ex gr. *pertusa*, *Fursenkoina schreibersiana*, *Sphaeroidina bulloides*, *Bolivina goudkoffi*, etc.) indicates a wide connection between the Eastern Paratethys and Mediterranean. In the basin, neoautochthons were formed from migrant species (*Spiroplectammina caucasica*, *Uvigerinella californica* var. *uruchensis*, *Porosononion dendriculus*, etc.). The number of species that passed from the Oligocene is small (*Haplophragmoides* ex gr. *kjurendagensis*, *Rotaliammina* cf. *depressa*, *Bolivina* ex gr. *plicatella*, *Globigerina officinalis*, etc.). The typical beds for the Middle Maikopian are Beds with *Uvigerinella* ex gr. with *Uvigerinella californica*–*Bolivina goudkoffi* (Bogdanowicz, 1971, 1986), which are widespread in the Crimean–Caucasian region.

The Late Caucasian time is characterized by an impoverished foraminiferal composition, which was accompanied by an increase in abundance of the *Uvigerinella* ex gr. *californica* group. The absence of new alien species indicates a limited communication between the basin and open seas (Bogdanowicz, 1986).

Table 1. Distribution of characteristic foraminifer species in the Middle–Upper Maikopian deposits of Ciscaucasia (according to Bogdanowicz, 1960a, 1965; Ter-Grigor'yants, 1964, supplemented by the author)

No.	Foraminifers/stratons	Caucasian				Sakaraulian				Kozakhurian			
		Northern Ciscaucasia											
	areas	Western	Northern	Central	Eastern	Western	Northern	Central	Eastern	Western	Northern	Central	Eastern
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	<i>Saccammina variabilis</i> Bogdanowich, 1963	x				x				x	x		x
2	<i>Saccammina zuramakensis</i> Bogdanowich, 1954									x	x	x	x
3	<i>Saccammina complanata</i> (Franke, 1912)	x				x				x			
4	<i>Saccammina bulla</i> Bogdanowich, 1960		x			x							
5	<i>Saccammina grzybowskii</i> Bogdanowich, 1960					x		x					
6	<i>Saccammina ovalis</i> Subbotina	x						x				x	x
7	<i>Saccammina suzini</i> Bogdanowich, 1954	x											x
8	<i>Hyperammina caucasica</i> Bogdanowich, 1960	x				x		x			x		
9	<i>Hyperammina djanaica</i> Bogdanowich, 1960	x	x			x							
10	<i>Ammodiscus tenuiculus</i> Subbotina, 1960	x	x		x	x							
11	<i>Ammodiscus</i> aff. <i>pellucidus</i> Andrea, 1884	x		x				x					
12	<i>Ammodiscus granatus</i> Bogd.		x										x
13	<i>Ammodiscus dignus</i> Ter-Grigorjanz, 1965	x				x		x					
14	<i>Reophax dentaliniformis</i> Brady, 1881	x				x				x			
15	<i>Reophax splendida</i> Grzybowski, 1898.	x	x	x		x		x					
16	<i>Haplophragmoides deformabilis</i> Subb., 1950	x				x							
17	<i>H. stavropolensis</i> Ter-Grigorjanz, 1965	x	x			x							
18	<i>H. rotundidorsatus granatus</i> Ter-Grig., 1964	x						x				x	
19	<i>H. karadjalgensis</i> Ter-Grigorjanz, 1964	x		x									
20	<i>H. ex gr. kjurendagensis</i> Morosova, 1949	x	x	x		x	x	x					
21	<i>H. kjurendagensis karadjalgensis</i> Ter-Grig.			x				x					
22	<i>H. aff. periferoexcavatus</i> Subbotina, 1936	x				x							
23	<i>H. inaequilateralis</i> Subbotina, 1936	x						x					
24	<i>H. ex gr. rotundidorsatus</i> (Hantken, 1875)	x					x	x					
25	<i>H. aff. latidorsatus</i> (Bornemann, 1855)	x						x					
26	<i>H. ex gr. canariensis</i> (d'Orbigny, 1839)							x					
27	<i>H. aff. quenquelocularis</i> Subbotina, 1960							x					
28	<i>Trochamminoides concentricus</i> Subbotina, 1960					x							
29	<i>Trochammina florifera</i> Subbotina, 1973	x				x							
30	<i>Trochammina chadumica</i> Ter-Grigorjanz, 1964		x										
31	<i>Trochammina vera</i> Ter-Grig.						x						
32	<i>Trochamminoides rotaeformis</i> Subbotina							x					
33	<i>Trochammina depressa</i> Subbotina, 1973							x					
34	<i>Ammoscalaria</i> sp.	x				x							
35	<i>Rotaliammina</i> cf. <i>depressa</i> Subbotina, 1973	x				x							
36	<i>Ammomarginulina lobsanense</i> (Andrea)			x				x					
37	<i>Cyclammina turosa</i> Ter-Grigorjanz, 1964	x				x		x					
38	<i>C. constrictimargo</i> Stewart et Stewart, 1930		x										
39	<i>Cyclammina kapustiana</i> Ter-Grigorjanz							x					

Table 1. (Contd.)

No.	Foraminifers/stratons	Caucasian				Sakaraulian				Kozakhurian			
		Northern Ciscaucasia											
	areas	Western	Northern	Central	Eastern	Western	Northern	Central	Eastern	Western	Northern	Central	Eastern
1	2	3	4	5	6	7	8	9	10	11	12	13	14
40	<i>Cyclammina kubanica</i> Ter-Grigorjanz							x					
41	<i>Pseudocyclammina transcaspensis</i> Mor., 1949	x											
42	<i>Pseudocyclammina insignedentata</i> Subbotina			x									
43	<i>Spiroplectammina carinata</i> (d’Orbigny, 1846)	x		x									
44	<i>S. terekensis</i> Bogdanowich, 1960	x	x	x	x								
45	<i>Spiroplectammina caucasica</i> Djanelidze, 1970	x		x	x	x		x			x		
46	<i>Karreriella longula</i> Subbotina, 1964							x					
47	<i>Gaudryina gracilis</i> Cushman, Laiming, 1931		x	x									
48	<i>Verneuilinoides rasilis</i> (Subbotina, 1973)			x				x					
49	<i>Verneuilinoides tripartita</i> (Subbotina, 1973)	x	x	x				x					
50	<i>Quinqueloculina</i> sp.	x	x			x	x						
51	<i>Quinqueloculina ermani</i> Bornemann							x					
52	<i>Sigmoilina</i> sp.	x				x							
53	<i>Sigmoilina tenuis</i> (Czizek)			x									
54	<i>Miliolinella circularis</i> (Bornemann)							x					
55	<i>Triloculina tricarinata</i> Orbigny			x									
56	<i>Globulina gibba</i> Orb.,						x						
57	<i>Globulina minuta</i> (Roemer)			x									
58	<i>Globulina flexa</i> Cushman et Ozawa			x									
59	<i>Guttulina irregularis</i> (Orbigny)			x									
60	<i>Nodosaria</i> sp.					x	x						
61	<i>Lagena laevigata</i> (Reuss, 1850).	x				x							
62	<i>Lagena vulgaris</i> Williamson, 1858	x		x		x							
63	<i>Lagena oblonga</i> (Reuss, 1850).			x				x					
64	<i>Lenticulina angustimargo</i> (Reuss)			x									
65	<i>Robulus inornatus</i> (Orbigny)			x									
66	<i>Ammoscalaria impexus</i> Subbotina			x									
67	<i>Discorbis</i> sp.	x			x								
68	<i>Valvulineria cubanica</i> Subb., Myatlyuk, 1953	x			x								
69	<i>Pseudoparella caucasica</i> Bogdanowich, 1960	x		x		x							
70	<i>Cibicidoides almaensis</i> (Samoilova, 1947)	x				x		x					
71	<i>Cibicidoides oligocenicus</i> (Samoilova, 1947)		x										
72	<i>C. pseudoungeriana</i> (Cushman, 1922).						x						
73	<i>Cibicides ornatus</i> Bogdanowich, 1960	x	x	x		x							
74	<i>Cibicides stavropilensis</i> Bogdanowich, 1960	x	x			x		x					
75	<i>Cibicidina amphisyliensis</i> (Andreae, 1884)		x		x		x						
76	<i>Pullenia bulloides</i> (Orbigny, 1826)			x									
77	<i>Asterigerina</i> aff. <i>bracteata</i> Cush.		x										
78	<i>Asterigerina lucida</i> Minakova et Myatlyuk 1953			x									
79	<i>Melonis dosularensis</i> (Khalilov, 1957)			x									

Table 1. (Contd.)

No.	Foraminifers/stratons	Caucasian				Sakaraulian				Kozakhurian			
		Northern Ciscaucasia											
	areas	Western	Northern	Central	Eastern	Western	Northern	Central	Eastern	Western	Northern	Central	Eastern
1	2	3	4	5	6	7	8	9	10	11	12	13	14
80	<i>Astrononion ergenicus</i> Bogd.						x						
81	<i>Porosononion polymorphus</i> Subb.						x	x					
82	<i>Porosononion dendriculus</i> (Khalilov, 1957)	x	x			x		x					
83	<i>Porosononion</i> aff. <i>martcobi</i> Bogd., 1950				x								
84	<i>Rotalia propinqua</i> (Reuss).		x	x									
85	<i>Ammonia</i> ex gr. <i>beccarii</i> (Linnaeus, 1758)	x				x							
86	<i>Elphidium onerosum</i> Bogdanowich, 1960	x				x	x	x					
87	<i>Caucasinella</i> aff. <i>elongata</i> (d’Orbigny, 1826)					x	x	x					
88	<i>Caucasina oligocenica</i> Khalilov, 1951	x											
89	<i>Caucasina</i> aff. <i>tumidula</i> Bogdanowich, 1960	x		x		x	x						
90	<i>Caucasina schischkinskayae</i> (Samoilova, 1947)	x		x									
91	<i>Caucasina buliminoides</i> Bogdanowich			x	x								
92	<i>Caucasinella elongata leninabadensis</i> Kusnetzova, 1964					x							
93	<i>Caucasinella kasachensis</i> Kusnezova			x									
94	<i>Caucasinella</i> sp.					x	x						
95	<i>Bulimina ovata</i> Orbigny			x				x					
96	<i>Uvigerinella californica parva</i> Kleinpell, 1938	x		x									
97	<i>Uvigerinella californica</i> Cushman, 1926	x	x	x	x								
98	<i>U. californica</i> var. <i>uruchensis</i> Bogd., 1960	x	x			x							
99	<i>Angulogerina</i> aff. <i>angulosa</i> Will.			x	x								
100	<i>Angulogerina gracilis</i> (Reuss, 1851)	x											
101	<i>Bolivina mississippiensis</i> Cushman, 1922	x		x			x						
102	<i>Bolivina goudkoffi caucasica</i> Bogd., 1960	x	x	x		x							
103	<i>Bolivina dilatata</i> Reuss, 1850			x		x							
104	<i>Bolivina</i> ex gr. <i>floridana</i> Cushman, 1918	x	x			x							
105	<i>Bolivina</i> ex gr. <i>plicatella</i> Cushman, 1930	x	x		x	x							
106	<i>Fursenkoina schreibersiana</i> (Czjzek, 1848)	x	x										
107	<i>Virgulinella</i> ex gr. <i>pertusa</i> (Reuss, 1861)	x	x	x									
108	<i>V.</i> aff. <i>neobuliminiformis</i> Kusnezova, 1964			x									
109	<i>Virgulinella eaquele</i> Z.Kusn.,		x										
110	<i>Cassidulina oblonga</i> Reuss, 1850	x		x		x		x					
111	<i>Globigerina officinalis</i> Subbotina, 1953	x											
112	<i>Globigerina</i> aff. <i>bulloides</i> (d’Orbigny, 1826)	x		x	x			x					
113	<i>Globigerina</i> sp.	x			x	x							
114	<i>Globigerina tarchanensis</i> Subb., Chut., 1950					x		x					
114	<i>G. ouachitaensis ouachitaensis</i> Howe, Wall.			x				x					
115	<i>Sphaeroidina bulloides</i> (d’Orbigny, 1826)					x							
116	<i>Cassidulina oblonga</i> Reuss, 1850			x				x					

In the Lower Miocene part of the Western Ciscaucasia, Maikopian deposits along the southern edge of the Western Kuban Foredeep are quite fully characterized by finds of microfauna with respect to the taxonomic composition; however, their quantitative composition is poor. More than 100 foraminifer species were found in the sections of wells and outcrops.

At the base of the Caucasian Regional Stage, there are calcareous clays with planktonic and benthic fauna of the Alkunian Horizon (the Fyuntv River, the right tributary of the Belaya River), where the assemblage of *Spiroplectammina* aff. *terekensis*, *Trochammina depressa*, *Baggina* sp., *Cibicides* aff. *pseudoungerianus*, *C. almaensis*, *Caucasina* aff. *buliminoides*, *Fursenkoina* ex gr. *pertusa*, *Fursenkoina schreibersiana*, *Globigerina praebuloides*, *G. yeguaensis yeguaensis*, *Globorotalia* sp., *Guembelina gracillima*, and other characteristic of the *Vergulinella* Beds of the base of the Caucasian Regional Stage (Bogdanowicz, 1986) or *Fursenkoina schreibersiana*—*Caucasina* sp. Beds, was found (Pinchuk, 2006, 2018).

The Voskovogorsk Formation contains an assemblage of *Bolivina goudkoffi caucasica* Beds (Bogdanowicz, 1965, 1986, 1971) and is characterized by core from deep well sections on the southern edge of the West Kuban Trough, from the Khadyzhenskaya area to the Fedorovskaya Field, where *Bolivina plicatella*, *B.* aff. *goudkoffi caucasica*, *Uvigerinella californica*, *U. californica uruchensis*, *Virgulinella* aff. *pertusa*, *V. eaquale*, *Fursenkoina schreibersiana*, *Globorotalia* sp., *Asterigerina* aff. *bracteata*, *Cibicidina* aff. *amphisylensis*, *C.* aff. *oligocenicus*, etc., were found in clays interbedded with sideritized marl. Within the platform facies, the assemblage is enriched with agglutinated foraminifer species *Haplophragmoides* aff. *kjurendagensis*, *H. stavropolensis*, *Ammodiscus tenuiculus*, *Cyclammina constrictimargo*, etc. There are representatives of *Bolivina*, *Uvigerinella*, *Cibicides*, and other, probably of Mediterranean origin. The *Bolivina goudkoffi caucasica* Beds are widespread in Ciscaucasia, Ukraine, Transcaucasia, and the Black Sea region in the interval of the lower part of the Caucasian Regional Stage, middle part of the Maikopian subseries.

The *Uvigerinella californica* Beds (Bogdanowicz, 1960a, 1986; Nosovskii and Bogdanowicz, 1980). The assemblage contains *Haplophragmoides* sp., *Spiroplectammina caucasica*, *Reophax splendidus*, *Cibicides ornatus*, *Uvigerinella* ex gr. *californica*, *Bolivina goudkoffi caucasica*, *Bolivina* ex gr. *floridana*, *Caucasinella elongata*, *Virgulinella aequale*, *Porosononion dendriculus*, and *Rotalia propinqua*. In well cores of the West Kuban trough, sterrasters, plant remains, pyritized nuclei of diatoms, and foraminifers were found in the Mingrelskaya, Fedorovskaya, Kubanskaya SG-12000 and many other areas in gray noncalcareous clays, namely, *Hyperammina* sp., *Saccamina* sp., *Haplophragmoides kjurendagensis*, *Haplophragmoides* sp.,

Trochamminoides sp., *Uvigerinella* ex gr. *californica*, *Uvigerinella* sp., *Bolivina* sp., *Cibicides* aff. *stavropolensis*, *Cibicidina* sp., and other. This shows that the *Uvigerinella californica* Beds belong to the Caucasian Regional Stage. The beds are traced in sections of Ciscaucasia, the Black Sea region, Crimea, and Transcaucasia and correspond to the upper part of the Caucasian Regional Stage and upper part of the Middle Maikopian.

The Maikopian deposits of Central Ciscaucasia differ facially. The southern Stavropol region is characterized by relatively deep-water and transitional facies with foraminifer assemblages containing planktonic and benthic microfauna. The northern Stavropol region is characterized by shallow-water facies with a benthic fauna collection. Thus, *Ammodiscus incertus*, *Cibicides stavropolensis*, *Pseudoparella caucasica*, *Caucasina* sp., *Uvigerinella* aff. *californica*, *Bolivina* ex gr. *plicatella*, *B.* ex gr. *floridana*, *Virgulinella neobuliminiformis*, and *Globigerina* sp. were identified in the stratotype section along the Kuban River in clays of the Alkunian Horizon.; *Ammodiscus tenuiculus*, *Discorbis* sp., *Quinqueloculina* sp., *Angulogerina* sp., *Globigerinella* sp., and *Cibicides amphisylensis* (Nosovsky and Bogdanowicz, 1979) and the dominance of *Virgulinella* and *Bolivina* shells (Bogdanowicz, 1986) were also recorded here. Species of the genus *Virgulinella* were also found in the Early Miocene in the Northern Caucasus (outcrops along the Belaya, Laba, Uruk, Fiagdon, Assa, Argun, and Sulak rivers), in Ciscaucasia (sections along the wells of the Armavir, Groznensky, and Elistinsky areas), in Crimea (Vernigorova and Ryabokon', 2018), and in the northern part of the Caspian Sea (Ulanovskaya et al., 2004).

According to Bogdanowicz (1960a), the Alkunian Horizon along the Alkunka stream (a tributary of the Assa River) is characterized by foraminifers *Porosononion* aff. *martcobi* *Uvigerinella* ex gr. *californica*, *Angulogerina* aff. *angulosa*, *Bulimina* sp., *Globigerina* aff. *bulloides*, etc. In the Northern Black Sea region, the lower part of the Arabat Formation (deposits containing foraminiferal *Haplophragmoides periferocavatus* Beds), developed along the Parpach Ridge on the Kerch Peninsula, and an undetermined part of the Alagol Formation in the eastern Kerch Peninsula correspond to the Caucasian Regional Stage (Vernigorova and Ryabokon', 2018).

In the northeastern Stavropol region, a rich microfauna with *Vergulinella* and *Bolivina goudkoffi* was found in the Derbetovskaya-37 well (a reference well for the Caucasian Regional Stage) in analogs of the Alkunian Horizon. The assemblage includes *Uvigerinella californica uruchensis*, *Spiroplectammina caucasica*, etc. (Nosovskii and Bogdanowicz, 1979). Two microfaunal zones were recognized based on the well cores (Salskaya, Ivanovskaya, Ipatovskaya, and Manychskaya areas): the *Trochamminoides concentri-*

cus Beds in sediments of the Zelenchuk formation (Ter-Grigor'yants, 1964) (these beds constantly contain *Trochammina florifera*, *Pseudocyclammina insignedentata*, *Hyperammina* sp., *Ammodiscus tenuiculus*, *Saccammina variabilis*) and the *Haplophragmoides kjurendagensis* Beds (Ter-Grigor'yants, 1964) in deposits of the Karadzhalka Formation/ These beds are characterized by abundant assemblage of foraminifers of the genera *Haplophragmoides*, *Cyclammina*, *Uvigerinella*, *Cibicides*, etc., as well as by representatives of the genera *Nonion* and *Eponides* and the species *Bolivina goudkoffi* and *Spiroplectammina caucasica*, which appear for the first time.

The foraminiferal assemblage of the Central Ciscaucasia is quantitatively richer than that of Western Ciscaucasia. Here, the Early Miocene part of the Maikopian contains 68 species; 42% of them (including benthic and planktonic species) pass from underlying deposits.

The assemblages of benthic foraminifers of the reference section of the Caucasian Regional Stage from the Novopokrovskaya-4 well are divided into *Bolivina goudkoffi caucasica* Beds (interval 790–855 m) (Nosovskii and Bogdanowicz, 1980) or *Haplophragmoides kjurendagensis* Beds. The latter assemblage includes the following species: *Haplophragmoides* aff. *kjurendagensis*, *H. stavoropolensis*, *Ammodiscus perllucidus*, *Cyclammina clivosa*, *C. aff. constrictimargo*, *Cibicoides tachtaensis*, *Bolivina goudkoffi*, *B. aff. floridana*, *Porosonion dendriticum*, and other. Upward from the base Bogdanowicz recognized *Uvigerinella californica* Beds (in the interval of 750–790 m).

In Ciscaucasian sections, *Bolivina goudkoffi caucasica* and *Uvigerinella californica* Beds do not contain planktonic foraminifers; however, they are traced above the Alkunian Horizon, which yields planktonic foraminifers and belongs to the Lower Miocene according to nannofossil data.

In the Northern Black Sea region, the typical species are *Porosonion dendriticus*, *Elphidium onerosum*, and *Heterolepa ornata* in the lower strata of the Lower Miocene in the Gornostaevskaya Formation and *Spiroplectammina caucasica*, *Bolivina goudkoffi*, and *Sphaeroidina variabilis* in sandy facies (Nosovskii and Semenenko in Neogenovaya sistema, 1986).

In the sediments of southern Ukraine, the *Bolivina goudkoffi caucasica* Beds and *Uvigerinella californica* Beds are dated to the Late Oligocene (Chattian), based on dinocysts. On the Kerch Peninsula, the Upper Kerleut Subformation with the same foraminiferal beds is of Late Oligocene age according to phytoplankton data (Vernigorova and Ryabokon', 2018; Vernyhorova and Ryabokon, 2020).

Fifty-two species passed from the Oligocene; 15 of them are also known in the Mediterranean and the others were described from sections of the Eastern Paratethys. Seventeen of the total number of species

survived until the Sakaraulian time and only eight species were found in the Kozakhurian.

Sakaraulian Regional Stage

The lower part of the Upper Maikopian, presumably correlated with the Sakaraulian, in Northern Ciscaucasia is recognized as ***Caucasinella elongata* Beds** based on microfauna (Bogdanowicz, 1986; Pinchuk, 2006). The assemblage contains *Rhabdammina cylindrica*, *Haplophragmoides* aff. *stavoropolensis*, *H. aff. rotundidorsatus*, *Trochammina vera*, *Cibicides stavoropolensis*, *Elphidium onerosum*, *Bulimina tumidula*, *Caucasinella elongata*, *Bolivina dilatata*, *B. ex gr. floridana*, *B. ex gr. plicatella*, and other.

In the section of the Kuban ultradeep well SG-12000, located in the central part of the West Kuban trough, only the middle and upper parts of exposed Maikopian deposits 661-m thick, was characterized by microfauna. A depleted foraminifer microfauna was found along the section of the supposed Sakaraulian analogs; it is represented mainly by benthic and, less frequently, planktonic species, from *Caucasinella elongata* Beds (Fig. 16). This interval contains species that passed from the underlying deposits (*Haplophragmoides kujurendagensis*, etc.), and characteristic species *Haplophragmoides rotundidorsatus*, *H. rotundidorsatus granatus*, *Caucasinella* aff. *elongata*, etc., appear here. In sections of the West Ciscaucasian subzone, the beds are distributed in the Fedorovskaya, Il'skaya, Severo-Krasnodarskaya, Timashevskaya, Vysel'kovskaya, Beisugskaya, and other areas. The lower part of the Upper Maikopian, recognized as *Caucasinella elongata* Beds, contains *Haplophragmoides kujurendagensis*, *Quinqueloculina* sp., *Globulina gibba*, *Bolivina mississippiensis*, *Cibicides pseudoungerianus*, *C. aff. amphisyliensis*, *Caucasinella* aff. *elongata*, *Caucasina schischkinskiae*, and *Gaudryina* sp.

The distribution of the Upper Maikopian sediments is restricted in the Azov subzone; their absence is recorded in the northern part due to subsequent erosion. To the south, rocks contain foraminifers characteristic of the lower part of the Upper Maikopian: *Nodosaria* sp., *Bulimina tumidula*, *Cibicides stavoropolensis*, and *Cibicides* sp. *Porosonion dendriticus* Beds and *Caucasinella elongata*—*Cibicides stavoropolensis* Beds are recognized here (Bogdanowicz, 1965, 1986); these beds contain an assemblage of foraminifers with *Haplophragmoides* aff. *rotundidorsatus*, *Trochammina vera*, *Cibicides stavoropolensis*, *Elphidium onerosum*, *Astrononion ergenicus*, *Bulimina tumidula*, *Caucasinella elongata*, and other.

In the Central Ciscaucasia, the *Caucasinella elongata* Beds contain an assemblage of agglutinated and calcareous forms: *Haplophragmoides rotundidorsatus*, *H. peripheroexcavatus*, *Trochammina depressa*, *T. inflata*, *Ammodiscus tenuiculus*, *Caucasinella elon-*

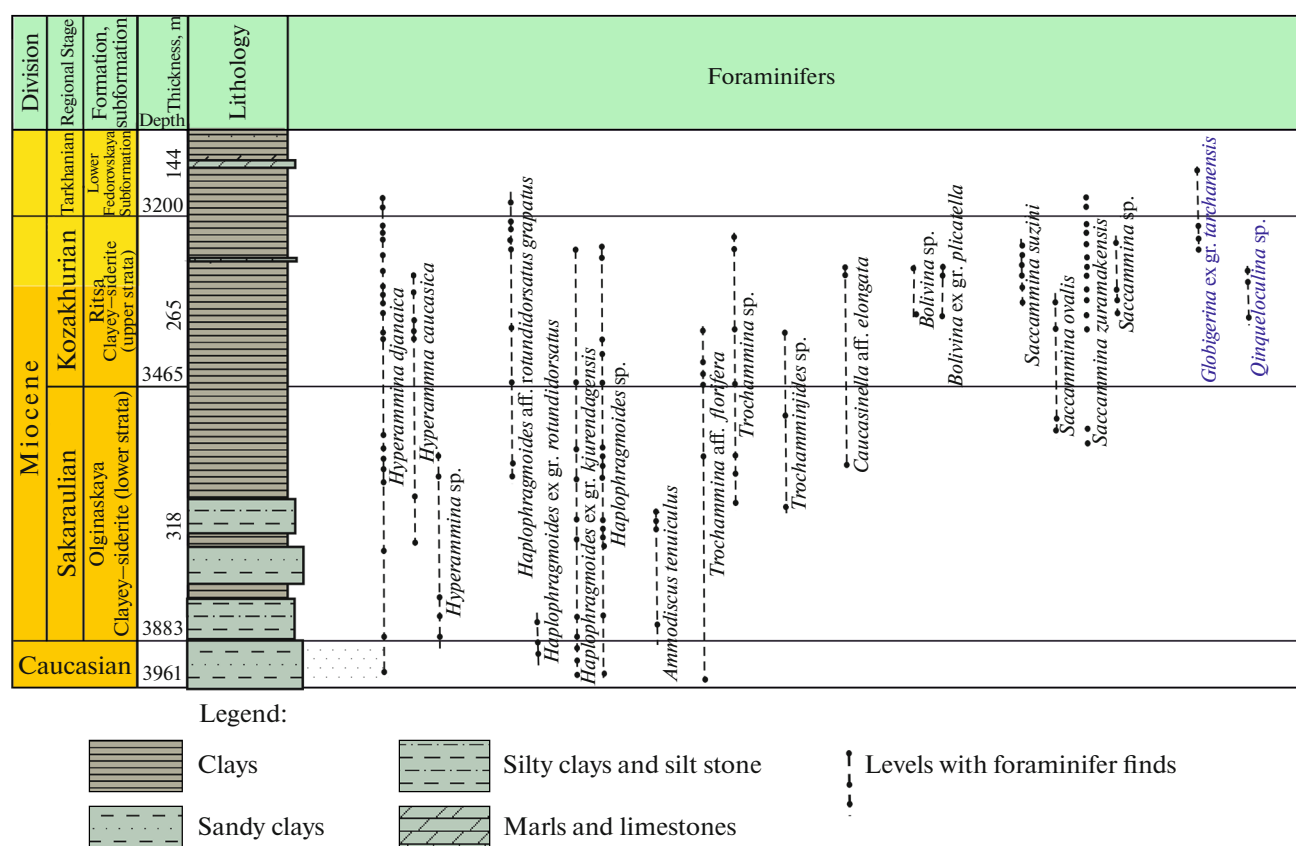


Fig. 16. Scheme of foraminifer distribution in the Lower Miocene section in the Kubanskaya SG-12000 ultradeep well.

gata, *Bulimina tumidula*, *Cibicides stavropolensis*, *C. almaensis*, *Elphidium onerosum*, etc. (Ter-Grigor'yants, 1964). In the Olginskaya Formation, *Haplophragmoides periferioexcavatus*, *H. inaequilateralis*, *Hyperammina* sp., *Ammodiscus granatus*, *Trochammina depressa*, *Trochamminoides* sp., and *Cyclammina* (?) sp., *Bulimina* cf. *ovata*, *Bolivina* sp., and *Globigerina* sp. were recorded in the Kuban River section (recognized by Subbotina and Bogdanowicz, 1961, 1986). The author also identified an abundant assemblage of agglutinated species including *Ammodiscus* aff. *pellucidus*, *Haplophragmoides latidorsatus*, *H. aff. kjurendagensis*, *H. kjurendagensis karadjalensis*, *H. periferioexcavatus*, *Pseudocyclammina* sp., *Cyclammina turosa*, *Cyclammina* sp., *C. aff. kapustina*, *Ammomarginulina* aff. *lobsanense*, *Rotaliammina depressa*, *Verneuilioides* aff. *rasilis*, etc.

In the southern Ukraine *Haplophragmoides rotundidorsatus* was recorded in the Upper Oligocene (Vernigorova and Ryabokon', 2018). In the Black Sea region and on the Black Sea shelf, this species occurs in the bathysiphon stage of the *Caucasinella elongata* and *Haplophragmoides periferioexcavatus* fold, according to E.A. Kraeva (in Astakhova et al., 1984).

In Azerbaijan the *Caucasinella elongata leninabadensis* Beds, recognized by Z.V. Kuznetsova, are

assigned to the Sakaraulian (Khalilov and Kuznetsova, 1964); they contain *Bulimina tumidula*, *Virgulina schreibersiana*, *Elphidium kvesanensis*, *Cibicides variolatum*, *Florilus* aff. *incisus*, *Lagena vilardeboana*, *Bolivina punctata*, and *Astronion ergenicis*, and are considered to be analogous to *Caucasinella elongata* Beds.

In western Georgia and Abkhazia, two microfaunal assemblages were identified within the Sakaraulian Regional Stage: the lower part included the "*Uvigerinella* zone" and the upper part included *Caucasinella* (= *Neobulimina*) *abchasiensis* "zone" (Dzhanelidze, 1964, 1970).

The Lower Miocene forms (Aquitainian and Burdigalian), which migrated to the Sakaraulian basin from southern open water bodies, include the following species: *Quiqueloculina agglutinans*, *Polymorphina incerta*, *Nonion granosus*, *Florilus boueanus*, *Virgulina pertusa*, *Bolivina floridana*, *Caucasinella elongata*, *Ammonia beccarii*, and other.

The foraminifer species in the Sakaraulian common for the entire Eastern Paratethys are *Hyperammina caucasica*, *Bolivina* ex gr. *floridana*, *Bulimina tumidula*, *Caucasinella* aff. *elongata*, *Cibicides stavropolensis*, *Astronion ergenicis*, *Ammomarginulina*

depressa, *Porosononion dendriculus*, and *Elphidium onerosum* (Bogdanowicz, 1986).

The communication between the Eastern Paratethys and normal marine basins in the Sakaraulian led to the formation of a rather rich assemblage of foraminifers in Northern Ciscaucasia (up to 40 genera, 50 species) and Georgia and Abkhazia (up to 38 genera and 100 species). The basin was dominated by representatives of *Caucasinella*, *Bulimina*, *Bolivina*, *Porosononion*, etc. The agglutinated forms included species of *Saccammina*, *Haplophragmoides*, *Cyclammina*, etc. The rare plankton was represented by a single *Globigerina*. The migrant species included *Caucasinella* aff. *elongata*, *Bolivina* ex gr. *floridana*, etc.; neoautochthons included *Cibicides stavropilensis*, *Caucasinella elongata leninabadensis*, *Bulimina tumidula*, etc. One should note species that passed from the preceding Caucasian basin, namely, *Porosononion dendriculus*, *Hyperammina caucasica*, *Elphidium onerosum*, and other.

Kozakhurian Regional Stage

The upper part of the Upper Maikopian is characterized by a depleted assemblage of foraminifers, which were assigned to the Turammin zone by Subbotina (1936) or recognized as *Saccammina zuramakensis* Beds (Bogdanowicz, 1954, 1960a, 1986; Bogdanowicz, 1971). Their characteristic features are the confinement of Saccaminae to the upper part of the Maikopian and wide distribution in Ciscaucasian sections. In Kerch sections, *Saccammina zuramakensis* was recorded as single specimens in the Korolevian Formation, according to V.F. Kozyreva (in Astakhova et al., 1984). Despite the rare finds of Saccaminae and other foraminifer groups in the upper part of Maikopian sediments, it is possible to correlate different formations across the Crimean–Caucasian region. The assemblage contains the following species: *Saccammina zuramakensis*, *S. ovalis*, *Saccammina suzini*, *Ammodiscus granatus*, and *Elphidium* aff. *onerosum*. In the southern Stavropol Region, they are confined to the Ritsa Formation; in the northern areas, deposits of the Upper Maikopian are eroded or absent.

The Kozakhurian basin was characterized by desalinated regime; only neoautochthonous *Saccammina* species were preserved here. However, faunal beds alternate with barren strata in sections of wells SG-12000 (Fig. 16) and of the Priyutninskaya area in the lower part of the Kozakhurian section, which is accompanied by gradual disappearance of calcareous Maikopian species and by rare occurrence of planktonic *Globigerina* sp. and *G. tarchanensis*, which indicates connection with open basins.

Tarkhanian Regional Stage

The Tarkhanian foraminifer assemblage contains planktonic and benthic species, which are described in

the works of Bogdanowicz (1947, 1951, 1965, 1986), Gerke (1938), Dzhanlidze (1970), Krashenninnikov (1959), Krashenninnikov et al. (2003), Konenkova (1984), Ivanova et al. (1998), Nosovskii and Ivanova (2005), Pinchuk (2006), Vernigorova (2014), Ivanova and Bondar' (2014), and Golovina and Bylinskaya (2020).

The Tarkhanian Basin is characterized by a rich assemblage of foraminifers (up to 46 genera and 130 species), which resulted from the establishment of a new communication of the Eastern Paratethys with Tethys and Central Paratethys seas (Table 2). Benthic foraminifers are represented mainly by miliolids (*Quinqueloculina*, *Sigmoilinita*, *Varidentella* (*Miliolinella*), and *Triloculina*) and by members of *Nodosaria*, *Lagena*, *Bolivina*, *Caucasina*, *Guttulina*, *Polymorphina*, *Florilus*, and some other genera.

The distribution of foraminifers in the Tarkhanian section makes it possible to establish the characteristic assemblages identified by Bogdanowicz as “zones” or Beds with fauna. We use the second term.

Kuvinian beds. The lower part of the Tarkhanian hypostratotype in the Bulganak Bay is composed of dark gray noncalcareous clays containing the following foraminifers: *Saccammina zuramakensis*, *S. ovalis*, *Hyperammina* sp., *Discorbis* sp., *Cibicides* cf. *borislavensis*, *Bolivina tarchanensis*, etc. (Nosovskii et al., 1976; Bogdanowicz, 1986). The deposits of this part of the section were recognized by the authors of the first publication as Kamyslak beds. However, the same beds underlying the “Tarkhanian marl” were previously called Kuvinian beds (Merklin et al., 1964); therefore, we use the latter name, which is given a priority. For the foraminifer association in these beds, Bogdanowicz (in Nevesskaya et al., 1975) proposed to distinguish *Globigerina tarchanensis*–*Saccammina zuramakensis* Beds for the Kuvinian beds. The assemblage includes *Saccammina zuramakensis*, *Textularia tarchanensis*, *Quinqueloculina boueana*, *Sigmoilinita tenuis*, *Triloculina gibba*, *T. austriaca*, *Nonion granosus*, *Bolivina tarchanensis*, *Globigerina tarchanensis*, *G. parva*, etc. The lower boundary is defined by reduction of agglutinated *Saccammina* species and by a sharp appearance of planktonic and calcareous benthic forms of the Tarkhanian (Pinchuk, 2006).

Based on the composition of foraminifers, **Terek beds** were recognized as *Globigerina tarchanensis* Beds (Bogdanowicz, 1971), which contain the most polyhaline foraminifer assemblage with *Haplophragmoides periferioexcavatus*, *Textularia tarchanensis*, *Quinqueloculina boueana*, *Triloculina gibba*, *T. gubkini*, *Sigmoilinita tenuis*, *Entosolenia ovulum*, *Bolivina tarchanensis*, *B. aff. floridana*, *Uvigerina* ex gr. *pygmaea*, *Polymorphina* aff. *striata*, *Ammoina* ex gr. *beccarii*, *Globigerina tarchanensis*, *G. parva*, and *G. bulloides*; foraminifers are small-sized and thin-walled and numerous (Pinchuk, 2006). Although the species *Globigerina tarchanensis* occurs at different levels of the Lower and

Table 2. Distribution of foraminifers in the sediments of the Tarkhanian Regional Stage in different areas of the Eastern Paratethys (according to Bogdanowicz, 1965; Dzhanelidze, 1970; Krashennnikov et al., 2003; Nosovskii and Ivanova, 2005; Minashvili and Ananiashvili, 2013, supplemented by the author)

No.	Foraminifer species	Ciscaucasia			Crimea	Georgia		Apsheron Peninsula
		Western	Central	Eastern		Western	Eastern	
1	2	3	4	5	6	7	8	9
1	<i>Hyperammia</i> aff. <i>algaeformis</i> Brady, 1879		x	x				
2	<i>Hyperammia</i> sp.			x	x			
3	<i>Saccammina zuramakensis</i> Bogd., 1947	x			x			
4	<i>Saccammina ovalis</i> Subb., 1947	x			x			
5	<i>S. vulgaris</i> Bogd.	x		x				
6	<i>Trochammina</i> sp.			x		x	x	
7	<i>Haplophragmoides</i> sp.	x	x					
8	<i>Textularia tarchanensis</i> Bogd., 1950	x				x	x	
9	<i>T. deperdita</i> (Orb., 1846)	x				x	x	
10	<i>Textularia</i> sp.	x	x	x				
11	<i>Quinqueloculina akneriana</i> Orbigny, 1846		x	x	x	x		x
12	<i>Quinqueloculina akneriana rotunda</i> (Gerke, 1938)	x	x	x	x	x		
13	<i>Quinqueloculina</i> ex gr. <i>badenensis</i> Orb., 1846	x	x		x			x
14	<i>Q.</i> ex gr. <i>circularis</i> (Bornemann, 1855)	x						
15	<i>Q. boueana</i> Orbigny, 1846	x			x	x	x	x
16	<i>Q. boueana plana</i> O. Djan., 1958					x	x	
17	<i>Q. boueana levis</i> O. Djan., 1958					x	x	
18	<i>Q. grasilis</i> Karrer, 1867			x				
19	<i>Q. laevigata</i> Orb., 1846		x	x		x		
20	<i>Q. ungeriana</i> Orb., 1846	x	x			x		
21	<i>Q.</i> aff. <i>cubanica</i> Bogd., 1950		x	x		x		
22	<i>Articulina</i> sp.	x	x					
23	<i>Spiroloculina</i> sp.			x				
24	<i>Siphonoperta mediterraneensis</i> (Bogd., 1950)	x	x	x	x	x		x
25	<i>Sigmoilinita haidingerii</i> (Orbigny, 1846)	x	x		x			
26	<i>Sigmoilinita tenuis</i> (Czjžek, 1848)	x	x	x	x	x	x	
27	<i>Sigmoilinita tenuis tarchanensis</i> O. Djan, 1958					x	x	
28	<i>Sigmoilinita tschokrakensis</i> (Gerke, 1938)	x			x			
29	<i>Triloculina selene</i> (Karrer, 1868)	x	x			x	x	
30	<i>Triloculina gubkini</i> (Bogd., 1947)		x	x				
31	<i>T. gibba</i> Orb., 1826	x	x			x	x	
32	<i>T.</i> aff. <i>austriaca</i> Orb., 1857	x				x	x	
33	<i>T. subfoliacea</i> (Bogd., 1947)	x						
34	<i>Tschokrakella parensis</i> Bogd., 1950	x	x					
35	<i>Nodosaria badensis</i> Orb. <i>caucasica</i> Bogd., 1947	x						
36	<i>Nodosaria</i> sp.	x	x					
37	<i>Nodosaria</i> ex gr. <i>soluta</i> Reuss, 1851				x			
38	<i>N.</i> cf. <i>marie</i> Orb., 1839					x	x	
39	<i>Nodosaria radricula</i> (Linnaeus, 1758)					x		
40	<i>N. tarchanensis</i> O.Djan., 1958					x		
41	<i>Lagena</i> sp.	x	x	x	x			
42	<i>Lagena vulgaris</i> Will., 1858.	x				x	x	
43	<i>Lagena vulgaris clavata</i> Will., 1858					x		
44	<i>Lenticulina simplex</i> (d'Orbigny, 1846)	x				x		

Table 2. (Contd.)

No.	Foraminifer species	Ciscaucasia			Crimea	Georgia		Apsheron Peninsula
		Western	Central	Eastern		Western	Eastern	
1	2	3	4	5	6	7	8	9
45	<i>L. aff. similis</i> (Orb., 1846)		x	x		x		
46	<i>L. inornata</i> (Orb., 1846)		x	x	x	x		
47	<i>Dentalina elegans</i> Orb., 1846				x			
48	<i>Guttulina</i> sp.	x						
49	<i>G. austriaca</i> Orb.	x	x	x	x	x	x	
50	<i>G. lactea</i> (W. et J.)				x	x		
51	<i>Discorbis tschokrakensis</i> Bogd., 1947	x	x			x		
52	<i>D. leo</i> O.Djan. 1958					x		
53	<i>D. tarchanensis</i> O. Djan., 1958					x		
54	<i>D. arcuatus</i> O. Djan., 1958					x		
55	<i>Glabratella tarchanensis</i> (O.Djan. 1952)				x	x		
56	<i>Glabratella aff. imperatoria</i> (Orb. 1839)				x			
57	<i>Siphonina aff. reticulata</i> (Czjzek, 1848)				x			
58	<i>Asterigerina risilla</i> Jarz.				x			
59	<i>Cibicides ex gr. lobatulus</i> (W. et J., 1798)	x	x	x		x	x	
60	<i>Cibicides ungerianus</i> (Orb., 1846)				x			
61	<i>Nonion punctatus</i> (Orb., 1846)				x			
62	<i>Porosonion subbotina</i> Chutzieva, 1952.	x				x	x	
63	<i>Nonionella pulchella</i> O.Djan., 1958					x	x	
64	<i>Florilus parvus</i> (Bogd., 1950)					x		
65	<i>Florilus boueanus</i> (Orb., 1826)	x	x	x	x	x	x	x
66	<i>Melonis pompilioides</i> (F. et M.)	x	x	x				
67	<i>Globigerina tarchanensis</i> Subb. et Chutz., 1950	x	x	x	x	x	x	x
68	<i>Globigerina aff. bollii</i> (Cita, Premoli Silva, 1960)				x			
69	<i>G. bradyi</i> Wiesner, 1931				x			
70	<i>Globigerina bulloides</i> Orb., 1826	x	x		x			x
71	<i>G. cognata</i> (Pichvanova, 1958)							
72	<i>G. officinalis</i> Subb. et Chutz., 1953	x			x			
73	<i>G. praebulloides</i> Blow, 1959	x			x			
74	<i>Globigerina dubia</i> Egger, 1857	x	x					
75	<i>Globigerina glutinata</i> Egger, 1893	x						
76	<i>Globigerinita uvula</i> (Ehrenberg, 1861)	x	x	x				
77	<i>G. opinata</i> Pichvanova, 1959	x						
78	<i>Globigerina falconensis</i> Blow, 1959	x		x	x			
79	<i>G. brevispira</i> Subbotina, 1960	x						
80	<i>Tenuitella pseudoedita</i> (Subbotina, 1960)	x	x	x				
81	<i>Tenuitella angustiumbilocata</i> (Bolli, 1957)	x	x					
82	<i>Globoturborotalita woodi</i> (Jenkins, 1960)	x	x	x				
83	<i>Globoturborotalita euapertura</i> Jenkins, 1960		x					
84	<i>Paragloborotalia birnageae</i> (Blow, 1959)	x	x					
85	<i>Paragloborotalia continua</i> Blow, 1959	x	x		x			
86	<i>P. acrostoma</i> (Wezel, 1966)		x					
87	<i>Paragloborotalia birnageae</i> (Blow, 1959)	x	x					
88	<i>Globorotalia (Catapsydrax) scitula</i> (Brady, 1882)	x						
89	<i>Gl. (Fohsella) peripheroronda</i> (Blow, Ban., 1966)	x	x					

Table 2. (Contd.)

No.	Foraminifer species	Ciscaucasia			Crimea	Georgia		Apsheron Peninsula
		Western	Central	Eastern		Western	Eastern	
1	2	3	4	5	6	7	8	9
90	<i>Globoturborotalita euapertura</i> (Jenkins, 1960)	x		x				
91	<i>Turborotalita quinqueloba</i> (Natland, 1938)	x		x				
92	<i>Streptochilus pristinum</i> Brönnim. et Resig, 1971	x	x					
93	<i>Ciperoella anguliofficialis</i> (Blow, 1969)	x						
94	<i>Planorotalia minutissima</i> (Bolli)				x			
95	<i>Ammonia simplex</i> (Orb., 1846)				x			
96	<i>Ammonia mjatliukae</i> (Putrja)				x			
97	<i>Ammonia</i> ex gr. <i>beccarii</i> (Linne, 1758)	x	x	x		x	x	x
98	<i>Ammonia</i> aff. <i>compacta</i> Hofker, 1964	x	x	x		x	x	
99	<i>Ammonia pseudobeccarii</i> (Putrja)				x			
100	<i>Rotalia maschanliensis</i> Pron.		x	x		x	x	
101	<i>Rotalia bullaeformis</i> Pron.						x	
102	<i>Elphidium</i> ex gr. <i>macellum</i> (F. et M., 1803)	x	x	x				
103	<i>Elphidium</i> aff. <i>antonina</i> (Orb. 1846)		x					
104	<i>Elphidium</i> aff. <i>fichtellianum</i> (Orb., 1846)		x	x				
105	<i>Elphidium</i> sp.						x	
106	<i>Virgulina tarchanensis</i> Bogd., 1947	x				x	x	x
107	<i>Virgulina schreibersiana</i> Czjzek, 1848			x		x		
108	<i>Enosolenia ovulum</i> Subb. et Chutz., 1952		x	x		x	x	
109	<i>Caucasinella</i> aff. <i>elongata</i> (d'Orbigny, 1826)	x	x			x		
110	<i>Bolivina tarchanensis</i> Subb. et Chutz., 1950	x	x					
111	<i>Bolivina floridana</i> Cushman, 1918	x	x					
112	<i>Caucasina</i> aff. <i>spinulifera</i> Bogd., Gavr., 1965	x						
113	<i>Pseudopolymorphina uniserias</i> Suzin, 1950	x	x					
114	<i>P. subbotinae</i>					x		
114	<i>P. compressa</i> (Orb., 1846)					x	x	
115	<i>Globulina gibba</i> Orb., 1846		x	x	x			
116	<i>G. tuberculata</i> Orb., 1846						x	
117	<i>G. striata</i> Egger, 1857						x	
118	<i>Caudina caudata</i> (Suzin)	x	x	x	x	x	x	
119	<i>Patellina corrugata</i> Will., 1858		x	x		x		
120	<i>Loxostomum colchicum</i> O.Djan., 1970					x		
121	<i>Reussella spinulosa</i> (Reuss, 1850)						x	
122	<i>Angulogerina angulosa</i> (Will., 1858)	x				x		
123	<i>Caucasina schischkinskaye</i> (Sam., 1947)		x	x		x		
124	<i>Caucasina buliminoides</i> Bogd., 1947	x	x	x		x		
125	<i>Cassidulina</i> sp.	x						
126	<i>Cassidulina tarchanensis</i> Chutz., 1952		x	x	x			
127	<i>C. subglodosa</i> Brady, 1881	x	x	x				
128	<i>Cassidulinoides tarchanensis</i> Chutz., 1952	x	x	x		x		
129	<i>Bolivina miocenica</i> Macf.		x	x	x			
130	<i>B. floridana</i> Cushman, 1918	x	x	x	x	x		
131	<i>B. tarchanensis</i> Subb. et Chutz., 1952	x	x	x	x	x	x	
132	<i>B. fastigia</i> Cushman, 1936		x	x				

Middle Miocene (from the Sakaraulian to the Chokrakian), it is usually represented by single specimens; however, a mass number of shells of this species has been recorded in the Tarkhanian; therefore, it is indicated as an index species for the Middle Tarkhanian.

In Argun *Sigmoilinita haidingerii* beds (Bogdanowicz, 1971), the foraminifer assemblage includes *Bolivina tarchanensis*, *Quinqueloculina akneriana*, *Miliolinella selene*, *Sigmoilinita tarchanensis*, *S. haidingerii*, *Triloculina gibba*, *Florilus boueanus*, and *Globigerina tarchanensis*. Foraminifers are small in size and numerous (Pinchuk, 2006).

While discussing the position of the Tarkhanian–Chokrakian boundary in the lectostratotype, Bogdanowicz believed that only the lowermost strata of Andrusov's "Spirialis Clays" (10 m thick) corresponded to the Argun beds of the Tarkhanian (Bogdanowicz and Goncharova, 1976). He assigned the overlying clays to *Bolivina tarchanensis* Beds, which he dated to the Lower Chokrakian, mainly by the disappearance of the most polyhaline species (Table 3, marked in dark orange) and dominance of endemic species (marked in light orange).

The study of "Spirialis Clays" in the Malyi Kamyshlak, Skelya, and Cape Takil sections by numerous researchers (Bogdanowicz, Dzhanelidze, Konenkova, N. A. Trofimovich, Yu. V. Vernigorova, et al.) showed that the boundary between the Tarkhanian and Chokrakian regional stages was fairly completely characterized by foraminifers. The crucial value for defining this boundary based on foraminifers is determined by the level of appearance of Chokrakian index species, such as *Quinqueloculina akneriana*, *Q. aff. dmitrovae*, *Q. orbignyana*, *Q. laevigata*, *Q. circularis*, *Q. selene*, and *Ammonia beccarii*, which become numerous in the lower part of "spirialis clays."

The Late Tarkhanian period was characterized by impoverished composition of foraminifers due to the beginning of isolation of the Eastern Paratethys and to decreased in the salinity of surface waters. Nodosariids, textulariids, and some other benthic species, which are characteristic of the Early Tarkhanian, disappeared; the number of planktonic species significantly decreased (Bogdanowicz, 1986). However, the salinity still remained high in the immersion zones: in some sections of deep wells of the West Kuban Trough (Pribrezhnaya, Peschanaya, Varavenskaya, and other areas, author's data), the Upper Tarkhanian deposits are characterized by cooccurrence of foraminifers *Globigerina tarchanensis* and *Sigmoilinita haidingerii*.

The similarity of a number of Tarkhanian foraminifer assemblages from the Eastern Paratethys with those from the Miocene Central Paratethys and Mediterranean species suggests that a significant part of Tarkhanian microfauna originates from coeval Western European marine basins. Some migrant species are indistinguishable from Viennese or Galician–

Podolian species (*Sigmoilinita tenuis*, *Florilus boueanus*, etc.) (Bogdanowicz, 1950, 1986); others underwent significant evolutionary changes and gave rise to new neoautochthonous species: *Textularia tarchanensis*, *Sigmoilinita tschokrakensis*, *Nonion bogdanowiczii*, *Bolivina tarchanensis*, etc. Agglutinated benthos is less common and is represented mainly by the genera *Hyperammina*, *Saccammina*, and *Textularia*. Among them, representatives of *Saccammina* were probably genetically related to *Saccammina zuramakensis* from the Kozakhurian basin.

Chokrakian Regional Stage

The Chokrakian sediments of the Eastern Paratethys contain a rich foraminiferal fauna, mostly inherited from the Tarkhanian basin. The foraminifer assemblages of Chokrakian deposits from the Eastern Paratethys are well elucidated in publications of Gerke (1938), Bogdanowicz (1947, 1960b, 1965), Dzhanelidze (1970), Krashennnikov (1959, 2003), Konenkova (1989), Satanovskaya (1994), Ivanova (1999, 2014), and Pinchuk (2006, 2011).

The Chokrakian stratotype is located on the Kerch Peninsula, on the eastern bank of the Lake Chokrakian, and is represented by limestones of shallow water facies (Bogdanowicz and Goncharova, 1976). The foraminifer assemblage contains *Quinqueloculina akneriana*, *Q. akneriana longa*, *Discorbis figuratus*, *D. ukrainicus*, *Florilus communis*, *Ammonia maschanliensis*, *A. simplex*, *Elphidium* aff. *rugosum*, *E. rugosum atschiensis*, *Bolivina tarchanensis*, etc.

The richest foraminiferal assemblages were found by the author in outcrops along Northern Caucasus rivers (Belaya, Pshekha, Bolshoy Zelenchuk, Kuban, and other rivers) and in sections of deep wells of the West Kuban trough. The identified assemblages are characterized by a significant number of miliolids; they include mainly benthic species, while plankton is less common. In total, more than 36 genera and 103 species of foraminifers were recorded in the Chokrakian (Table 4). The common species for the Chokrakian basin of the Eastern Paratethys are *Triloculina austriaca*, *Tschokrakella caucasica*, *Sigmoilinita tschokrakensis*, *Quinqueloculina consobrina*, *Q. akneriana*, *Milliolinella selene*, *Articulina tschokrakensis*, *Florilus parvus*, *Elphidium* ex gr. *macellum*, *Bolivina tarchanensis*, *Entosolenia mironovi*, *Pseudopolymorphina uniserialis*, and other.

The analysis of vertical distribution of foraminiferal fauna allowed Bogdanowicz (1950, 1971) to subdivide the Chokrakian into three parts. This subdivision is currently not generally accepted; the lower and middle Bogdanowicz substages based on the bipartite division of the Chokrakian correspond to the lower Chokrakian based on mollusks according to I. A. Goncharova (1989). In deposits of the Lower Chokrakian of Ciscaucasia, the dominant species were different miliol-

Table 3. Distribution of foraminifers in the Malyi Kamyshlak section according to Bogdanowicz (unpublished materials to the article: (Bogdanowicz and Goncharova, 1976)

Stage	Foraminiferal beds	Beds according to Andrusov	Lithology	Exposed beds	Sample number to Goncharova, 1989
Tarkhanian	Tarkhanian	Beds with <i>Globigerina tarchanensis</i>	Argun Beds	3	64
				3	65
				3	66
				3	67
				3	68
				4	69
				4	70
				4	71
				5	72
				5	73
Lower Chokrakian	Beds with <i>Bolivina tarchanensis</i>	Spiralis Beds	Lithology	5	74
				6	75
				6	76
				7	77
				7	78
				7	79
				8	80
				8	81
				9	82
				9	83
Middle Chokrakian	Beds with <i>Tschokrakella caucastica</i>	"Chokrak" beds	Lithology	10	84
				10	85
				10	86
				10	87
				12	88
				15	89
				17	90
				17	91
				18	92
				19	93
Middle Chokrakian	Beds with <i>Tschokrakella caucastica</i>	"Chokrak" beds	Lithology	20	94
				21	95
				21	96
				23	97
				23	98
				23	99
				23	100
				23	101
				23	102
				23	103
Middle Chokrakian	Beds with <i>Tschokrakella caucastica</i>	"Chokrak" beds	Lithology	24	104
				24	105
				24	106
				24	107
				24	108
				24	109
				24	110
				24	111
				24	112
				24	113
Middle Chokrakian	Beds with <i>Tschokrakella caucastica</i>	"Chokrak" beds	Lithology	25	114
				25	115
				25	116
				25	117
				25	118
				25	119
				25	120
				25	121
				25	122
				25	123

Table 4. Distribution of foraminifers in the sediments of the Chokrakian Regional Stage in different areas of the Eastern Paratethys (according to Bogdanowicz, 1965; Dzhanelidze, 1970; Krashennnikov et al., 2003; Nosovskii and Ivanova, 2005; Minashvili and Ananiashvili, 2013, supplemented by the author)

No.	Foraminiferal species	Northern Ciscaucasia			Crimea	Georgia		Apsheron Peninsula
		Western	Central	Eastern		Western	Eastern	
1	2	3	4	5	6	7	8	9
1	<i>Hyperammina</i> sp.	x						
2	<i>H. aff. algaeformis</i> Brady	x	x		x			
3	<i>Hippocrepinella hirudiformis</i> Suzin		x	x				
4	<i>Saccammina vulgaris</i> Bogd., 1947	x						
5	<i>Haplophragmoides</i> sp.	x	x					
6	<i>Textularia</i> sp.	x						
8	<i>Q. akneriana akneriana</i> Orb., 1846	x	x	x	x	x	x	x
9	<i>Q. akneriana argunica</i> Gerke, 1938	x	x	x	x	x	x	
10	<i>Q. akneriana rotunda</i> Gerke, 1938	x	x	x	x	x	x	x
11	<i>Q. akneriana elongata</i> Gerke, 1938	x	x	x	x	x	x	
12	<i>Q. longiuscula</i> (Bogd., 1947)	x	x	x				x
13	<i>Q. laevigata</i> Orb.	x				x		
14	<i>Q. circularis</i> Orb., 1846	x						
15	<i>Quinqueloculina aff. pauperata</i> Orb.				x			
16	<i>Q. lachesisi</i> (Kar.) var. <i>gracilissima</i> Bogd.			x	x	x	x	
17	<i>Q. pyrilla</i> (Karrer)			x		x	x	
18	<i>Q. brevis</i> Bogd., 1947	x						
19	<i>Q. ungeriana</i> Orb., 1846	x		x	x			
20	<i>Q. akneriana longa</i> Gerke, 1938	x	x	x	x	x	x	
21	<i>Q. consobrina consobrina</i> Orb., 1846	x						
22	<i>Q. badenensis</i> Orb., 1846	x	x					
23	<i>Q. orbignyana</i> Bogd., 1950	x			x			
24	<i>Q. confortata</i> Orb., 1846	x						
25	<i>Q. ex gr. circularis</i> Born.	x			x			
26	<i>Q. dmitrievae</i> (Bogd., 1950)	x		x				
27	<i>Q. serovae</i> Bogd., 1952	x		x		x	x	
28	<i>Milliolinella selene</i> (Karrer, 1938)	x	x	x	x	x		
29	<i>Tschokrakella parensis</i> Bogd., 1965	x						
30	<i>Tschokrakella caucasica</i> (Bogd., 1950)	x	x	x	x	x		x
31	<i>T. longiuscula</i> (Bogd.)	x						
32	<i>T. litoralis</i> (Bogd., 1950)	x						
33	<i>Triloculina austriaca</i> Orb.	x	x	x	x			
34	<i>T. austriaca</i> Orb. var. <i>eggeri</i> Bogd.	x						
35	<i>T. subfoliacea</i> Bogd.	x		x		x	x	
36	<i>T. gibba</i> Orb.	x						
37	<i>Siphonaperta mediterraneensis</i> (Bogd.)	x	x	x	x	x	x	
38	<i>Sigmoilinita tenuis</i> Orb.	xx						
39	<i>S. haidingerii</i> Orb.	x		x	x	x	x	
40	<i>S. haidingerii haidingerii</i> Bogd.	x			x	x		
41	<i>S. haidingerii aculeata</i> Bogd.	x		x		x	x	
42	<i>S. tschokrakensis</i> Gerke, 1938	x	x	x	x	x	x	x

Table 4. (Contd.)

No.	Foraminiferal species	Northern Ciscaucasia			Crimea	Georgia		Apsheron Peninsula
		Western	Central	Eastern		Western	Eastern	
1	2	3	4	5	6	7	8	9
43	<i>S. tschokrakensis plana</i> O. Djan.					x	x	
44	<i>S. tschokrakensis media</i> Bogd.	x						
45	<i>Spiroloculina irma</i> Bogd., 1950	x	x	x		x	x	
46	<i>Flintina georgii</i> Bogd., 1950	x						
47	<i>Adelosina</i> sp.	x						
48	<i>A. aff. schreibersi</i>	x	x	x		x	x	
49	<i>Articulina tschokrakensis</i> Bogd., 1950	x		x				x
50	<i>Articulina agglutinans</i> Bogd., 1950	x						
51	<i>Articulina</i> sp.	x	x	x	x	x	x	x
52	<i>Nodobaculariella aff. sulcata</i> (Reuss)	x						
53	<i>Nodosaria</i> sp.	x						
54	<i>Lagena</i> sp.	x	x	x	x	x	x	x
55	<i>Guttulina aff. communis</i> Orb.	x						
56	<i>G. gibba</i> Orb.	x				x		
57	<i>G. austriaca</i> Orb.	x				x		
58	<i>Pseudopolymorphina uniserialis</i> Suzin	x						
59	<i>P. caudata</i> Suzin, 1950	x						
60	<i>P. tschokrakensis</i> O.Djan., 1970					x	x	
61	<i>Globulina</i> sp.	x						
62	<i>Fissurina aff. mironovi</i> Bogd.	x						
63	<i>F. marginata</i> (Mor.)	x						
64	<i>Globigerina tarchanensis</i> Subb. et Chut.	x	x	x	x	x		x
65	<i>Globigerina bulloides</i> Orb.	x			x			
66	<i>G. falconensis</i> Blow, 1959	x	x		x			
67	<i>Globigerina</i> sp.	x	x	x	x	x	x	x
68	<i>Globorotalia woodi</i> (Jenkins, 1960)	x	x		x			
69	<i>Dicrorbis tschokrakensis</i> Bogd., 1950	x			x			
70	<i>Discorbis figuratus</i> Konen.				x			
71	<i>D. kudakoensis</i> Bogd., 1965	x						
72	<i>D. klavdia</i> Bogd., 1965	x						
73	<i>D. ukrainicus</i> Satanov.				x			
74	<i>Cibicides ex gr. lobatulus</i> (Walk. et Jac.)	x						
75	<i>Cibicides</i> sp.	x						
76	<i>Florilus parvus</i> (Bogd., 1950)	x	x	x	x	x	x	
77	<i>Florilus bogdanowichi</i> Volochina	x						
78	<i>Florilus granosus parvus</i> (Bogd., 1965)	x	x	x	x	x	x	
79	<i>Florilus boueanus</i> Orb.	x	x	x		x		x
80	<i>Florilus communis</i> Orb.				x			
81	<i>Porosononion martcobi</i> (Bogd.)	x	x	x	x	x	x	x
82	<i>P. granosus</i> (Bogd.)	x	x	x				
83	<i>Ammonia ex gr. beccarii</i> (Linnaeus)	x				x		
84	<i>Ammonia</i> sp.	x	x	x	x	x	x	x

Table 4. (Contd.)

No.	Foraminiferal species	Northern Ciscaucasia			Crimea	Georgia		Apsheron Peninsula
		Western	Central	Eastern		Western	Eastern	
1	2	3	4	5	6	7	8	9
85	<i>Ammonia maschanliensis</i> (Pron.)		x		x			
86	<i>A. simplex</i> (Orb.)				x			
87	<i>Elphidium</i> ex gr. <i>macellum</i> Fish. et Molli	x	x	x	x	x	x	
88	<i>E. rugosum</i> (Orb.)	x	x	x	x			
89	<i>E. rugosum</i> (Orb.) var. <i>atschiensis</i> Suzin		x	x	x	x	x	
90	<i>Caucasinella</i> ex gr. <i>elongata</i> Orb.	x	x		x			
91	<i>Caucasina</i> sp.	x						
92	<i>Entosolenia mironovi</i> Bogd., 1947	x	x	x	x			
93	<i>E. ex. gr. marginata</i> (Walker et Boys)	x						
94	<i>Entosolenia</i> sp.	x	x	x				
95	<i>Caudina caudata</i>	x	x	x	x			
96	<i>Cassidulina</i> sp.	x		x				
97	<i>Bulimina</i> sp.	x						
98	<i>Bolivina tarchanensis</i> Subb.et Chutz., 1950	x	x	x	x	x		x
99	<i>B. ex gr. floridana</i> Cushman	x			x	x	x	x
100	<i>B. dilatata</i> Cushman	x	x	x				
101	<i>Patellina</i> aff. <i>corrigata</i> Will.	x			x			
102	<i>Turrispirillina</i> sp.	x	x	x				
103	<i>Conicospirillina</i> sp.	x						

ids (*Triloculina austriaca*, *Quinqueloculina akneriana*, *Sigmoilinita tschokrakensis*, *Milliolinella selene*, *Ammonia maschanliensis*, and *A. simplex*) and numerous *Bolivina* aff. *tarchanensis*, which made it possible to recognize ***Bolivina tarchanensis* Beds** (Bogdanowicz, 1971; Pinchuk, 2006). These beds in sections of wells of the West Kuban trough are represented only in deep-water facies, while they are often absent along the edges due to erosion and changes in tectonic plan at the beginning of the Chokrakian.

In the Middle Chokrakian, a peculiar diverse microfauna of foraminifers was formed under conditions of isolation of the Eastern Paratethys and decrease in salinity (Table 4); this microfauna is represented both by species that passed from the Tarkhanian (*Siphonaperta mediterraneensis*, *Florilus parvus*, *Bolivina tarchanensis*, etc.) and by new invaders similar to the Western European Middle Miocene fauna unknown from the Tarkhanian (*Quinqueloculina* ex gr. *circularis*, *Triloculina austriaca*, etc.), as well as by species that are inherent only in the Chokrakian (*Tschokrakella caucasica*, *Sigmoilinita tschokrakensis*, *S. tschokrakensis media*, etc.). This assemblage, characteristic of most of the Chokrakian, was recognized as ***Tschokrakella caucasica* Beds** (Bogdanowicz,

1960b, 1975; Bogdanowicz, 1971), dominated by different miliolids. The assemblage generally consists of numerous species: *Quinqueloculina consobrina*, *Q. akneriana akneriana*, *Q. akneriana longa*, *Q. akneriana media*, *Q. akneriana rotunda*, *Q. gracilissima*, *Sigmoilinita tschokrakensis*, *Triloculina eggeri*, *T. subfoleacea*, *Articulina tschokrakensis*, *Protelphidium granosus*, *Florilus boueanus*, *Discorbis* sp., and *Bolivina* sp. *Bolivina* aff. *tarchanensis*, *Ammonia* ex gr. *beccarii*, etc.

In the Late Chokrakian, the species composition of the foraminiferal assemblage gradually decreased with decrease in water salinity; a small-sized fauna appeared in the ***Florilus parvus* Beds** (Bogdanowicz, 1965, 1971; Pinchuk, 2006). The foraminiferal assemblage contains small-sized shells: *Florilus parvus*, *Quinqueloculina akneriana akneriana*, *Q. akneriana elongata*, *Q. gracilissima*, *Q. laevigata*, *Sigmoilinita tschokrakensis*, *Florilus boueanus*, *Triloculina gibba*, *Discorbis* sp., etc. They are often represented by deformed, dwarf, abnormally developed shells. Deposits containing this foraminifer assemblage were recognized from the Kerch Peninsula to Mangyshlak and initially called the “*Nonion parvus*” zone (Bogdanowicz, 1965, 1971).

Karaganian Regional Stage

Foraminifers of the Karaganian Regional Stage and their distribution are reported in the works of Bogdanowicz (1965; 1971), Dzanelidze (1970), Krasheninnikov (1959), Zhgenti and Maisuradze (2016), Pinchuk (2006, 2017), and Vernigorova (2009).

The fauna of benthic foraminifers of the Karaganian is characterized by a sharply depleted composition and small abundance, which resulted from the isolation of the basin from the World Ocean, desalination, and reduction of marine fauna. The organisms that survived included only dwellers that were most resistant to salinity changes. In Western Ciscaucasia, the Karaganian fauna in outcrops and wells is represented by a depleted assemblage of foraminiferal **Discorbis Beds** (Bogdanowicz, 1971) or **D. urupensis Beds** (according to Pinchuk, 2006), which include *Quinqueloculina consobrina*, *Q. pseudoangustissima*, *Sigmoidella caucasica*, *Nonion* sp., *Porosonion martcobi*, *Discorbis* aff. *effusus*, *Discorbis urupensis*, etc. Tests are small in size and do not constantly occur in sections of Western Ciscaucasia. The composition of the Karaganian foraminifer assemblage in Ciscaucasia was depleted to 39 species, of which 92% were euryhaline species.

The common species for different areas of the Eastern Paratethys are *Quinqueloculina* ex gr. *consobrina*, *Q. ersaconica*, *Discorbis urupensis*, *D. kartvelicus*, *Nonionella karaganica*, and *Cassidulina bulbiformis*. The complete assemblage of Karaganian foraminifers includes 39 species of 17 genera (Table 5).

The most common species were *Quinqueloculina* ex gr. *consobrina*, *Elphidium* ex gr. *macellum*, *E. cubanicum*, *Nonion bogdanowiczi*, *Discorbis urupensis*, *D. conicus*, *D. kartvelicus*, *Ammonia pschechensis*, and *Cassidulina bulbiformis*. Small-sized, shallow-water species were dominant. Only nine species (mainly deep-water forms) were recorded in the Karaganian of Kuban well SG-12000 (Savopulo et al., 1991).

Genetically, the Karaganian microfauna originates from the Chokrakian microfauna, and endemism and the absence of Mediterranean species among them indicate the isolation of the Karaganian Sea from fully-saline basins. The paucity of microfauna in Karaganian Beds may also indicate great depths and, possibly, anoxic conditions in the bottom waters. The presence of the sandy genera *Rhabdammina*, *Hyperammina*, and *Saccammina* indicates great depths of the basin areas where they lived.

Species of *Discorbis*, *Nonion*, *Elphidium*, *Quinqueloculina*, etc., lived in the Karaganian basin. In the Crimean–Caucasian area, Krasheninnikov (1959) described an assemblage with small and thin-walled *Quinqueloculina ersaconica*, *Triloculina confirmata*, *Elphidium cubanicum*, *Nonionella karaganica*, *Discorbis urupensis*, *D. effusus*, *Rotalia pshechensis*, *Cassidulina bulbiformis*, etc. The Karaganian assemblage contains numerous small-sized tests of representatives of

Cassidulina and *Discorbis*; among them, *Discorbis urupensis* is most common and represents an index species (Pinchuk, 2006).

In the second half of the Karaganian, there was probably a short-term communication between the Eastern Paratethys and fully saline basins, as evidenced by finds of *Caucasinella elongata* and *Dentritina* sp. (Bogdanowicz, 1965; Dzanelidze, 1970). In the Karaganian section of the Belaya River, the author found beds containing planktonic foraminifers represented by the species *Globigerina bullodes*, *G. aff. tarchanensis*, etc. In Georgia, the Varna Beds also contains small forms of globigerins and rotraliids (Dzanelidze, 1970). The planktonic microfauna did not develop further in the Karaganian basin of the Eastern Paratethys in Ciscaucasia and was soon extinct due to changes in habitat conditions and desalination of the basin.

Konkian Regional Stage

In the Eastern Paratethys, deposits of the Konkian Regional Stage are ubiquitous and subject to significant facies changes and uneven distribution of microfauna. The Konkian assemblage differs from the Karaganian microfauna in the presence of foraminifers of Mediterranean origin, a more diverse composition and significant development of miliolids, buliminids, nonionids, and elphidiids, and the appearance of many species that did not occur in the underlying deposits. The fauna of foraminifers of Konkian deposits and its distribution are described in the works of Bogdanowicz (1947, 1965, 1971), Dzanelidze (1953, 1970), Krasheninnikov (1959, 1960), Krasheninnikov et al. (2003), Zhgenti and Maisuradze (2016), Pinchuk (2006, 2017), Vernigorova (2009, 2015), Vernigorova et al. (2006), and Ivanova and Bondar' (2014).

In this research Konkian deposits are divided into Kartvelian, Sartaganian, and Veselyanka Beds. The position of Kartvelian Beds is often understood ambiguously; they were initially assigned by Andrusov (1917a) to the lower strata of the Konkian; however, many researchers attributed them to the upper part of the Karaganian (Zhizhchenko, 1940; Bogdanowicz, 1971; *Neogenovaya sistema*, 1986). In the Kartvelian "stage," Dzanelidze (1970) identified Karaganian foraminifers, the species of which continue to exist in Varna, Kartvelian, and Konkian s. str. deposits without change. She considered the Kartvelian stage (as well as the Varna Stage) independent and equivalent to the regional stage. The suppression and depletion of the foraminiferal fauna of the Kartvelian Stage, represented by an assemblage of benthic foraminifers with *Discorbis*, *Nonion*, and *Elphidium*, indicates stress conditions in the Kartvelian Basin, along with a rampant flowering of *Barnea* and rare stenohaline species.

On the whole, according to the analysis of publications on Konkian deposits in the Northern Caucasus,

Table 5. Distribution of foraminifers in the sediments of the Karaganian Regional Stage in different areas of the Eastern Paratethys (according to Pobedina et al., 1956; Dzhanelidze, 1970; Krashennnikov et al., 2003; Zhgenti and Maisuradze, 2016, supplemented by the author)

No.	Foraminiferal species	Northern Ciscaucasia	Crimea	Georgia		Apsheon Peninsula
				Western	Eastern	
1	2	3	4	5	6	7
1	<i>Hyperammmina</i> sp.	x				
2	<i>Saccammina</i> sp.	x				
3	<i>S. aff. vulgaris</i> Bogd.	x				
4	<i>Lagena</i> sp.	x	x	x	x	x
5	<i>Quinqueloculina</i> ex gr. <i>consobrina</i> (Orb., 1846)	x		x	x	
6	<i>Q. ersaconica</i> Krash., 1959	x		x	x	
7	<i>Quinqueloculina</i> aff. <i>conforta</i> Orb.	x			x	x
8	<i>Q. gracilis</i> Karrer, 1867	x				
9	<i>Q. reussi sartaganica</i> Krash., 1959	x		x	x	
10	<i>Q. sp.</i>	x	x	x	x	x
11	<i>Miliolinella reussi</i> (Karrer, 1868)	x		x	x	
12	<i>Triloculina confirmata</i> Krach., 1959	x				
13	<i>Dendritina</i> sp.			x	x	
14	<i>Discorbis urupensis</i> Krasch., 1959	x		x		
15	<i>D. effusus</i> Krash., 1959	x		x	x	
16	<i>D. conicus</i> Bogd., 1959	x		x	x	
	<i>D. arculus</i> Chutz.	x				x
17	<i>D. kartvelicus</i> Krash., 1959	x		x	x	
18	<i>Discorbis</i> sp.	x	x	x	x	x
19	<i>Lamarckina</i> sp.			x	x	
20	<i>Cibicides</i> sp.			x		
21	<i>Nonion</i> sp.	x	x	x	x	x
22	<i>N. aff. punctatus</i> (Orb., 1846)			x	x	
23	<i>Nonion</i> aff. <i>biporus</i> Krash., 1959	x				
24	<i>Nonion</i> aff. <i>tauricus</i> Krasch., 1959	x				
25	<i>N. miocenicus</i> Pobedina et Vorosh., 1956					x
26	<i>Nonionella karaganica</i> Krash., 1959	x				
27	<i>Globigerina</i> sp.	x	x	x	x	
28	<i>Ammonia</i> ex gr. <i>beccarii</i> (Linne)	x		x	x	x
29	<i>Rotalia pschechensis</i> Krash., 1959	x	x	x	x	
30	<i>Elphidium</i> ex gr. <i>macellum</i> (Fich. et Molli)	x	x	x	x	x
31	<i>E. cubanicum</i> Krasch., 1959	x	x	x	x	
32	<i>Florilus bogdanowichi</i> Voloch., 1950	x				
33	<i>Porosonion martcobi</i> (Bogd., 1947)	x	x	x	x	x
34	<i>Melonis</i> aff. <i>pompilioides</i> (Fisch. et Moll, 1798)	x				
35	<i>Cassidulina bulbiformis</i> Krash., 1959	x	x	x	x	
36	<i>Cassidulina micra</i> Djan.1970			x	x	
37	<i>Caucasina</i> cf.	x	x	x	x	
38	<i>Bolivina</i> sp.	x	x	x	x	x
39	<i>Bolivina</i> aff. <i>scaprata</i> Cushman, 1936	x				
40	<i>Spirillina</i> sp.	x				

Crimea, and Georgia, the foraminiferal assemblage has a rich composition (up to 44 genera and 197 species) (Table 6).

The Kartvelian Beds with rich fauna of planktonic and benthic foraminifers were found in the Belaya River section at the top of the Karaganian deposits. They contain *Quinqueloculina laevigata*, *Q. consobrina*, *Q. aff. microdon*, *Q. ersaconica*, *Cibicides aff. badenensis*, *C. aff. konkoensis*, *Rotalia conquisita*, *Ammonia beccarii*, *Rotalia maschanliensis*, *Porosononion martcobi*, *Melonis soldanii*, *Nonion biporus*, *N. tauricus*, *Nonionella karaganica*, *Caucasinella elongata*, *Elphidium incertum*, *E. aff. kudakoense*, *E. horridum*, *E. angulatum*, *Discorbis supenus*, *D. kartvelicus*, *D. aff. gigai*, *D. leo*, *D. aff. imperatoris*, *Globoturborotalia woodi*, *Paragloborotalia mayer*, *Globigerina bulloides*, *G. praebulloides*, *G. sp.*, *Guembelina aff. globulosa*, etc. (Pinchuk, 2017).

In the sections of Taman and Ciscaucasia, the Sartaganian Beds are characterized by an assemblage of foraminifers that lived in fully saline basins: *Globigerina bulloides* and *Globorotalia sp.*; according to Krasheninnikov, Bogdanowicz, and Dzhanlidze, the most characteristic species for Sartagan Beds among benthic species are *Cycloforina gracilis*, *Varidentella reussi sartaganica*, *Articulina cubanica*, *Bolivina dilatata*, etc. (Vernigorova et al., 2006). Sartagan Beds are characterized by the appearance of a large number of new migrant species (*Quinqueloculina badensis*, *Caucasinella aff. elongata*, etc.); at the same time, this was accompanied by the appearance of species that significantly deviated in their development from ancestral forms to the level of endemic subspecies (*Articulina tenella konkensis*, *Melonis soldanii jarsensis*, etc.). A significant role is played by the appearance of new Konkian neautochthonous species: *Nodobaculariella konkensis*, *Nonionella ventragranosa*, *Spirolina ustjurenensis*, and many others. The Sartaganian foraminiferal assemblage of Ciscaucasia is characterized by a significant number of miliolids, buliminids, nonionids, and elphidiids; an important feature is the presence of the genera *Nubecularia*, *Wiesnerella*, and *Haurina*, which are almost unknown in the underlying deposits. Species widely represented in Karaganian deposits are rare. The most characteristic species included *Cornuspira plicata*, *Quinqueloculina badensis*, *Adelosina konkensis*, *Cycloforina gracilis*, *Sinuloculina microdon*, *Nodobaculariella aff. sulcata*, etc. Bogdanowicz (1971) identified this assemblage as *Adelosina konkensis* Beds. The common species for the Sartaganian beds in different areas of the Eastern Paratethys are *Quinqueloculina badensis*, *Quinqueloculina schweyeri*, *Nodobaculariella konkensis*, *Articulina tenella konkensis*, *Porosononion martcobi*, *Elphidium ex gr. macellum*, *E. kudakoense*, *E. antonina*, *Caucasinella ex gr. elongata*, etc. (Bogdanowicz, 1986).

The species diversity significantly decreases upward the section of Konkian deposits on the Taman

Peninsula. Single representatives of the genera *Quinqueloculina*, *Bolivina*, and *Nonion* are small, suppressed, and often indetermined to the species level. The light marking layer of Taman nannoplankton marl contained only single specimens of *Quinqueloculina*, *Fissurina*, *Cassidulina*, *Nonion*, *Florilus*, *Discorbis*, and *Ammonia*. The dominant species are representatives of the genus *Elphidium*, including *E. horridum*, which is characteristic of Veselyanka beds in Georgia (Dzhanlidze, 1970; Vernigorova, 2009).

The Veselyanka Beds of Ciscaucasia are also characterized by some depletion of the composition due to a gradual isolation of the basin and a decrease in salinity. The most polyhaline migrant species disappeared and euryhaline representatives of the genera *Nonion*, *Elphidium*, and *Quinqueloculina* were widespread. In Ciscaucasia, this assemblage was recognized as ***Elphidium horridum* Beds** (Bogdanowicz, 1971). The common species for the Veselyanka Beds from different areas of the Eastern Paratethys are *Articulina tenella konkensis*, *Quinqueloculina ex gr. consobrina*, *Porosononion martcobi*, *Elphidium ex gr. macellum*, *E. horridum*, *E. joukovi*, *Florilus bogdanowicchi*, *Bulminella elegantissima*, etc. (Bogdanowicz, 1986).

The thickness of the Konkian deposits from well cores in Western Ciscaucasia is low (20–30 m) and they cannot always be subdivided; therefore, they are most often combined into ***Adelosina konkensis–Elphidium horridum* Beds** (Pinchuk, 2006).

The lower boundary of Konkian deposits is defined by the appearance of a rich polyhaline foraminiferal fauna. The upper boundary is defined by the disappearance of Mediterranean species and a significant development of euryhaline foraminifers.

Sarmatian Regional Stage

Foraminifers are widespread in the Sarmatian deposits of the Eastern Paratethys and the results of their study are outlined in the works of Bogdanowicz and Fedorov (1932), Bogdanowicz (1947, 1952, 1960b, 1965), Bogdanowicz and Voloshinova (1949), Pobedina et al. (1956), Krasheninnikov (1958a, 1959, 1960), Krasheninnikov et al. (2003), Pronina (1959), Didkovskii (1966), Didkovskii and Satanovskaya (1970), Dzhanlidze (1953), Maisuradze (1971, 1980), Maisuradze et al. (2004), Koiava (2006), Pinchuk (2006, 2011), etc.

Lower Sarmatian. At the beginning of the Sarmatian, the Eastern Paratethys formed a single basin with the Central Paratethys; the communication with the open seas was interrupted (Bogdanowicz, 1986) or became limited. The Early Sarmatian foraminiferal fauna is poor (about 16 genera, more than 40 species) and is dominated by miliolids, nonionids, and elphidiids. Some of the species belong to Konkian relicts: *Porosononion martcobi*, *Articulina problema*, etc. A significant part of the Early Sarmatian microfauna was

Table 6. Distribution of foraminifers in the sediments of the Konkian Regional Stage in different areas of the Eastern Paratethys (according to Pobedina et al., 1956; Dzhanelidze, 1970; Krashenninnikov et al., 2003; Zhgenti and Maisuradze, 2016, supplemented by the author)

No.	Foraminiferal species	Northern Ciscaucasia	Northern Black Sea Region	Crimea	Georgia		Apshe- ron Peninsula
					Western	Eastern	
1	2	3	4	5	6	7	8
1	<i>Ammodiscus</i> sp.	x					
2	<i>Textularia</i> sp.				x		
3	<i>Tritaxia</i> sp.				x		
4	<i>Cornuspira involvens</i> (Reuss, 1839)	x					
5	<i>C. plicata</i> (Czjzek, 1848)	x					
6	<i>Colominella</i> aff. <i>paalzowi</i> (Cushman, 1936)				x		
7	<i>Pseudogaudryina karreriana</i> (Cushman, 1926)				x		
8	<i>Dorothia</i> sp.				x		
9	<i>Glomospira gordialis</i> (Jones & Parker, 1860)				x		
10	<i>Haplophragmoides</i> sp.	x					
11	<i>Nubecularia novorossica</i> m. <i>crustaformis</i> Bogd.	x		x			
14	<i>Quinqueloculina schweyeri</i> Bogd., 1952	x					
15	<i>Quinqueloculina minakovae minakovae</i> Bogd.	x	x	x	x	x	
16	<i>Q. minakovae ukrainica</i> Didk., 1961		x				
17	<i>Q. andrussovi</i> (Bogd.)	x			x	x	
18	<i>Q. badenensis</i> Orb., 1846	x		x	x	x	
19	<i>Q. badenensis badenensis</i> Orb., 1846		x				
20	<i>Q. ex gr. consobrina</i> Orb., 1846	x			x	x	
21	<i>Quinqueloculina</i> aff. <i>dilatata</i> d'Orb., 1846	x		x			
22	<i>Q. inornata</i> (Orb., 1846)	x		x	x	x	
23	<i>Quinqueloculina</i> sp.	x		x	x	x	x
24	<i>Q. aff. akneriana</i> Orb., 1864				x	x	
25	<i>Q. angustissima</i> Krash.,				x		
26	<i>Q. aff. angustioris</i> Bogd., 1952	x			x		
27	<i>Q. consobrina sarmatica</i> Gerke, 1952	x		x			
28	<i>Q. intermedia</i> (Karrer, 1867)	x					
29	<i>Q. collaris</i> G. et Iss., 1952	x					
30	<i>Q. irregularis</i> Serova, 1955		x	x			
31	<i>Q. reussi reussi</i> Bogd., 1947						
32	<i>Q. laticostata</i> Didk., 1961		x				
33	<i>Q. longescula</i> Didk., 1961		x				
34	<i>Adelosina konkensis</i> Bogd.	x					
35	<i>Sinuloculina microdon</i> (Reuss, 1950)	x	x	x	x	x	
36	<i>S. pseudoangustissima</i> (Krasch.)	x			x	x	
37	<i>S. inflata</i> (Orb., 1846)				x	x	
38	<i>S. consobrina consobrina</i> (Orb., 1846)				x	x	
39	<i>S. consobrina nitens</i> Reuss	x					
40	<i>Cycloforina gracilis</i> (Karrer, 1867)	x	x	x	x	x	
41	<i>Affinetrina guriana</i> (O.Djan.)				x	x	
42	<i>Triloculina gibba</i> Orb., 1846	x			x	x	

Table 6. (Contd.)

No.	Foraminiferal species	Northern Ciscaucasia	Northern Black Sea Region	Crimea	Georgia		Apshe- ron Peninsula
					Western	Eastern	
1	2	3	4	5	6	7	8
43	<i>Triloculina intermedia</i> (Karrer, 1867)				x		
44	<i>Triloculina inornata</i> d'Orb, 1846	x					
45	<i>Varidentella reussi sartaganica</i> Krasch., 1959				x	x	
46	<i>Varidentella reussi</i> (Bogd., 1947)	x			x		
47	<i>Sigmoilinita tenuissima</i> (Reuss, 1867)			x	x	x	
48	<i>Spiroloculina konkensis</i> Bogd., 1948	x	x	x			
49	<i>Spiroloculina</i> aff. <i>kolesnikovi</i> Bogd., 1952	x				x	
50	<i>Spiroloculina</i> sp.	x					x
51	<i>Siphinoperta</i> aff. <i>mediterraneensis</i> (Bogd., 1950)	x		x			
52	<i>Pyrgo controversa</i> Bogd., 1952	x					
53	<i>Pyrgo inornata</i> (d'Orbigny, 1946)				x		
54	<i>Articulina tenella konkensis</i> Bogd., 1952	x		x	x		x
55	<i>Articulina</i> aff. <i>problema</i> Bogd., 1952	x					
56	<i>A. cubanica</i> Bogd., 1952	x		x			
57	<i>A. vermicularis</i> Bogd., 1952	x		x			
58	<i>A. nitida gibbosula</i> Orb., 1846			x	x		x
59	<i>A. tarchancutica</i> Krasch., 1959			x			
60	<i>A. tenella</i> (Eichw., 1850)						x
61	<i>A. articuloides</i> Gerke et Iss., 1952	x					
62	<i>A. sarmatica</i> (Karrer, 1877)	x					
63	<i>A. tamanica</i> Bogd., 1952	x					
64	<i>Flintina corporata</i> Bogd., 1950	x					
65	<i>Haurina composita</i> Serova, 1955			x	x		
66	<i>H. compressa</i> Orb. 1846			x	x		
67	<i>H. guriana</i> O. Djan., 1953				x		
68	<i>H. lamarcae</i> O. Djan., 1953				x		
69	<i>H. plana</i> Serova, 1955			x			
70	<i>H. podolica</i> Serova, 1955	x			x		
71	<i>H. thamarcae</i> O. Djan., 1953			x	x		
72	<i>H. tumida</i> Serova, 1955				x		
73	<i>Nodobacularella</i> aff. <i>sulcata</i> (Reuss, 1850)	x		x	x	x	
74	<i>N. konkensis</i> Bogd., 1952	x		x			
75	<i>N. gracilis</i> Bogd., 1952	x		x			
76	<i>N. didkowskii</i> Bogd., 1952	x		x	x	x	
77	<i>Nodobacularella</i> sp.	x		x	x		
78	<i>Wiesnerella plana</i> Bogd., 1952	x					
79	<i>Wiesnerella</i> sp.	x		x	x		
80	<i>Dendritina elegans</i> Orb., 1846			x	x		
81	<i>Spirolina austriaca</i> (Orb., 1846)	x		x	x	x	
82	<i>S. juleana</i> (Orb., 1846)					x	
83	<i>S. konkia</i> Didk., 1959				x		

Table 6. (Contd.)

No.	Foraminiferal species	Northern Ciscaucasia	Northern Black Sea Region	Crimea	Georgia		Apsheron Peninsula
					Western	Eastern	
1	2	3	4	5	6	7	8
84	<i>S. ustjurtensis</i> Bogdanowicz, 1952	x			x		
85	<i>Peneroplis laevigatus</i> Karrer, 1877				x		
86	<i>Peneroplis supsensis</i> O. Djan., 1953				x		
87	<i>Borelis melo</i> (F. et M., 1803)	x		x	x	x	
88	<i>B. haueri</i> (Orb., 1846)	x		x			
89	<i>B. pilus</i> Serova, 1955					x	
90	<i>Nodosaria</i> sp.	x					
91	<i>Polymorphina</i> sp.	x					
92	<i>Pyrila</i> sp.	x					
93	<i>Lagena pulverulenta</i> Bogd., 1965	x		x	x	x	
94	<i>Lagena</i> sp.	x	x	x	x	x	x
95	<i>Dentalina spinosa</i> Orb., 1846	x					
96	<i>Lenticulina</i> cf. <i>affinis</i> (Orb., 1846)	x					
97	<i>L. sartaganica</i> Krash., 1949	x		x	x	x	
98	<i>L. inornata</i> (Orb., 1846)	x					
99	<i>L. simplex</i> (Orb., 1846)	x					
100	<i>Guttulina</i> sp.	x					
101	<i>Entosolenia imeretica</i> O. Djan, 1953	x			x	x	x
102	<i>E. ex gr. marginata</i> (Walker et Boys, 1784)	x					
103	<i>Entosolenia</i> sp.	x	x	x	x	x	x
104	<i>Globulina gibba</i> Orb., 1846	x		x	x		
105	<i>Sigmoidella caucasica</i> Krasch., 1958	x					
106	<i>Dicrorbis squamulus</i> (Reuss, 1874)	x					
106	<i>Discorbis effusus</i> Krasch., 1958					x	
107	<i>D. supinus</i> Krasch., 1958	x					
108	<i>D. kartvelicus</i> Krasch., 1958	x		x	x	x	
109	<i>D. aff. patellinoides</i> Krasch., 1958	x					
110	<i>D. risillus</i> Bogd., 1958	x					
111	<i>D. ukrainicus</i> Satanov.	x					
112	<i>Conorbina miocenica</i> Krash., 1958			x	x		
113	<i>Eponides probatus</i> Krasch., 1958			x			
114	<i>E. repandus</i> (F. et M., 1798)	x					
115	<i>Glabratella</i> aff. <i>imperatoria</i> (d'Orb., 1846)	x					
116	<i>Cibicides konkensis</i> Krasch., 1959			x		x	
117	<i>Cibicides ex gr. lobatulus</i> (Walker, Jacob, 1798)	x					
118	<i>Cibicides</i> sp.	x					
119	<i>C. aff. amphisylenensis</i> (Andrea, 1884)	x					
120	<i>Cibicidoides ornatus</i> (Cicha et Zapletova)	x			x		
121	<i>Hanzawaia boueana</i> (Orb., 1846)				x		
122	<i>Osangularia</i> sp.				x	x	
123	<i>Florilus boueanus</i> Orb., 1846	x		x		x	

Table 6. (Contd.)

No.	Foraminiferal species	Northern Ciscaucasia	Northern Black Sea Region	Crimea	Georgia		Apshe- ron Peninsula
					Western	Eastern	
1	2	3	4	5	6	7	8
124	<i>Florilus bogdanowichi</i> Volochina, 1950	x		x		x	
125	<i>Nonion biporus</i> Krasch., 1958	x			x		
126	<i>Florilus communis</i> (d'Orb., 1846)	x					
127	<i>Nonion granosus</i> (Orb., 1846)	x			x	x	
128	<i>N. delicatula</i> O.Djan., 1958				x		
129	<i>N. guriensis</i> O.Djan., 1958				x		
130	<i>N. polymorphus</i> Bogd., 1949				x		
131	<i>N. tauricus</i> Krasch., 1959					x	
132	<i>N. aff. tumidulus</i> Pishv., 1960	x			x	x	
133	<i>Nonionella ventragranosa</i> Krasch., 1959	x					
134	<i>Nonionella karaganica</i> Krasch., 1959				x		
135	<i>Porosonion martcobi</i> (Bogd., 1947)	x			x	x	x
136	<i>P. subgranosus</i> (Egger, 1857)	x		x	x	x	
137	<i>P. guriensis</i> O. Djanelidze, 1958				x	x	
138	<i>P. subgranosum subgranosum</i> (Egger, 1857)				x	x	
139	<i>Melonis soldanii</i> (Orb., 1846)	x		x	x		
140	<i>M. pseudosoldanii</i> (Krasch., 1959)	x			x	x	
141	<i>Melonis pompilioides</i> (d'Orbigny, 1846)				x		
142	<i>Globigerina bulloides</i> Orb., 1826	x		x			
143	<i>G. dubia</i> Egger, 1857		x	x			
144	<i>G. cf. conga</i> Pischv., 1958			x			
145	<i>G. cf. falconensis</i> Blow, 1959	x		x			
146	<i>G. tarchanensis</i> Subb. et Chutz., 1950	x		x			
147	<i>Globorotalia woodi</i> (Jenkins, 1960)	x				x	
148	<i>Paragloborotalia mayery</i> (Cus. et Ell., 1939)	x		x			
149	<i>Tenuitella clemenciae</i> (Bermudez)					x	
150	<i>Ammonia</i> ex gr. <i>beccarii</i> (Linne, 1758)	x		x		x	
151	<i>Ammonia viennensis</i> (Orb., 1846)	x		x		x	
152	<i>Ammonia conquisita</i> Krasch., 1959	x		x			
153	<i>Ammonia</i> sp.	x		x		x	x
154	<i>Rotalia maschanliensis</i> Pron.,	x		x	x	x	
155	<i>R. conquisita</i> Krasch., 1959	x					
156	<i>Elphidium</i> ex gr. <i>macellum</i> Fish. et Molli, 1803	x		x	x	x	x
157	<i>E. kudakoense</i> Bogd., 1947	x			x	x	x
158	<i>Elphidium aculeatum</i> (Orb., 1846)	x		x	x	x	
159	<i>E. angulatum</i> (Egger, 1857)	x			x	x	
160	<i>E. joukovi</i> Serova, 1955	x		x	x	x	
161	<i>E. incertum</i> (Will., 1858)	x					
162	<i>E. antonina</i> (Orb., 1846)	x		x	x	x	
163	<i>E. farsiensis</i> Krash., 1960	x					
164	<i>E. fichtellianum</i> (Orb., 1846)					x	

Table 6. (Contd.)

No.	Foraminiferal species	Northern Ciscaucasia	Northern Black Sea Region	Crimea	Georgia		Apsheron Peninsula
					Western	Eastern	
1	2	3	4	5	6	7	8
165	<i>E. horridum</i> Bogd., 1965	x					
166	<i>E. koberi</i> Nollm.				x	x	
167	<i>E. multicamerum</i> Krasch., 1960	x					
168	<i>E. aff. podolicum</i> Serova, 1955	x					
169	<i>E. aff. listeri</i> Orb., 1846			x			
170	<i>E. aff. striato-punctatum</i> (F. et M., 1803)	x					
171	<i>Elphidiella artifex</i> (Serova, 1955)					x	
172	<i>Canalifera eichwaldi</i> (Bogd., 1947)	x		x	x		
173	<i>Caudina caudata</i> (Suzin, 1950)	x		x			
174	<i>Caucasinella</i> ex gr. <i>elongata</i> (Orb., 1826)	x		x	x	x	x
174	<i>Caucasina</i> sp.	x				x	x
176	<i>Fursenkoina</i> aff. <i>schreibersiana</i> Cz.	x			x		
177	<i>Bulimina</i> sp.	x	x	x	x	x	x
178	<i>B. aff. pupoides</i> Orb., 1846	x					
179	<i>B. elongata subulata</i> Cusch. et Park.			x	x	x	
180	<i>B. insignis</i> Lugzkowska, 1953	x			x		
181	<i>Bulimina rostrata</i> Brady	x					
182	<i>B. aculeata</i> Orb., 1846						x
183	<i>B. konkensis</i> Pobedina, 1956					x	x
184	<i>Buliminella elegantissima</i> (Will., 1839)	x			x		
185	<i>Entosolenia mironovi</i> Bogd., 1947	x		x			
185	<i>Entosolenia</i> ex gr. <i>marginata</i> (Walk., Boys)	x					
186	<i>Entosolenia</i> sp.	x					
187	<i>Oolina imeretica</i> (O.Djanelidze, 1953)				x		
188	<i>Reussella spinulosa</i> (Reuss, 1850)	x			x		
189	<i>Uvigerinella</i> sp.	x			x		
190	<i>Uvigerina gracilissima</i> Pobed., 1956	x			x	x	
191	<i>Angulogerina</i> aff. <i>angulosa</i> (Will., 1858)	x			x	x	x
192	<i>Cassidulina</i> sp.	x					
193	<i>Cassidulina bogdanowiczi</i> Konenkova			x			
194	<i>C. bulbiformis</i> Krasch., 1959	x			x	x	
195	<i>C. farsensis</i> Bogd., 1965	x					
196	<i>C. bulloides</i> Pobedina, 1956				x		
197	<i>Bolivina antiqua</i> Orb., 1846	x					
198	<i>B. dilatata</i> Reuss, 1850	x			x	x	x
199	<i>Bolivina dilitata dilitata</i> Reuss, 1850				x		x
200	<i>B. ex gr. floridana</i> Cushman, 1918	x					
201	<i>B. elegans</i> Orbigny, 1946				x		
202	<i>B. aff. tarchanensis</i> Subb. et Chutz., 1950	x					
203	<i>Pseudohastigerina</i> sp.	x			x		

formed by invaders from the Central Paratethys: *Articulina sarmatica*, *Miliolinella sarmatica*, *Parallina regina*, *Porosonion subgranosus*, etc. The complete assemblage of foraminifers confined to the Volhynian Substage is presented in Table 7.

The Lower Sarmatian assemblage is characterized by a wide development of three families miliolids, nonionids, and elphidiids; the most common species are members of *Quinqueloculina*, *Articulina*, *Porosonion*, and *Elphidium*; other genera are represented by a small number of species.

According to foraminifers, the Lower Sarmatian of Western Ciscaucasia was assigned to the **Varidentella reussi Beds** (Bogdanowicz, 1971; Pinchuk, 2006), which are divided into two facial assemblages. *Elphidium macellum*, *E. obtusum*, *Elphidiella artifex*, *Nonion tumidulus*, *Sinuloculina nitens*, *Porosonion subgranosum*, *P. martkobi*, and *Varidentella reussi* prevail in the coastal and shallow-water areas of the basin, while miliolids (*Varidentella reussi*, *V. sartaganica*, *Affinetrina guria*, *Sinuloculina consobrina*, and *Quinqueloculina collaris*) are dominant in deposits of the deeper sea on soft grounds; *Nonion bogdanowiczi*, *Elphidium macellum*, *Porosonion martkobi*, *P. subgranosum*, etc., are characterized by a comparatively lower abundance.

Two assemblages are identified in Georgia: **Varidentella reussi Beds** and **Elphidium aculeatum Beds** (Maisuradze et al., 2004). Here, the upper part of the Lower Sarmatian is also characterized by different assemblages, depending on the depth of sedimentation basin. The coastal sediments are generally dominated by *Nonion*, *Elphidium*, and *Porosonion* species, while deep sea sediments are dominated by miliolids: *Varidentella reussi*, *Articulina problema*, and *Sinuloculina consobrina*. Along with miliolids, thin-walled nonionid specimens are also often recorded namely, *Nonion bogdanowiczi* and *Porosonion subgranosum*.

The common species for different areas of the Eastern Paratethys in the Lower Sarmatian assemblage are *Varidentella reussi*, *Articulina sarmatica*, *A. tamanica*, *Porosonion subgranosus*, *Porosonion martkobi*, *Elphidium* ex gr. *macellum*, *Quinqueloculina* ex gr. *consobrina*, *Florilus bogdanowicchi*, etc.; in total, the assemblage contains more than 40 species from 16 genera (Table 7). The abundance of foraminifers and their species diversity suggest that the main structure of the microfauna assemblages was already formed in the Early Sarmatian and continued to develop in the Middle Sarmatian.

The lower boundary of the Volhynian Substage is defined by the disappearance of polyhaline Konkian foraminifers and appearance of *Varidentella reussi*; the upper boundary is marked by the appearance of numerous miliolids. The index foraminifers for the Lower Sarmatian are *Varidentella reussi*, *Quinqueloculina collaris*, and *Articulina tamanica*.

Middle Sarmatian. Foraminiferal associations consist mainly of the same families as those in the Lower Sarmatian; however, many of the Early Sarmatian miliolid species gave rise to new forms and the assemblages are characterized by the appearance of endemic genera, such as *Dogielina*, *Sarmatiella*, and *Meandroloculina*; the assemblage also contains nubecularians unknown from underlying deposits.

The common species for different areas of the Eastern Paratethys in the interval of the Bessarabian substage are *Nubecularia novorossica*, *Cycloforina complanata*, *Affinetrina voloshinovae*, *Sarmatiella costata*, *Porosonion subgranosum subgranosum*, *Porosonion martkobi*, *Florilus bogdanowiczi*, *Elphidium* ex gr. *macellum*, *Dogielina sarmatica*, etc. (more than 120 species of 30 genera, Table 8).

The assemblages of Middle Sarmatian foraminifers of the Eastern Paratethys are characterized by the appearance of endemic species and even genera that are inherent only in them, as well as by a large proportion of euryhaline nonionids and elphidiids. The development of such endemism was determined by a high degree of isolation of the Sarmatian Sea from fully saline basins and its continued desalination, as a result of which most of foraminifers were extinct by the end of the Middle Sarmatian. The assemblage includes foraminifers endemic to the Sarmatian: the genus *Sarmatiella* and species *Quinqueloculina consobrina sarmatica*, *Varidentella sarmatica*, *Triloculina ukrainica sarmatica*, *Articulina sarmatica*, *Dogielina sarmatica*, *Peneroplis sarmaticus*, *Bolivina sarmatica*, etc.

In Western Ciscaucasia, the index miliolid groups are meander loculinas, sarmatellas, and the species *Affinetrina voloshinovae*, *Quinqueloculina consobrina*, *Q. cubanica*, *Spiroloculina grosnyensis*, *Flintina tutkowski*, *Articulina apscheronica*, *A. kalinckii*, etc. Each area has its own foraminiferal assemblage diagnosing the Middle Sarmatian deposits. Thus, **Dogielina sarmatica Beds** were recognized in Western Ciscaucasia (Bogdanowicz, 1971; Pinchuk, 2006). In Georgia, the **Affinetrina voloshinovae Beds**, **Porosonion aragviensis Beds**, and **Porosonion hyalinum Beds** were recognized in the Middle Sarmatian interval (Koiava, 2006).

The lower boundary of the Middle Sarmatian is marked by the appearance of a rich miliolid fauna with index species of the genera *Dogielina*, *Meandroloculina*, and *Sarmatiella*, as well as with *Nubecularia*, which are characteristic of these deposits. The upper boundary of the Middle Sarmatian is characterized by rapid extinction of a large part of foraminifers; euryhaline species that lived in basins with low salinity are preserved.

Upper Sarmatian. Marine conditions were preserved only in the immersed part of the Eastern Paratethys, and the Late Sarmatian foraminiferal assemblage lived under conditions of significant freshening of the basin and was depleted. The Late Sarmatian for-

Table 7. Distribution of foraminifers in Lower Sarmatian sediments from different areas of the Eastern Paratethys (according to Pobedina et al., 1956; Krashenninnikov, 1960; Bogdanowicz, 1965, 1986; Maisuradze et al., 2004; Koiava, 2006, supplemented by the author)

No.	Foraminiferal species	Northern Ciscaucasia	Black Sea Region	Crimea	Georgia		Apsheon Peninsula
					Western	Eastern	
1	<i>Saccamina vulgaris</i> Bogd.	x					
2	<i>Quinqueloculina collaris</i> G. et Iss., 1952	x					x
3	<i>Q. ex gr. consobrina</i> Orb., 1846	x		x	x		
4	<i>Q. aff. enoplostoma</i> d'Orb, 1839	x					
5	<i>Q. angustoris</i> (Bogd., 1952)	x	x	x			
6	<i>Q. karreri</i> Reuss, 1869	x		x			
7	<i>Q. irregularis sarmatica</i> Didk., 1961		x				
8	<i>Q. cubanica</i> Bogd., 1947	x					
9	<i>Quinqueloculina</i> sp.	x	x	x	x	x	x
10	<i>Varidentella reussi</i> (Bogd., 1947)	x		x	x	x	x
11	<i>V. reussi azerbaijanica</i> (Podobina, 1956)						x
12	<i>V. sartaganica</i> (Krasch., 1960)				x	x	
13	<i>V. reussi reussi</i> Bogd., 1947	x					x
14	<i>V. sarmatica</i> (Karrer, 1877)						x
15	<i>Affinetrina guria</i> (O. Djan., 1953)	x			x	x	
16	<i>Sinuloculina consobrina</i> (d'Orb., 1846)				x	x	
17	<i>Wiesnerella plana</i> Bogd., 1947	x					
18	<i>Fissurina cubanica</i> (Bogd., 1947)	x					
19	<i>Articulina problema</i> Bogd., 1952	x		x	x	x	
20	<i>A. tamanica</i> Bogd., 1952	x		x	x		
21	<i>A. articulinoidea</i> Gerke et Iss., 1952	x					x
22	<i>A. sarmatica</i> (Karrer, 1877)	x		x	x		x
23	<i>Articulina</i> sp.	x	x	x	x	x	x
24	<i>Sinuloculina nitens</i> (Reuss)				x	x	
25	<i>Discorbis perlucudus</i> Bogd.	x					
26	<i>Discorbis</i> sp.	x					
27	<i>Florilus bogdanowichi</i> Volochina, 1950	x		x	x		
28	<i>Nonion tumidulus</i> Pish., 1960				x		
29	<i>Nonion bogdanowiczi</i> Volosh., 1950			x	x	x	
30	<i>Nonion</i> sp.	x		x	x	x	x
31	<i>Porosonion subgranosus</i> (Egger, 1857)	x		x	x	x	
32	<i>Porosonion martcobi</i> (Bogd., 1947)	x		x	x	x	x
33	<i>Porosonion</i> sp.	x				x	
34	<i>Ammonia ex gr. beccarii</i> (Linne, 1758)	x		x		x	
35	<i>Elphidium ex gr. macellum</i> Fish. et Molli, 1803	x		x	x	x	x
36	<i>E. angulatum</i> (Egger, 1857)	x					
37	<i>Elphidium aculeatum</i> (Orb., 1846)	x					x
38	<i>E. crispum</i> (Linnaeus, 1758)	x					
39	<i>E. obtusum</i> (d'Orb., 1846)				x		
40	<i>E. horridum</i> Bogd., 1965	x					
41	<i>E. echinus</i> Serova, 1955						x
42	<i>Elphidium</i> sp.	x		x	x		x
43	<i>Elphidiella artifex</i> (Serova, 1955)				x	x	
44	<i>Parellina regina</i> (Orbigny, 1846)						x
45	<i>P. regina</i> (Orb.) var. <i>caucasica</i> Bogd., 1947	x					
46	<i>Entosolenia ex gr. marginata</i> (Walk. et Boys)	x		x		x	
47	<i>Entosolenia cubanica</i> Bogd., 1947	x					
48	<i>Cassidulina</i> sp.	x				x	

Table 8. Distribution of foraminifers in Middle Sarmatian deposits in different areas of the Eastern Paratethys (according to Podobina et al., 1956; Krashenninnikov, 1960; Bogdanowicz, 1965, 1986; Maisuradze et al., 2004; Koiava, 2006, supplemented by the author)

No.	Foraminifer species	Northern Ciscaucasia	Black Sea Region	Crimea	Georgia		Apsheron Peninsula
					Western	Eastern	
1	2	3	4	5	6	7	8
1	<i>Saccamina vulgaris</i> Bogd., 1947	x					
2	<i>Nubecularia novorossica</i> f. <i>crustaformis</i> Bogd., 1952	x	x	x			
3	<i>N. novorossica</i> f. <i>deformis</i> Bogd., 1952	x	x				
4	<i>N. novorossica nodulus</i> Kar. et Sinz., 1876	x	x	x			
5	<i>Nubecularia</i> sp.	x					
6	<i>Varidentella reussi</i> (Bogd., 1947)	x		x	x	x	x
7	<i>V. sarmatica</i> Karrer, 1877	x		x			
8	<i>Quinqueloculina</i> sp.	x			x	x	ч
9	<i>Q. complanata</i> (Bogd., 1952)	x	x		x		
10	<i>Q. ex gr. consobrina</i> Orb., 1846	x	x	x			x
11	<i>Q. consobrina plana</i> Vol., 1952		x	x			
12	<i>Q. consobrina sarmatica</i> Gerke, 1952	x	x	x			
13	<i>Q. consobrina nitens</i> Reuss., 1869		x	x			
14	<i>Quinqueloculina odessae</i> Didk., 1961		x	x			
15	<i>Q. carina</i> Didk., 1961		x	x			
16	<i>Quinqueloculina collaris</i> (Gerke et Iss., 1952)	x			x	x	
17	<i>Q. cubanica</i> Bogd., 1947	x					
18	<i>Q. oblonga</i> Didk., 1961		x				
19	<i>Q. baranovae</i> Didk., 1961		x	x			
20	<i>Q. minakovae ukrainica</i> Didk., 1961		x				
21	<i>Q. perlucida</i> (Bogd., 1947)	x					
22	<i>Q. scythica</i> Bogd., 1965	x					
23	<i>Q. costata</i> Karr., 1867			x			
24	<i>Q. arcuata</i> (Didk. et Gudina, 1958)		x				
25	<i>Q. corrudis</i> (Gerke et Issaeva, 1952)	x					
26	<i>Q. karreri</i> Reuss, 1869	x	x	x			
27	<i>Q. ex gr. enoplostoma</i> Reuss, 1869	x					
28	<i>Q. aff. dilatata</i> Orb., 1846	x					
29	<i>Q. perelegantissima</i> Didk., 1961		x	x			
30	<i>Q. aff. floriformis</i> (Bogd., 1952)	x					
31	<i>Q. fasseta</i> Didk., 1961		x				
32	<i>Q. delicatula</i> Kolesnikova	x					
33	<i>Affinetrina voloshinovae</i> (Bogd., 1947)			x		x	x
34	<i>Affinetrina voloshinovae voloshinovae</i> (Bogd., 1947)	x				x	
35	<i>A. voloshinovae eldarica</i> Koiava, 2006				x	x	
36	<i>A. voloshinova pecteniformis</i> (Bogd., 1952)				x	x	x
37	<i>A. guriana</i> (O.Djan., 1953)				x	x	
38	<i>Sinuloculina</i> aff. <i>angustoris</i> Bogd., 1952	x			x	x	
39	<i>Cycloforina complanata</i> (Gerke et Jss., 1952)	x		x		x	
40	<i>C. karreri ovata</i> (Serova, 1955)				x	x	
41	<i>Spiroloculina grosnyensis</i> Bogd., 1947	x	x	x			
42	<i>S. kolesnikovi</i> Bogd., 1952	x		x			

Table 8. (Contd.)

No.	Foraminifer species	Northern Ciscaucasia	Black Sea Region	Crimea	Georgia		Apsheron Peninsula
					Western	Eastern	
1	2	3	4	5	6	7	8
43	<i>S. okrajantzi</i> Bogd., 1952	x		x			
44	<i>Triloculina</i> aff. <i>ukrainica</i> (Serova, 1955)			x			
45	<i>Triloculina ukrainica sarmatica</i> Didk., 1961		x	x			
46	<i>T. ukrainica siwaschica</i> Didk., 1961		x	x			
47	<i>Flintina tutkowskii</i> Bogd., 1952	x	x	x		x	
48	<i>F. schweyeri</i> Bogd., 1952	x					
49	<i>Wiesnerella plana</i> Bogd., 1952	x					
50	<i>Wiesnerella</i> sp.	x					
51	<i>Articulina</i> aff. <i>problema</i> Bogd., 1952	x		x	x	x	x
52	<i>A. articuloides</i> (Ger. et Iss., 1952)	x			x	x	x
53	<i>A. voloshinovae</i> Bogd., 1952	x	x				
54	<i>A. sarmatica</i> (Karrer, 1877)	x		x	x	x	
55	<i>A. stelligera</i> Didk., 1958		x	x	x		
56	<i>A. apscheronica</i> Bogd., 1952	x					
57	<i>A. kalickii</i> Bogd., 1952	x					x
58	<i>A. paradoxalis</i> Bogd.	x					
59	<i>A. cf. bidentata</i> Didk., 1958	x	x				
60	<i>A. kudakoensis</i> Vol., 1952	x					
61	<i>Dogielina sarmatica</i> Bogd. et Vol., 1949	x		x	x	x	x
62	<i>D. kaptarenko</i> Didk., 1951		x		x	x	
63	<i>Sarmatiella costata</i> Bogd., 1952	x		x	x	x	
64	<i>S. moldawiensis</i> Bogd., 1952		x		x	x	
65	<i>S. prima</i> Bogd., 1952	x			x	x	
66	<i>S. tuberculata</i> Bogd., 1965	x					
67	<i>S. subtilis</i> (Bogd., 1952)					x	
68	<i>Spirolina littoralis</i> Didk., 1960		x	x			
69	<i>Peneroplis sarmaticus</i> Didk., 1960		x	x			
70	<i>Meandroloculina bodatschovi</i> Bogd., 1952	x			x		
71	<i>M. schirwanensis</i> Bogd., 1952	x			x	x	
72	<i>M. conicocameralis</i> Bogd., 1952	x					
73	<i>M. minor</i> Bogd., 1952	x					
74	<i>M. gracilis</i> Bogd., 1952	x			x	x	
75	<i>M. invenusta</i> Bogd., 1952	x					
76	<i>M. dentata</i> Bogd., 1965	x					
77	<i>M. littoralis</i> Bogd., 1952			x			
78	<i>Wiesnerella</i> sp.	x					
79	<i>Globulina gibba</i> Orb. 1846	x					
80	<i>Fissurina elongata</i> (Pobed.),				x	x	
81	<i>Fissurina cubanica</i> (Bogd., 1947)	x			x	x	
82	<i>Dicrorbis perlucidus</i> Bogd., 1947	x					
83	<i>Discorbis</i> sp.	x			x		
84	<i>Cibicides</i> ex gr. <i>lobatulus</i> (Walker et Jacob, 1798)	x					
85	<i>Cibicides</i> sp.	x					

Table 8. (Contd.)

No.	Foraminifer species	Northern Ciscaucasia	Black Sea Region	Crimea	Georgia		Apsheron Peninsula
					Western	Eastern	
1	2	3	4	5	6	7	8
86	<i>Florilus bogdanowiczi</i> (Vol., 1950)	x		x	x	x	
87	<i>Nonion tumidulus</i> Pish., 1960	x	x		x	x	
88	<i>N. miocenicus</i> Podobina et Volosh., 1956						x
89	<i>Nonion</i> sp.	x					
90	<i>Porosonion martcobi</i> (Bogd., 1947)	x		x			x
91	<i>Porosonion granosum</i> (d'Orb., 1846)				x	x	x
92	<i>P. subgranosum subgranosum</i> (Egger, 1857)			x		x	x
93	<i>P. subgranosum umboelata</i> (Gerke, 1960)				x	x	
94	<i>P. subgranosus</i> (Egger, 1857)	x			x	x	x
95	<i>P. hyalinum</i> (Bogd., 1960)			x	x	x	
96	<i>P. aragviensis</i> (O. Djan., 1953)					x	
97	<i>P. subgranosus</i> var. <i>perforata</i> (Didk.)		x	x			
98	<i>Ammonia</i> ex gr. <i>beccarii</i> (Linne, 1758)	x		x			
99	<i>Ammonia</i> sp.	x		x	x	x	x
100	<i>Elphidium</i> ex gr. <i>macellum</i> Fish. et Molli, 1803	x			x	x	x
101	<i>E. macellum macellum</i> (F. et M., 1803)				x	x	
102	<i>E. macellum tumidocamerale</i> Bogd, 1952				x	x	
103	<i>Elphidium aculeatum</i> (Orb., 1846)	x		x			x
104	<i>E. angulatum</i> (Egger, 1857)	x					
105	<i>E. crispum</i> (Linne, 1758)	x			x	x	x
106	<i>E. hauerinum</i> (Orb., 1846)	x			x	x	
106	<i>E. georgium</i> Veng., 1958		x	x			
107	<i>E. incertum</i> (Will., 1858)			x			
108	<i>E. fichtellianum</i> d'Orb., 1846			x	x	x	
109	<i>E. flexuosum</i> (d'Orb. 1846)				x	x	
110	<i>E. ukrainicum</i> Krash., 1960				x	x	
111	<i>Elphidium</i> sp.	x			x	x	x
112	<i>Parellina regina</i> (d'Orb., 1946)	x		x		x	x
113	<i>P. regina</i> (Orb.) var. <i>caucasica</i> Bogd., 1932	x					
114	<i>Neobulimina</i> sp.	x			x		
115	<i>Buliminella elegantissima</i> Orb., 1946			x			
116	<i>Entosolenia</i> ex gr. <i>marginata</i> (Walker et Boys, 1784)	x					
117	<i>Entosolenia cubanica</i> Bogd., 1947	x					
118	<i>E. irma</i> Bogd., 1952	x					
119	<i>E. karreri</i> Bogd., 1952	x					
120	<i>E. horrida</i> Bogd., 1952	x					
121	<i>Entosolenia</i> sp.	x					
122	<i>Cassidulina</i> sp.	x			x		
123	<i>Bolivina sarmatica</i> Didk., 1959			x			
124	<i>B. nisporenica</i> Didk., 1959			x			
125	<i>B. sagittula</i> Didk., 1959			x			

aminiferal fauna includes no more than ten genera and 15 species. In sections of Western Ciscaucasia, Bogdanowicz (1965) identified the following species: *Quinqueloculina* ex gr. *consobrina*, *Articulina* aff. *problema*, *Discorbis* sp., *Florilus bogdanowiczi*, *Porosonion martcobi*, *P. subgranosum subgranosum*, *Ammonia* ex gr. *beccarii*, *Elphidium* ex gr. *macellum*, *Entosolenia* ex gr. *marginata*, and *Bolivina* sp. The assemblage is composed of species known from the underlying deposits; however, most of foraminifers are characterized by small tests and recorded in small numbers. Sections of the Taman Peninsula contain a similar assemblage of foraminifers of the genera *Quinqueloculina* (five species), *Elpidium* (three species), and *Spiroloculina*, *Sarmatiella*, *Articulina*, and *Protoelphidium*. In sections of Western Ciscaucasia and in Kuban well SG-12000, The ***Quinqueloculina consobrina* Beds** were recognized for the upper part of the Sarmatian (Pinchuk, 2006).

Didkovskii (1964) identified dwarf forms of *Porosonion subgranosum* and *Ammonia beccarii* and elphidiids in sections of the Upper Sarmatian (Khersonian) deposits of the Northern Black Sea region. In the Crimea, *Quinqueloculina consobrina consobrina* was found in the Upper Sarmatian.

The common species for different areas of the Eastern Paratethys, where Upper Sarmatian deposits are widespread, are the species *Elphidium macellum*, *Porosonion subgranosum*, *Florilus bogdanowiczi*, and *Quinqueloculina* ex gr. *consobrina* (Bogdanowicz, 1986).

Maeotian Regional Stage

Data on composition and distribution of the Maeotian fauna of foraminifers are known mainly from publications of Bogdanowicz (1947, 1952, 1965, 1969, 1986), Pobedina et al. (1956), Didkovskii (1958a, 1958b; 1966), Didkovskii and Satanovskaya (1970), Krashenninnikov (1959), and Pinchuk (2006, 2011).

The Early Maeotian foraminiferal fauna is characterized by the richness of species, indicating a renewed communication between the Eastern Paratethys and open sea waters. The assemblage consisted mainly of alien species of Mediterranean origin, which often remained unchanged after migration (*Quinqueloculina gracilis*, *Cornuspira involvens*, *Elphidium macellum*, etc.) (up to 24 genera and 68 species) (Table 9).

The assemblage of the lower (Bagerovian) Substage is the richest in species and number of individuals; it is characterized by a significant content of miliolid species: *Quinqueloculina seminulum* maeotica, *Q. pseudocuneata*, *Q. gracilis*, *Q. bogatschovi*, *Q. aff. guria*, *Q. (?) fragilis*, *Articulina arcuata*, *A. tenella maeotica*, *Nodobaculariella (?) obscura*, *Hauerina subbotinae*, *H. fulgida*, *Elphidium fedorowi*, and *Spirolina poroshini*. The presence of *Spirolina*, *Dendritina*, *Cornuspira*, and *Bolivina* species and a significant diversity of

Discorbis are typical of this substage (Table 9). The subordinate position is occupied by representatives of *Porosonion* and *Elphidium*, which included the same species as those in the Sarmatian. It is also important that representatives of marine genera *Caucasinella* and *Virgulina* reappear in the Maeotian.

The ***Quinqueloculina seminulum maeotica* beds** were recognized in the Western Ciscaucasia (Bogdanowicz, 1971; Pinchuk, 2006). The assemblage contains a large number of foraminifers, in particular, miliolids, including *Nodobaculariella maeotica*, *N. sulcata*, *Quinqueloculina seminulum maeotica*, *Q. vermicularis*, *Q. undosa*, *Cycloforina gracilis*, *Articulina tenella maeotica*, *Hauerina subbotinae*, *Nonion bogdanowiczi*, *Dendritina poroshini*, and many others. The lower boundary with the Sarmatian is defined by the appearance of marine species of the Maeotian. The rich assemblage of the Lower Maeotian is greatly depleted towards its end.

The Maeotian assemblage of foraminifers of the upper (Akmanai) substage is very depleted in species and almost devoid of Mediterranean elements. It corresponds to the new stage of dissociation of the Eastern Paratethys from the fully saline basin and its desalination. The beginning of this stage is marked by a rapid extinction of most migrant species and their varieties, including new endemics. The assemblage of the Akmanaian Substage is very impoverished (four genera, up to ten species); foraminifers are rare and few, except euryhaline species such as *Quinqueloculina* ex gr. *consobrina*, *Q. seminulum*, *Porosonion martcobi*, *Elphidium* ex gr. *macellum*, *Ammonia* ex gr. *beccarii*, and a few other species, which continue to exist not only until the end of the Maeotian, but also pass into the Pontian basin (Bogdanowicz, 1986; Pinchuk, 2006).

Pontian Regional Stage

Pontian foraminifers lived under conditions of a significant decrease in salinity; they were small in number and were represented by miliolids, elphidiids, bolivinids, rotaliids, and some others (about ten species of six genera). The most common species are *Quinqueloculina seminulum*, *Q. ex gr. consobrina*, *Elphidium* ex gr. *macellum*, *Elphidium* sp., *Cassidulina* sp., *Bolivina* sp., etc. (Bogdanowicz, 1986). The fauna of foraminifers is of relict nature; a large number of ostracods appeared at that time in the basin.

Planktonic Foraminifers

The classical stratigraphy of the Eastern Paratethys and identification of regional divisions, which later served as a basis for the stratigraphic scheme of the Neogene of southern Russia, were based on studying the benthic groups of fauna, mainly mollusks and benthic foraminifers (Andrusov, 1884, 1912, 1923; Bogdanowicz, 1951, 1965, 1986, etc.). This is determined

Table 9. Distribution of foraminifers in the sediments of the Lower Maeotian in different areas of the Eastern Paratethys (according to Pobedina et al., 1956; Didkovskii, 1958a, 1958b, 1964; Krashennnikov, 1959; Bogdanowicz, 1969, 1986; Pinchuk, 2006, supplemented by the author)

No.	Foraminiferal species	Northern Ciscaucasia	Crimea	Southern Ukraine	Apsheron Peninsula
1	2	3	4	5	6
1	<i>Cornuspira</i> aff. <i>involvens</i> (Reuss, 1839)	x			
1	<i>Nubecularia horrida</i> Bogd., 1965	x			
2	<i>Nubecularia cristellaroides</i> Terq. 1978	x		x	
3	<i>Nubecularia</i> sp.	x			x
4	<i>Quinqueloculina seminulum maeotica</i> Gerke, 1938	x	x	x	x
5	<i>Q. seminulum seminulum</i> (Linnaeus, 1767)	x	x	x	
	<i>Q. seminulum pseudocuneata</i> Gerke	x			x
6	<i>Quinqueloculina seminulum ukrainica</i> Didk., 1961		x	x	
7	<i>Q. pseudocuneata</i> Gerke, 1938	x			x
8	<i>Q. attalica</i> Didk. 1961		x	x	
9	<i>Q. akneriana akneriana</i> Orb., 1864	x			
10	<i>Q. bogatschovi</i> Bogd., 1969	x			
11	<i>Q. aff. ludwigi</i> (Reuss, 1839)	x	x		
12	<i>Q. sulacensis</i> Gerke, 1938	x			
13	<i>Q. aff. brauni</i> (Reuss, 1839)	x			
14	<i>Q. (?) fragilis</i> Bogd., 1965	x		x	
15	<i>Q. ex gr. consobrina</i> (Orb., 1846)	x			x
16	<i>Q. consobrina maeotica</i> Didk., 1961		x	x	x
17	<i>Q. undosa</i> Karrer, 1938	x			
18	<i>Q. vermicularis</i> Karrer, 1938	x		x	
19	<i>Q. aff. chutzievae</i> Bogd., 1952	x			
20	<i>Q. consobrina sarmatica</i> Gerke, 1952			x	
21	<i>Q. venusta</i> Bogd., 1965	x		x	
22	<i>Q. Maeotiaca</i> Didk., 1961		x	x	
23	<i>Q. lachesis</i> Karrer, 1938	x	x	x	
24	<i>Quinqueloculina</i> sp.	x	x	x	x
25	<i>Q. quadrilonga</i> (Podobina, 1956)				x
26	<i>Q. simplex</i> Podobina, 1956				x
27	<i>Affinetrina</i> aff. <i>guriana</i> (O.Djan., 1953)	x	x		
28	<i>Milliolinella circularis</i> (Born.)	x			
29	<i>Cycloforina gracilis</i> Karrer, 1867	x			
30	<i>Spirolina</i> cf. <i>stelligera</i> Didk., 1961		x	x	
31	<i>Spirolina elegans maeltica</i> Didk., 1959			x	
32	<i>Spirolina rimosa rimosa</i> Didk., 1959		x	x	
33	<i>Spirolina stelligera mucronata</i> Didk., 1959		x	x	
34	<i>Spirolina stelligera stelligera</i> Didk., 1959		x	x	
35	<i>Spiroloculina</i> sp.	x			x
36	<i>Sigmoilinita</i> sp.	x			
37	<i>Articulina arcuata</i> Bogd., 1952	x			
38	<i>A. tenella</i> (Eichw.) <i>maeotica</i> Bogd., 1969	x			
39	<i>A. sulacensis</i> Gerke, 1938	x		x	

Table 9. (Contd.)

No.	Foraminiferal species	Northern Ciscaucasia	Crimea	Southern Ukraine	Apsheron Peninsula
1	2	3	4	5	6
40	<i>A. cf. stelligera</i> Didk., 1958	x	x	x	
41	<i>Articulina</i> sp.	x		x	x
42	<i>Triloculina inflata maeotica</i> Didk., 1961	x			
32	<i>T. clavata</i> Didk., 1961		x	x	
33	<i>T. nitens</i> Reuss, 1839			x	
34	<i>Nodobaculariella maeotica</i> Bogd. et Budanova, 1952			x	
35	<i>Nodobaculariella obscura</i> Bogd., 1969	x		x	
36	<i>N. sulcata</i> (Reuss, 1839)	x			
37	<i>Nodobaculariella</i> sp.	x	x		
38	<i>Wiesnerella</i> ex gr. <i>plana</i> Bogd., 1952	x			
39	<i>Hauerina subbotinae</i> Bogd. et. Budanova, 1952	x	x	x	
40	<i>H. fulgida</i> Bogd., 1969	x			
41	<i>Hauerina</i> sp.	x			
42	<i>Dendritina poroshini</i> Bogd., 1965	x			
43	<i>Spirolina cf. stelligera</i> Didk., 1961	x	x	x	
44	<i>Discorbis maeotica</i> Bogd. et Kalug., 1952	x	x	x	
45	<i>Discorbis</i> sp.	x	x	x	x
46	<i>D. risillus</i> Bogd., 1958	x		x	
47	<i>Cibicides lobatulus</i> (Walker et Jacob, 1798)	x			
48	<i>Cibicides</i> sp.		x	x	
49	<i>Florilus</i> aff. <i>bogdanowicz</i> Vol.	x		x	
50	<i>Porosononion martcobi</i> (Bogd., 1947)	x		x	x
51	<i>P. subgranosum subgranosum</i> (Egger, 1857)	x	x		
52	<i>P. subgranosum umbrolata</i> Gerke, 1960	x	x		
53	<i>Porosononion</i> sp.	x			x
54	<i>Ammonia</i> ex gr. <i>beccarii</i> (Linne, 1758)	x	x	x	x
56	<i>Ammonia</i> sp.	x	x	x	x
57	<i>Elphidium</i> ex gr. <i>macellum</i> Fish. et Molli, 1803	x	x	x	
58	<i>Elphidium kudakoense</i> Bogd., 1947	x			
59	<i>Elphidium fedorowi</i> Bogd., 1947	x	x	x	
60	<i>Elphidium</i> sp.	x		x	x
61	<i>Caucasinella</i> aff. <i>elongata</i> (Orb., 1864)	x	x		
62	<i>Caucasinella</i> sp.	x		x	
63	<i>Fursenkoina</i> aff. <i>schreibersiana</i> Cz.	x		x	
64	<i>Entosolenia</i> ex. gr. <i>marginata</i> (Walker et Boys, 1784)	x		x	
65	<i>Entosolenia</i> sp.	x		x	
66	<i>Cassidulina</i> sp.	x	x		
67	<i>Bolivina</i> ex gr. <i>floridana</i> Cushman, 1918	x		x	
68	<i>Bolivina</i> sp.	x	x	x	
69	<i>Patellina</i> aff. <i>corrugata</i> Will., 1957	x			
70	<i>Spirillina</i> sp.	x		x	

by shallow-water conditions and, as a rule, a low salinity of Miocene basins, in which planktonic microorganisms could not fully develop and could form, at best, depleted assemblages. However, during the greatest penetrations of oceanic waters (at times of a stable connection with open water bodies), they penetrated into the basins of the Eastern Paratethys, which makes it possible to correlate them with the Central Paratethys and Mediterranean and refine the sedimentation environments and age of deposits.

The diversity and abundance of planktonic foraminifers recorded in the Miocene sediments of the Paratethys decreases from west to east. A significant assemblage of planktonic foraminifers was described from the Carpathian Foredeep, which belonged to the Central Paratethys in the Middle Miocene, including deposits from the Balichi Formation (Subbotina et al., 1960; Bobrinskaya et al. in Cicha et al., 1998). This formation contains plankton species unknown in the underlying sediments: *Globigerina bolli*, *Globigerinoides trilobus*, *G. bisphaericus*, *Globoquadrina dehiscens*, and *Globorotalia scitula* (Bobrinskaya et al., 1998, p. 38), based on which this formation was assigned to local *Cibicidoides budayi* Beds and correlated with the Ottnangian (Cicha et al., 1998, Fig. 23).

The overlying Bogorodchany Formation, composed of greenish-gray marls and marly clays, differs from other Miocene stages in a huge number of both benthic and planktonic foraminifers. Here, the most typical plankton species are *Orbulina suturalis* Bron., *O. bilobata*, *Globigerinoides trilobus*, *G. bisphaericus*, and *Paragloborotalia mayeri*. The age of the formation is determined as the Karpatian–Lower Badenian. A similar assemblage with *Orbulina suturalis* and *Præorbulina glomerata* was determined from Lower Badenian deposits from the northwestern part of the East European Platform (Volyn–Podolia). Judging from these assemblages of planktonic foraminifers, the deposits can be assigned to Middle Miocene zone M6 with *Orbulina suturalis* (Wade et al., 2011) and can be correlated with the Tarkhanian of southern Russia. In addition to zonal species, an interesting component of this assemblage is *Globigerina dubia*, a Miocene species that is characteristic of deposits of both the Central Paratethys and Northern Black Sea region. Stratigraphically higher in the Ciscarpathian trough and along the edge of the platform, there is a Tyras Formation composed of gypsum, anhydrites, and salts without fauna. Above is the Kosov Formation of the Upper Badenian, which contains a less diverse assemblage of planktonic foraminifers with *Globigerinoides trilobus*, *Turborotalia bykovae*, and *Paragloborotalia mayeri*. No planktonic foraminifers were found from the Dashava Formation (Lower Sarmatian). Judging from the composition of benthic foraminifers, which include numerous miliolids and nonionids, dominated by *Varidentella reussi*, *Porosonion (sub)granosum*, and *Ammonia beccarii* (Bobrinskaya et al., 1998, p. 39), the Dashava basin was rather shallow and desalinated.

Tarkhanian regional stage. In the Crimean–Caucasian area, planktonic foraminifers occur in sediments of the Tarkhanian and Konkian stages of the Middle Miocene. Until recently, the richest assemblages were described from the Crimea, whereas only one or two planktonic species (mainly *Globigerina tarchanensis*) were identified from the Northern Ciscaucasia and western and eastern Georgia (Krashennikov et al., 2003). Fifteen species of planktonic foraminifers, including *Globigerina* aff. *bolli*, *G. bradyi*, *G. officinalis*, *G. tarchanensis*, *Globorotalia continuosa*, *Paragloborotalia mayeri*, *Globigerinoides bisphaericus*, etc., were identified in sections of the Tarkhanian Regional Stage of Crimea.

Detailed studies of the sections of the Tarkhanian Regional Stage in Northern Ciscaucasia, performed by the author in recent years, showed the presence of a diverse planktonic foraminiferal assemblage, even though it is impoverished compared to the Middle Miocene associations of the Central Paratethys (Golovina and Bylinskaya, 2020). Foraminifers are characterized by an extremely small size and their taxonomic identification requires examination under a scanning microscope in some cases. Planktonic foraminifers were studied from the Tarkhanian deposits of the Chekokh, Pshekha, Belaya, Bolshoy Zelenchuk, and Kuban sections (Table 10). They were studied in most detail from the sections of the Pshekha and Bolshoy Zelenchuk rivers, as well as from the Malyi Kamyshlak section on the Kerch Peninsula.

The assemblage of planktonic foraminifers in the section of Tarkhanian deposits on the Pshekha River contains 19 species; four of them are extant and most of the others have a fairly wide stratigraphic range, mostly from the Oligocene to the Miocene. All these species were recognized in certain sections of Lower and Middle Miocene sediments of the Central Paratethys (Spezzaferri et al., 2009; Popescu and Crihan, 2011; Beldean et al., 2012), which confirms the communication between this basin and Eastern Paratethys in the Tarkhanian. In the section on the Pshekha River, planktonic foraminifers first occur in a bed representing an analog of the “Tarkhanian marl” (Terek beds), where seven species, including quite abundant *Globigerinita uvula*, *G. glutinata*, and *Turborotalita quinqueloba*, were found. The latter species is characterized by a large number of aberrant forms, which may indicate a rapid onset of transgression or stress conditions. The richest assemblage of planktonic foraminifers was found directly above the section, in a member with unconformable stratification. Along with the above-listed species *Ciperoella anguliofficialis*, *Tenuitella munda*, *T. pseudoedita*, *Globoturborotalita woodi*, *Globorotalia (Fohsella) peripheroronda*, *G. scitula*, and *Orbulina suturalis* were recorded. This composition of the assemblage indicates greater depths and, possibly, increased temperature. The overlying interval of the section does not contain plankton; whereas planktonic foraminifers *Tenuitella*

Table 10. Distribution of planktonic foraminifers in sections of the Tarkhanian sediments of Western and Central Ciscaucasia

Species	Sections				
	Chekokh River	Pshekha River	Belaya River	Bolshoy Zelenchuk	Kuban River (Yaman-Dzhalga)
<i>Globigerina tarchanensis</i> Subb. et Chutz.		+	+	+	+
<i>G. falconensis</i> Blow			+		
<i>G. foliata</i> Bolli		+	+		
<i>G. dubia</i> Egger			+	+	
<i>Tenuitella angustiumbilitata</i> (Bolli)		+	+	+	
<i>T. pseudoedita</i> (Subbotina)	+	+	+	+	
<i>T. munda</i> (Jenkins)	+	+	+	+	
<i>Ciperoella anguliofficialis</i> (Blow)		+	+	+	+
<i>Turborotalita quinqueloba</i> (Natland)	+	+	+	+	+
<i>Globigerinita uvula</i> (Ehrenberg)		+	+	+	+
<i>G. glutinata</i> (Egger)	+	+	+	+	
<i>Globorotaloides hexagonus</i> (Natland)		+		+	
<i>Globigerinella obesa</i> (Bolli)		+			
<i>Globorotalia scitula</i> (Brady)		+			
<i>Gl. (Fohsella) peripheroronda</i> (Blow et Bann.)		+			
<i>Orbulina suturalis</i> Brönn.		+			
<i>Paragloborotalia birnageae</i> (Blow)		+			+
<i>P. acrostoma</i> (Wezel)		+			
<i>Globoturborotalita euapertura</i> (Jenkins)			+	+	+
<i>G. woodi</i> (Jenkins)		+		+	+
<i>Catapsydrax unicavus</i> Bolli, Loeb. et Tapp.	+	+			
<i>Globoquadrina cf. dehiscens</i> Chap., Parr et Coll.	+				
<i>Globigerinoides trilobus</i> (Reuss)	+				
<i>Streptochilus pristinum</i> Brönn. et Resig		+		+	

munda, *Globigerinella obesa*, *Globorotalia (F.) peripheroronda*, *Paragloborotalia acrostoma*, *Paragloborotalia* sp., and *Streptochilus pristinum* are recorded again in the upper Tarkhanian at the boundary with the Chokrakian.

Species of the Tarkhanian assemblage of planktonic foraminifers identified in the Pshekha River section, occur in the Burdigalian and Langhian sediments of the Transylvanian basin, Ciscarpathian trough, and Vienna basin (Beldean et al., 2012, etc.). To date, no species of planktonic foraminifers that could allow a more exact age determination than the Burdigalian–Langhian interval dated to 20.44–13.82 Ma (*International...*, 2021), have been found in the studied sections of Tarkhanian deposits in Northern Ciscaucasia and on the Kerch Peninsula. The plankton assemblage of the Eastern Paratethys is poorer than that of the Central Paratethys and the stratigraphically important species of *Praeorbulina* and *Orbulina* have not yet been found in this assem-

blage. Therefore, the finding of *Orbulina suturalis* in the Tarkhanian section on the Pshekha River is so significant. *O. suturalis* Brönn. was described from Trinidad (Venezuela) and is considered an immediate descendant of *Praeorbulina glomerosa circularis*. Its first appearance in the World Ocean is dated to 15.10 Ma and marks the base of the Middle Miocene zone M6 (Wade et al., 2011). The presence of *O. suturalis* in the Tarkhanian assemblage of planktonic foraminifers makes it possible to determine its age as Middle Miocene and to date it to the second half of the Langhian, despite a significant similarity of its composition with the plankton associations from the upper part of Lower Miocene sediments of the Central Paratethys.

In the Tarkhanian section on the Bolshoy Zelenchuk River, a similar distribution of planktonic foraminifers was found in Tarkhanian deposits. In the upper strata of the Kuvinian beds, few specimens of *Turborotalita quinqueloba*, *Ciperoella anguliofficialis*,

and *Tenuitella munda* were found directly beneath the Tarkhanian marl. Terek beds (Tarkhanian marl) contain a rich plankton assemblage of 13 species, including *Globigerina dubia*, *G. tarchanensis*, *Tenuitella munda*, *T. pseudoedita*, *T. angustiumbilitata*, *Globoturbotalita euapertura*, *G. woodi*, and other. In the overlying Argun deposits, the diversity and abundance of planktonic foraminifers gradually decrease upward the section.

In the Tarkhanian sediments of the Malyy Kamyshtak section on the Kerch Peninsula of Crimea, planktonic foraminifers are distributed as follows. In the upper part of the Kuvinian beds, few specimens of *Turbotalita quinqueloba*, *Tenuitella munda*, *Globigerina* aff. *tarchanensis*, and *Ciperoella anguliofficialis* were found 15 cm below the Tarkhanian marl. A rich plankton assemblage including *Turbotalita quinqueloba*, *Globigerina tarchanensis*, *G. dubia*, *Ciperoella anguliofficialis*, *Tenuitella munda*, *T. pseudoedita*, and *Globigerinita glutinata* was found directly beneath the Tarkhanian marl. The number of planktonic foraminifers is greater at this level and many aberrant specimens are recorded among them, which may indicate stress conditions, possibly sharp changes in the salinity of the basin. This bed resembles the Tarkhanian marl on the Pshekha River by this character. The Terek beds (Tarkhanian marl) in the Malyy Kamyshtak section contain *Ciperoella anguliofficialis*, *Tenuitella pseudoedita*, *T. aff. munda*, *Globigerina* aff. *dubia*, *G. aff. tarchanensis*, and *Turbotalita quinqueloba*. Scarce specimens of *Turbotalita quinqueloba*, *Tenuitella munda*, and *Globigerina* aff. *dubia* were encountered in the overlying Argun beds (7.5 m upward the section). An interesting and most numerous member of the assemblage at this level is the planktonic species *Streptochilus pristinum*, which was also found in the Upper Tarkhanian on the Pshekha and Bolshoy Zelenchuk rivers. Comparison of this plankton distribution with the coeval sections of Ciscaucasia shows that the appearance of fairly rich planktonic foraminiferal assemblage of is noted earlier in the Crimea, i.e., in sediments underlying the Tarkhanian marl.

The composition of planktonic foraminifers of the Tarkhanian Regional Stage indicates eutrophic conditions and cool temperatures, which is confirmed by an almost complete absence of species of the warm-water *Globigerinoides* group. At the same time, unlike the conditions of the Konkian transgression, the Tarkhanian marine basin was characterized by similar normal marine conditions both in the Crimea and Ciscaucasia, judging from the presence of similar plankton assemblages.

Konkian regional stage. In the Konkian time, the plankton composition was much richer in the Crimean region than in Ciscaucasia, which suggests a weakening of the effect of transgression towards the eastward (Krasheninnikov et al., 2003). Seven plankton species, including *Globigerina bulloides*, *G. dubia*,

G. cf. falconensis, *G. tarchanensis*, and *Paragloboborotalia mayeri*, were described from Konkian deposits of the Crimea. In Ciscaucasia, only *P. mayeri* was found in the sediments of this stage, and *Globoturbotalita woodi* was recorded in eastern Georgia (Krasheninnikov et al., 2003).

Therefore, planktonic foraminifers penetrated into the basins of both the Central and Eastern Paratethys during separate episodes of Lower and Middle Miocene transgressions. In the Eastern Paratethys, the last transgression, characterized by the occurrence of planktonic foraminifers took place in the Konkian Regional Stage, and more or less significant assemblage of this age is known from the Crimean sediments.

Mollusks

The stratigraphic scheme of the Eastern Paratethys was initially based on changes in bivalve assemblages, the composition of which was primarily determined by the ecological conditions and paleogeographic relationships of the basin. Since mollusks are confined mainly to shallow waters, the history of changes in this group primarily reflects the events observed in this zone: transgressive–regressive cyclicity and changes in salinity and the gas regime in the marginal zone of the sea.

Caucasian Regional Stage

In the Upper Maikopian deposits of Ciscaucasia, Mollusks are unknown at the level of the Septarian, Zelenchuk, and Karadzhalka formations. Presumably, they might not live here at that time due to the ongoing hydrogen sulfide contamination. Mollusks were recorded only in the marginal parts of the basin: in Georgia and on its northern and eastern edges. These assemblages are rather poor and poorly preserved, but are ubiquitously represented by marine forms.

The most representative assemblage of mollusks on the northern shelf (probably of Aquitanian age) is known from the Sivash Subformation of Ukraine. Due to an impoverished preservation (moulds and imprints in loose sandstone), many of the forms in this assemblage were identified only approximately (cf.) or to the genus level. Not less than 70 bivalve species of 50 genera and about ten gastropod species were identified from here (Amitrov, 1993; Popov et al., 1993b, pp. 195–198; Goncharova and Popov, 1995). A significant proportion of this fauna was represented by species that passed from the Oligocene, including endemic species for the Eastern Paratethys (*Plagiocardium abundans*, *Cerastoderma prigorovskii*, *Sphenia nana*, etc.). Nevertheless, the presence of numerous warm-water genera and species of Mediterranean origin in this assemblage is apparent, which distinguishes this assemblage (*Atrina*, *Isognomon*, *Divalinga*, *Europocardium*, *Venus* cf. *multilamella*, *Callista lilaci-*

noides, *Glycymeris pilosa deshayesi*, and *Glossus maior*) and makes it similar to the Late Egerian mollusk faunas of Central Europe.

Some species common with this assemblage (*Plagiocardium abundans* and *Cerastoderma prigorovskii*) are also known from the sections and wells of the Stavropol Region, Primanychye, and Ergeni at the level of deposits of the Caucasian Regional Stage.

Other, probably coeval assemblages (Kyzyl-Kumian and Kyzylchin assemblages in Turkmenistan and Gissarak assemblage in Tajikistan) are much poorer (they together contain 42 bivalve species). Based on their generic composition, zoogeographic characteristics, and, probably, age, they are correlated with the Sivash assemblage of Ukraine. Both forms that passed from the Oligocene and warm-water genera and species (*Atrina*, *Isognomon*, *Megaxinus*, *Glycymeris pilosa deshayesi*, *Venus* sp., and *Callista lilacinoides*) are also present here, which distinguishes these assemblages from the Chattian associations of the Eastern Paratethys.

The assemblage of bivalve mollusks on the southern shelf in the Early Miocene is known from Transcaucasia, from the Uplistsikhe Formation of Georgia (Kartli). The deposits are characterized by fauna are known only in the stratotype section below the city of Gori. Here, T.A. Kurtskhaliya (Kurtskhaliya et al., 1972; Kurtskhaliya, 1982) found a rather diverse assemblage of mollusks (about 30 species at the base of the formation in a member 3 gravel sandstones; later, we also collected this assemblage (Popov et al., 1993b, Table 9)). Only a few widespread species (*Nucula* cf. *compta*, *Glycymeris lunulata*, and *Corbula gibba*), recorded in this assemblage, pass from the Oligocene. Warm-water Mediterranean migrants appear here for the first time: *Arca biangula*, *Barbatia* (*Cucullaearca*) sp., *V. (Obliquarca) modioliformis*, *Isognomon* cf. *maxillatus*, *Arcopagia* cf. *crassa*, *Callista lilacinoides*, and *Corbula* (*Caryocorbula*) sp.

At the base of the upper subformation, mollusks were found in the gravelstone interbed of member 5 and overlying sandstone concretions; their composition is similar to the underlying assemblage, but differs in the additional presence of several warm-water forms (Popov et al., 1993b, Table 10): *Palliolum incomparabile*, *Ctena squamosa*, *Cardita calyculata*, *Cerithium* sp., *Nassarius* sp., and *Olivia flammulata*.

Sakaraulian Regional Stage

The mollusk assemblage of the Sakaraulian of Georgia is more representative (about 90 bivalve species and more than 50 gastropod species) (Kharatishvili, 1952; Popov et al., 1993b), although the species described from this assemblage certainly do not reflect the richness of this fauna. The large size and diversity of mollusks, as well as the presence of subtropical and some tropical genera, indicates their warm-water con-

finement. Among the species of wide geographical distribution, quite many species are common with Eggenburgian species from Central Europe (more than 35%); however, there are almost no species that are common with the Burdigalian fauna and Aquitaine of the Mediterranean and, at the same time, unknown in the Eggenburgian assemblages. On the other hand, there are quite a lot of allochthonous species in the composition of the Sakaraulian fauna, which are still conditionally endemic. The degree of succession of this fauna from the Oligocene fauna is approximately the same as that from the Eggenburgian fauna—about 40%.

The assemblage of mollusks of the Olginskaya Formation of Ciscaucasia is confined to clay facies. It is poor (25 bivalve species, according to Popov et al., 1993b, pp. 195–198) and not correlated with the described associations of Sakaraulian due to the facies differences and greater depths. Along with numerous species passing from the Oligocene, large representatives of *Glossus* (*G. ex gr. maior*) and *Saxolucina*, as well as *Modiolus* (*M. cf. katscharavai* Charat.), which is closely related to the species described from the Sakaraulian, appear in this assemblage.

Kozakhurian Regional Stage

The representative associations of the brackish-water malacofauna of the Kartli Depression, which served as a basis for identifying this regional stage (Davitashvili, 1934), are known only from Georgia (Kvaliashvili, 1962; Popov, 1983; Popov et al., 1993b). They include 18 bivalve species with genera endemic to the Paratethys (Fig. 17): *Eoprosodacna* (four species), *Limnopappia caucasica*, *Rzehakia dubiosa*, and species *Cerastoderma ivericum* and *C. lacustre*, extremely euryhaline species *Corbula* (*Lenticorbula*) sp. and *Polymesoda brongniarti*, *Congeria* (two species), and *Siliqua* (three species). Among gastropods, the most common representatives are species of Melanopsidae (*Melanopsis impressa*) and freshwater–brackish-water *Theodoxus*, *Anisus*, *Viviparus*, *Lymnea*, and *Radix*. All the genera and many of the species were common with the Late Ottnangian assemblages of the Central Paratethys (Popov and Voronina, 1983).

Only a few species of this fauna are recorded from Western Georgia [*Eoprosodacna kartlica*, *Rzehakia socialis* (= *R. dubiosa*), *Congeria transcaucasica*, and *Melanopsis* sp. (Ananiashvili, 1985, p. 11, 16)] and from the Kopetdag part of the basin: *Rzehakia dubiosa*, *Eoprosodacna* cf. *kartlica*, *Cerastoderma* cf. *ivericum*, and *Corbula* (*Lenticorbula*) sp. (Popov et al., 1993b, p. 199).

In Ciscaucasia, the Ritsa and Zuramakent formations are correlated with the Kozakhurian based on finds of *Rzehakia* and the euryhaline foraminifer *Saccammina zuramakensis* in these formations. We studied the assemblage of mollusks with *rzhakias* in Cis-

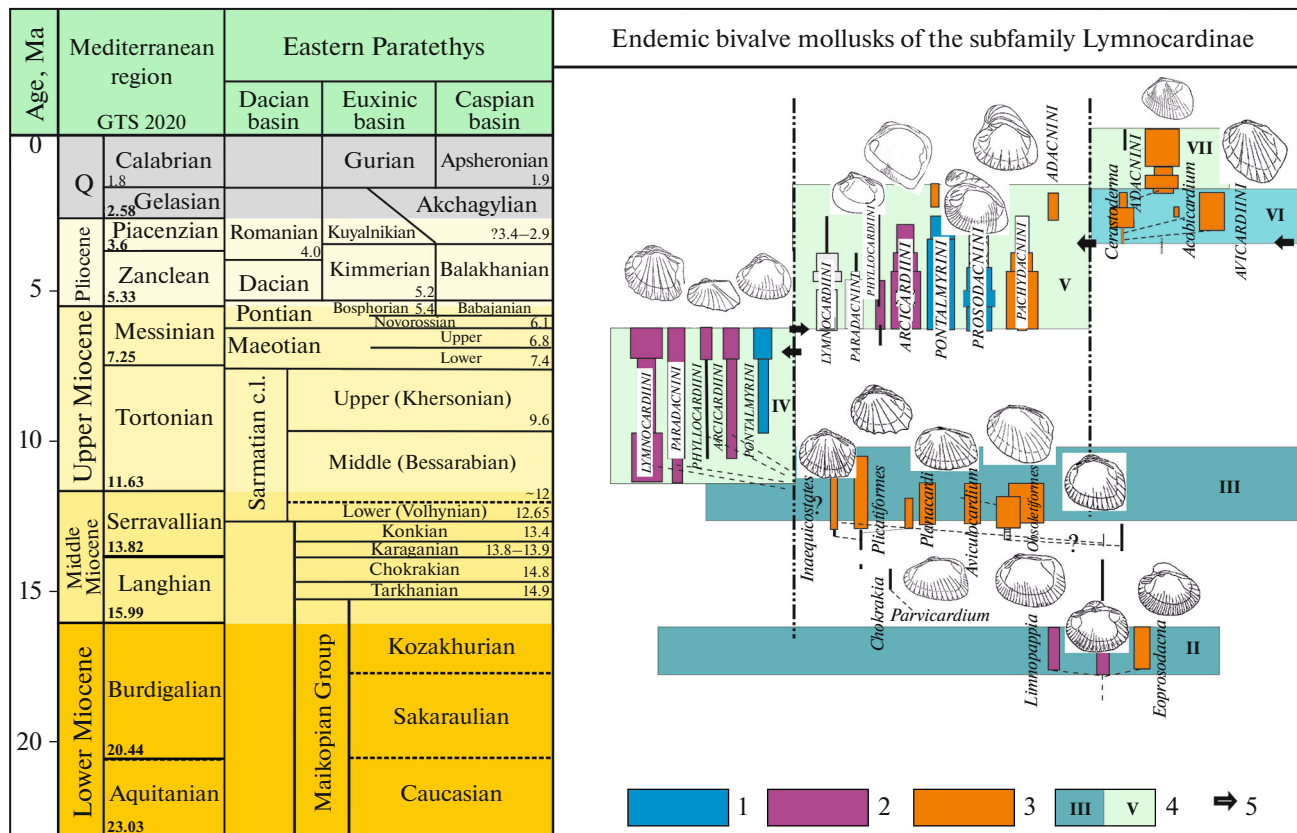


Fig. 17. Endemic lymnocardiini, the tribes and genera of which were formed in the Neogene basins of the Eastern Paratethys. Colors indicate: (1) taxa of Aegean origin; (2) taxa of Central Paratethys (Pannonian) origin; (3) taxa of Euxinic–Caspian origin; (4) intervals of formation of endemic faunas in semi-marine (III) and brackish-water (V) basins; (5) levels of main fauna migrations. Roman numerals indicate the main intervals of the formation of endemic faunas: (I) Solenovian interval (Oligocene); (II) Kozakhurian–Ottangian; (III) Sarmatian interval; (IV) Pannonian interval; (V) Pontian–Kuyalnikian interval; (VI) Akchagyl interval; (VII) Apsheronian interval.

caucasia from wells in the Priyutnensky area of the Manyche trough, where it is confined to clay facies. *Rzehakia dubiosa* and *Saccamina zuramakensis* Beds have a small thickness (up to 35 m); however, along with *Rzehakia* and *Saccamina*, there are also interbeds containing marine forms: *Nucula* (*Lamellinucula*) sp., *Parvicardium* cf. *striatulum*, *Cerastoderma* sp., and *Siliqua* sp. and imprints and fragments of venerids and tellinids, which are identified only to the family level. The marine species among foraminifers included *Caucasinella* (= *Neobulimina*) *elongata* and *Cibicides oligocenicus*. Marine bivalve species were also indicated in the Ritsa Formation by our predecessors (Liverovskaya, 1938; Grossgeym, 1960; Volkova, 1962).

These data and the composition of dinocyst assemblages in the Kozakhurian with the constant presence of marine taxa, including their occurrence in the Kozakhurian sections of the stratotype area (Popov et al., 2022; data of Zaporozhets and Aleksandrova in this paper) suggest communications between the Kozakhurian basin and open basins. At the same time,

the presence of brackish-water endemics indicates an unstable regime of salinity and a stratification of the water column with strong desalination, at least in the upper photic waterbody.

Tarkhanian Regional Stage

The Tarkhanian transgression led to the recovery of marine biota of Mediterranean–Atlantic origin in the Eastern Paratethys basin. Deeper sites were also inhabited as the normal gas regime was recovered after Maikopian anoxia. In the Late Tarkhanian, connections with neighboring sea basins began to be somewhat limited. In total, 92 bivalve species of 70 genera from 36 marine (mostly polyhaline) families and only one brackish-water *Congerina* species (a dweller of lagoons of the Tarkhanian Sea) were recorded in the Tarkhanian basin (Goncharova, 1989; Goncharova et al., 2001). Gastropods (according to incomplete data) were assigned to 54 species of 33 genera from 25 families (Iljina, 1993).

Early Tarkhanian. Bivalve mollusks of the Early Tarkhanian are represented by 67 species of 58 genera from 33 families. Gastropods are poorly studied and often poorly preserved. The bivalve mollusks were dominated by representatives of the polyhaline marine families Arcidae, Pectinidae, and Veneridae. Only two bivalve species, *Rzehakia dubiosa* and *Congeria nucleolus*, tolerant to low salinity, were inherited from the fauna of the shallow brackish-water zone of the preceding Kozakhurian basin. The other 65 bivalve species (97% of the total composition) and almost all gastropods are unknown in the Kozakhurian and its analogs. Only seven bivalve species (10%) (*Nuculana prendeli*, *Perna* (*Perna*) *tkvarcheliensis*, *Gregariella tarchanensis*, *Mactra bajarunasi*, *Macoma sokolovi*, *Gomphomarcia taurica*, and *Polititapes merklini*) are considered endemic, since they have not yet been found in neighboring basins. Neither endemic genera nor specific species were recorded at that time (Goncharova, 1989; Goncharova et al., 2001; Nevesskaya et al., 2005, p. 6, Table 3). The ratio of the number of species to the number of genera was 1.1 for bivalves and 1.6 for gastropods (for the entire Tarkhanian interval); i.e., the speciation was insignificant. Most of the bivalve species (58 of the 65 species) were of Mediterranean–Atlantic origin and common with the Badenian fauna of the Central Paratethys.

According to these calculations, the oyster beds of different regions of the Eastern Paratethys are rather conventionally assigned to the lower Tarkhanian, mainly based on their position in the sections and rzehakias, which are contained together with marine mollusks in these beds. They are known from Azerbaijan (“Melik–Kasum Horizon”), Georgia (the so-called “Gorian beds” with *Crassostrea gryphoides* and *Rzehakia dubiosa*), Kazakhstan (the eastern sections of Northern Ustyurt), and Turkmenistan (the southern part of the Krasnovodsk Plateau). Large oysters of the genus *Crassostrea*, *Arca noae*, *Barbatia barbata*, *Atrina* sp., *Isognomon rollei*, *Hinnites crispus*, *Pelecypora islandicoides*, and *Dosinia exoleta* and other dwellers of shallow waters were recorded only in these sandy facies. However, it should be noted that there is no consensus on the age of these oyster facies and their correlation with each other requires a detailed analysis using independent methods and data on other fauna and flora groups. Thus, the Tomakovka beds of Ukraine were previously considered in the Lower Tarkhanian; however, Vernigorova (2015) did not consider it possible to determine their exact position within this regional stage and correlates them with the undivided Tarkhanian. Ananiashvili (1985) dated the Georgian oyster beds to the Middle Tarkhanian based on analysis of mollusks, in which he indicated their abundance and denies the presence of the species *Lentipecten corneus denudatus* in the Lower Tarkhanian of Georgia.

Middle Tarkhanian. Fifty-nine marine bivalve species of 49 genera from 32 families and about 40 gastro-

pod species were identified the Middle Tarkhanian basin, which is lower than their number in the Early Tarkhanian. However, we believe that this information is only determined by the incompleteness of our data. Thus, the malacofauna of the Middle Tarkhanian in comparable relatively deep-water facies is richer than the Early Tarkhanian malacofauna, which has often been noted during previous discussions of certain sections and better corresponds to data on other groups of fauna and phytoplankton. In turn, the depletion of the taxonomic diversity is explained by the fact that facies of the most mollusk-rich shallow water areas with sandy facies are unknown for the Middle (and Upper) Tarkhanian (possibly, except Georgia, the section along the Apanta and Chkumi rivers, see Bagdasaryan, 1970).

In the Middle Tarkhanian, polyhaline families and genera continued to prevail (Goncharova, 1989; Il'ina, 1993) and the role of euryhaline marine families of bivalves (Mesodesmatidae, Cardiidae, Corbulidae, and Scrobiculariidae) also increased here. The fauna of the Middle Tarkhanian basin is generally inherited from the Early Tarkhanian basin (40 bivalve species, 68%). Eleven species (18%) came from the neighboring basins. The ratio of the number of species to the number of genera is 1.2 for bivalves, which indicates almost the same degree of speciation as that in the preceding basin.

Three endemic species—*Nuculana prendeli*, *Gregariella tarchanensis*, and *Mactra bajarunasi*—passed from the Early Tarkhanian basin (4%). One genus (*Davidaschvilia*) and seven bivalve species (14%) (*Acanthocardia centumpania*, *Parvicardium kubanicum*, *Europicardium pseudomulticostatum*, *Anadara bosphorana*, *Isognomon varnensis*, *Pteria mira*, and *Modiolus semirutus*), which are endemic to the Eastern Paratethys, formed here. The number of species endemic to the Eastern Paratethys is 11 (18%). Six species (10%) (*Mytilaster volhynicus*, *Musculus conditus*, *Isognomon radiatus*, *Parvicardium golubicense*, *P. scabrum*, and *Cultellus papyraceus*) were new endemics to the Paratethys and common to its western and eastern parts (Badenian and Tarkhanian).

Late Tarkhanian. In the Late Tarkhanian basin, we know 59 bivalve species of 47 genera from 32 families. Gastropods of this level are still insufficiently studied. The fauna of the basin is almost completely inherited from the preceding Middle Tarkhanian (54 species (91%) are common among bivalve mollusks). In the Late Tarkhanian basin, the role of euryhaline bivalve families increased, while the number of bivalve genera decreased. In addition to the above-listed Middle Tarkhanian taxa, Solenidae and Thyasiridae also became very important. The proportion of endemics of the Eastern Paratethys slightly increased (23%); the speciation index (ratio of the number of species to the number of genera) is 1.3 for bivalves. Endemic species became dominant in the communities. Four new spe-

cies endemic to the Eastern Paratethys—*Aequipecten praetrigonostoma*, *Cultellus probus*, *Cerastoderma bogatchevi*, and *Barnea ujraticum*—appeared. The latter is assumed to originate from an Indo-Pacific ancestor (Monari, 2009). One Mediterranean–Atlantic migrant, *Lembulus emarginata*, was recorded; it is characteristic of the mollusk assemblage of the Early Badenian (the upper lagenid zone with *Orbulina suturalis*, which Austrian scientists (Harzhauser et al., 2003; Hohenegger et al., 2014) date to the beginning of the Middle Badenian).

Correlation with the Central Paratethys. European colleagues (Rögl et al., 2002; Aeorie et al., 2004, etc.) established different ages of Karpatian deposits (as understood in the last century); at the same time, the name Karpatian was retained for its lower part, which was left in the Lower Miocene, while the upper younger part (Grund beds, Grund formation, lower lagenid zone) was assigned to the Middle Miocene and, accordingly, to the Lower Badenian.

The Tarkhanian bivalve assemblage is closer to Badenian mollusks of the Central Paratethys (Goncharova, 2001, Table 2) than to Karpatian ones with respect to its composition, even when the Karpatian is considered in its initial range (Karpatian, 2003). European researchers (Harzhauser et al., 2003) note two levels with mollusks in the Early Badenian. The first level is represented by mollusks of the lower lagenid zone from the Grund Formation (former Upper Karpatian), including the Grund locality (the Moravian stratotype). This level includes mollusks of the Gaindorf Formation of the Alpine Molasse Basin in north-eastern Austria (Mandič and Harzhauser, 2003; Harzhauser et al., 2003). The second younger assemblage of mollusks from the lower strata of the upper lagenid zone with *Orbulina suturalis* also includes the Baden–Soos locality (Rögl et al., 2007), Badenian stratotype.

Among these assemblages, the lower assemblage is more seaward and more warm-water. Its age (Early Badenian and Middle Langhian) is determined by the normal polarity of deposits correlated with the upper strata of chron C5Bn.2n, with an absolute age of 15.1 Ma, as well as by planktonic foraminifer zone M5 with *Praeorbulina glomerata circularis* and nannoplankton zone NN5 (Rögl et al., 2002). Ries-impact moldavites of the Grund Formation are dated to 14.8 Ma (Harzhauser et al., 2020, p. 189). The second, later, mollusk assemblage belongs to the lower part of the Upper Lagenid zone, *Orbulina suturalis* zone (Harzhauser et al., 2003), and corresponds to the upper strata of the Early Badenian and second half of Langhian.

The age of the Badenian localities for which the composition of mollusks was discussed in the work of B. Studencka et al. (1998) was revised by Austrian colleagues (Harzhauser et al., 2003). They assigned only the Lapudzhii and Kosteii localities (Romania) and

Malozhov locality (Poland) to the first Early Badenian level. The other five localities (Mikulov (Czech Republic), Steinabrunn (Austria), Varpalotta (Hungary), and Tarnene and Yasen (Bulgaria)) were considered younger and assigned to the second level.

Tarkhanian bivalves are less diverse than the Badenian ones, being only a third (34%) of the number of mollusks known from the Grund Formation, and slightly more than a third (40%) of the number of mollusks from the *Orbulina* zone (Grund mollusks are more numerous). This can be explained both by the greater depths that prevailed in the Tarkhanian basin than the depths in the Badenian basin and by its more limited relationships with neighboring water areas. The commonality of Tarkhanian mollusks with Badenian mollusks of both levels is about a quarter of common species (22 species (24%) with the lower Lagenid zone, *Praeorbulina glomerata circularis* zone) and 21 species (23%) with the upper (upper Lagenid zone, *Orbulina* zone). In addition, three species are common endemics with lower-level mollusks (*Isognomon radiatus*, *Parvicardium golubicense*, and *Cultellus papyraceus*) and two with the mollusk assemblage from the upper level (*Mytilaster volhynicus* and *Parvicardium scabrum*). One endemic, *Musculus conditus*, is common for all three communities. Nonetheless, with respect to mollusks, some preference can be given to the correlation of Tarkhanian with Grundian beds: similarly to the Tarkhanian, *Rzehakia* (Harzhauser et al., 2003), which inhabited the Central Paratethys since the Early Miocene, also disappears from here, *Hinnites crispus* (Mandič, 2004) and *Ervilia pusilla* are present here, and the tropical–subtropical families Isognomonidae and Pinnidae and genera *Pteria*, *Perna*, *Isognomon*, *Atrina*, *Limaria*, and *Chama* appear here (Goncharova et al., 2001), which indicates a climate optimum, also recorded in the biota of Grundian beds (Harzhauser et al., 2003). Interbeds with *Crasostrea*, more than 1 m thick, which are very characteristic of shallow-water Tarkhanian deposits, were also found in Grundian beds.

Chokrakian Regional Stage

Bivalve mollusks from the Chokrakian basin are less diverse than the Tarkhanian ones. Four families—Glycymeridae, Pinnidae, Trapeziidae, and Rzehakidae—did not pass to the Chokrakian. The number of genera and species decreased by about a quarter.

Early Chokrakian. The Early Chokrakian is represented by 71 bivalve species of 53 genera from 32 marine families (Goncharova, 1989; Studencka et al., 1998; Nevesskaya et al., 2005) and 85 gastropod species of 41 genera from 29 families (Il'ina, 2004). The role of euryhaline marine families of bivalve mollusks, such as Mytilidae, Mesodesmatidae, Donacidae, and Mactridae, increased.

The Chokrakian fauna was inherited mainly from Tarkhanian fauna. Fifty-three bivalve species (75%) and more than a third of gastropods were transient species. The index of speciation of bivalvians in the Early Chokrakian remained at the level of the Late Tarkhanian, being 1.3. A wide variability of species is very characteristic of this fauna.

The second group of Chokrakian mollusks is represented by migrants. These are nine bivalve species, which were recorded in the Early Tarkhanian and reentered the Eastern Paratethys in the Early Chokrakian or continued to live in the Tarkhanian in facies that were not preserved in the geological record (*Anadara diluvii*, *Perna* (*Perna*) *tkvarcheliensis*, *Cardites partschi*, *Irus irus*, *Circomphalus subplicatus*, *Gomphomarcia taurica*, *Pelecypora islandicoides*, *Lutraria lutraria*, and *L. sanna*). Five other bivalve species, namely, *Cubitostrea digitalina*, *Felaniella trigonula*, *Clausinella basteroti*, *Limaria* (*Limatulella*) *loscombii*, and *Dosinia* (*Asa*) *lupinus*, are new migrants that entered the Eastern Paratethys from neighboring seas. These Mediterranean–Atlantic species lived in the marine Badenian basin throughout its existence, except the latter two species, which were recorded only in the Late Badenian (Studencka et al., 1998). In addition to the European basins, five of the 14 migrant species were also recorded in the Middle Miocene fauna of the Eastern Mediterranean (in southeastern Anatolia (Erünal-Erentöz, 1958). Among Early Chokrakian gastropods, the new invaders to the Eastern Paratethys were most likely the species of *Skenea*, *Lacuna*, *Onoba*, *Pseudosetia*, *Rissoina*, *Jeffreysina*, *Potamides* (*Pirenella*), *Philbertia*, *Kleinella*, *Aclis* (*Murchisonella*), *Bacteridium*, and *Ringicula* (Il'ina, 2004). The species of some genera, which were clearly non-endemic and, at the same time, unknown outside the Paratethys, might originate from the insufficiently studied areas of the Eastern Mediterranean, Mesopotamia, and Indian Ocean (Iljina, 2004).

The third group of Chokrakian species was represented by endemics of the Eastern Paratethys (32%), of which 13% were species specific to the Chokrakian. These are the newly formed genus *Chokrakella* and eight bivalve species. The ancestors of six of these species (*Aequipecten varnensis*, *Pitar laskarevi*, *Chokrakella brykense*, *Ervilia praepodolica*, *E. megalodon*, and *Barnea praeustjurtensis*) can be found in the preceding Tarkhanian fauna (Bagdasaryan, 1965, 1970; Goncharova, 1989). The origin of three other species (*Donax* (*Paradonax*) *tarchanensis*, *D. (P.) bajaranasi*, and *Angulus fuchsi*) is not yet clear. The undoubted autochthonous endemics among gastropods were species of the genera *Gibbula* (six species), *Mohrensternia* (two species), and *Nassarius* (four species).

Comparison of the species composition of the Badenian and Chokrakian faunas shows the presence of 22 bivalve species common with the Lower Early Badenian assemblage and 25 bivalve species common

with the Upper Early Badenian (*Orbulina suturalis* zone). However, the vast majority of them were inherited from the Tarkhanian basin, which was widely connected to the Central Paratethys (Nevesskaya et al., 1986; Goncharova, 1989; Goncharova et al., 2002; Iljina, 2004). No new endemic common to the Eastern and Central Paratethys was recorded for this time, except the estuarine species *Congerina sandbergeri*.

The biogeographical distribution of the other species that inhabited the Eastern Paratethys in the Early Chokrakian suggests that there was no communication between the Eastern and Central Paratethys at that time. In turn, the finds of Middle Miocene Mediterranean–Atlantic species (*Limaria* (*Limatulella*) *loscombii* and *Dosinia* (*Asa*) *lupinus*) in the Early Chokrakian, which appeared in the Central Paratethys only in the Late Badenian (Studencka et al., 1998), may indicate a direct faunistic exchange with the Eastern Mediterranean bypassing the Central Paratethys.

Both the diversity and proportion of migrants significantly increased from northwest to southeast: no migrants were found in Bulgaria, two migrants were found in Turkey and the Kerch sections, four migrants in Ciscaucasian sections, three migrants in Georgia, and nine migrants are known from Transcaspiia. Data on gastropods (Iljina, 2004) also indicate the possible direct faunal exchange with the Eastern Mediterranean bypassing the Western Paratethys.

Late Chokrakian. The Late Chokrakian assemblages included only six euryhaline bivalve species: *Davidaschvilia intermedia*, *Ervilia praepodolica*, *Donax* (*Paradonax*) *tarchanensis*, *Abra parabilis*, *Barnea praeustjurtensis*, and *B. ujrata*. The first three species inhabited the shallow water areas of the entire basin, with *Donax* (*P.*) *tarchanensis* being more abundant in Georgia and Transcaspiia and *Abra parabilis* being characteristic of deep waters.

The boundary of the Chokrakian and Karaganian regional stages. In shallow-water facies, a sedimentation break is usually confined to this transition and a transgressive occurrence of Karaganian deposits is observed. The intermediate zone has interbeds of conglomerates, sometimes containing terrestrial mollusks (Belaya River section), as well as an outwash of the Chokrakian fauna in the basal beds of the Karaganian at this level, which also indicates a noticeable fall of sea level at this boundary.

In deeper continuous sections, the boundary Chokrakian–Karaganian deposits, even if they are characterized by malacofauna, are dated based on mollusks with great difficulty and only roughly due to a very gradual transition from small Late Chokrakian *Davidaschvilia intermedia* to larger thick-walled *Davidaschvilia* (*Zhgentiana*) *gentilis*, characteristic of the Karaganian.

Karaganian Regional Stage

Early Karaganian. The composition of mollusks in the lower (Arkhashen) beds of the Karaganian is extremely poor and most often contains only one or two species [*Davidaschvilia* (*Zhgentiana*) *gentilis* and *Mohrensternia grandis*, Fig. 18].

The taxonomy of the first form requires explanations. Until recently, this species was usually used with the generic name *Spaniodontella*, including our works (Neveeskaya et al., 1986, 1993). Since the genus *Spaniodontella* is the younger synonym of the genus *Alveinus* Conrad, 1865 (as was established by a number of researchers (Glibert and van de Poel, 1966; Zhgenti, 1976b)), we accept the new name *Zhgentiana* for this genus (in the rank of subgenus), which was proposed by European colleagues (Janssen et al., 2015). At the same time, we do not share the opinion of the latter authors on the assignment of *Davidaschvilia intermedia* and *Zhgentiana gentilis* to different families (since we observe a gradual transition from the first species to the second) and leave both of them in the family Lutetiidae (Goncharova, 2019).

Davidaschvilia (*D.*) *intermedia*, one of the few forms widely developed in the closed Late Chokrakian basin, was characterized by a wide variability, including the variability of the cardinal teeth. This intrapopulation variability eventually turned into the directed variability, and forms with a strongly reduced λ -shaped tooth (the former 3a and 3b) close to massive triangular–pyramidal central tooth 1 in the right valve began to predominate by the beginning of the Karaganian. In the left valve, teeth 2a and 2b completely joined and the thickness and length of the posterior branch of this hammer-shaped tooth (former 2b) exceeded those of the anterior branch (former tooth 2a), sometimes more than twice (Zhgenti, 1976a, 1999). This was accompanied by a simultaneous sharp increase in the size and thickness of mollusk shells. This resulted in the formation of a new endemic subgenus, *Davidaschvilia* (*Zhgentiana*), represented by a widespread and extremely variable species, *D.* (*Zh.*) *gentilis*, in the Early Karaganian basin.

Separate variants of variability of this species were quite often distinguished as independent species (*opistodon*, *tapesoides*, and *umbonata*); at the same time, a number of researchers pointed to the presence of transitional forms between these “species” (Osipov, 1932; Zhgenti, 1976b). This species colonized almost all grounds of the Early Karaganian basin except deep water areas. The species *D.* (*Zh.*) *ersaconensis* (Ciscaucasia) had a more local distribution. A new genus, *Savanella*, represented by the species *S. andrussovi*, was formed at the end of the Early Karaganian, apparently from *D.* (*Zh.*) *gentilis* (from the umbonata morph, according to Kojumdgieva, 1965); this genus was characterized by an even greater reduction of some cardinal elements. The cardinal area was almost completely reduced; in the right valve, the upper tooth

(3a and 3b) is small and has the shape of a brim and the lower tooth is massive and merges with the cardinal area. In the left valve, the difference in the size of cardinal teeth became even greater. The shell is high and has a protruding beak and a sharp concentric ornamentation (Zhgenti, 1999; Neveeskaya et al., 1986).

Beds with this abundant but extremely uniform fauna are usually significantly thick and correspond to the interval of 13.8–13.4 Ma in Zelensky sections (Taman Peninsula) and on the Belaya River, according to paleomagnetic data. Rare barneans, which are indeterminate to the species level, appear in the upper part of the lower beds.

Late Karaganian. The upper (Varna) substage of the Karaganian is marked by the appearance of the genus *Savanella* (*S. andrussovi*). This genus had a very limited temporal distribution and was typical only for the Late Karaganian, when it spread throughout the basin. *Davidaschvilia* (*Zhgentiana*) *gentilis*, *Mohrensternia grandis*, and rare barneans, including *Barnea ustjurtensis*, also continued to occur here.

Zhgentians probably also pass into the overlying Kartvelian (Barnean) beds and continue to occur in their basal part. This can be judged from the finds of paired valves at the base of the Kartvelian in the Belaya River section. It remains unclear whether savanellas pass to Kartvelian beds or not. They are quite common there, in particular, at the base, but they sometimes differ in the level of preservation and are redeposited. In other cases, this is not so evident.

Konkian Regional Stage

Kartvelian beds. Numerous *Ervilia trigonula* and species of the genus *Barnea* usually appear from the base of Kartvelian beds; sometimes, a rather diverse assemblage of marine mollusks, close to Sartaganian, also sometimes appear from the base of these beds. The richest assemblage of mollusks at this level was collected by R.L. Merklin from a section of the Ashchikhtai-pak area on the northern cliff of the Ustyurt Plateau, where *Anadara turonica*, *Anomia epippium*, *Aequipecten malviniae*, *Cerastoderma praeaplicatum*, *Loripes dentatus*, *Acanthocardia turonica*, *Ervilia pusilla trigonula*, *Gastrana fragilis*, *Varicorbula gibba*, *Callista* sp., *Neovenerella ustjurtensis*, *Gafrarium eximium*, *Eastonia rugosa*, and *Barnea ujraticamica*. *Callista italica*, *Gastrana fragilis*, *Modiolus* sp., cardiids, *Nassarius*, and moon snails were found in sections of southern Ustyurt and Tuarkyr at the base of Barnean beds (Eberzin, 1960; Sudo, 1961). *Callista italica*, *Pelecypora* (*Cordiopsis*) *islandicoides*, moon snails, and *Pirenella* (Bidzinashvili, 1974) were described from Georgia (Prone River, Kartli); *Nassarius dujardini* was found on the Belaya River in Ciscaucasia. It is important to note that not only marine species of wide geographical distribution, but also Konkian–Sarmatian endemics of the Eastern Paratethys (*Cerastoderma praeaplicatum*

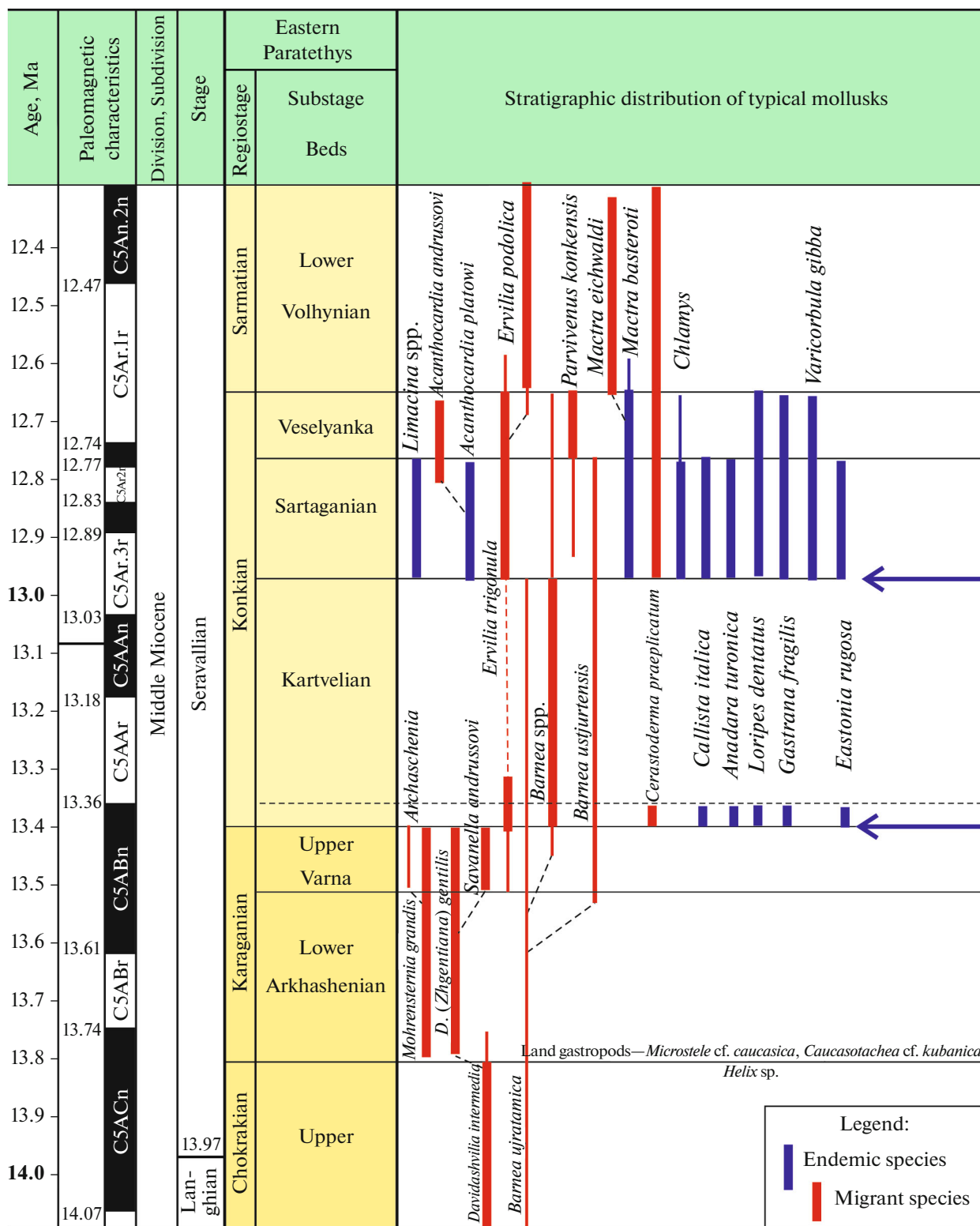


Fig. 18. Distribution of the most important and common mollusk species in the Upper Chokrakian, Karaganian, and Konkian deposits of the Eastern Paratethys.

and *Neovenerella ustjurtensis*) appear at this level for the first time.

Above this level, only barneas and, less often, ervilias occur in all studied sections, which indicates a new disturbance of the hydrological regime and stress conditions, at least in shallow water, which lasted until the second half of the Konkian time (up to about 13.0 Ma according to paleomagnetic data in Palcu et al., 2017).

Sartaganian beds. In the Sartaganian, the mollusk community becomes much richer again based on species common with the Badenian and Mediterranean fauna. The mollusk fauna of the Sartaganian includes not less than 75 bivalve species and 70 gastropod species (Iljina, 1993; Studencka et al., 1998; Popov et al., 2005); however, it is quite possible that data on the biodiversity of this fauna are still incomplete. About 40 species of them were fairly polyhaline. These are *Arca noae*, *Barbatia barbata*, *Aequipecten* ex gr. *malviniae*, *Atrina pectinata*, *Divalinga ornata*, *Carditamera auingeri*, *Glossus cor*, *Venus tauroverrucosa*, *Gafrarium eximium*, *Clausinella basteroti*, *Callista italica*, *Eastonia rugosa*, *Arcopagia crassa*, *Gibbula buchi*, *Diloma orientalis*, turitellids, *Alvania montagu*, etc. Only five bivalve species were endemic to the Eastern Paratethys and four barnean species (*B. kubanica*, *B. pseudoustjurtensis*, *B. scrinia*, and *B. ujraticum*) were Karaganian relicts, and *Neovenerella ustjurtensis* is a species that appeared here again. One species, *Gomphomarcia secunda*, is endemic to the Paratethys and common for the Sartaganian and Late Badenian.

Seven of the 70 gastropod species (*Gibbula sima*, *Pseudosetia eichwaldi*, *Obolus hydrobioides*, *Bittium amitrovi*, *Ceritium gilyandense*, *Dorsanum neutrum*, and *Odostomia nuda*) were endemic. The presence of representatives of the genera *Strombus*, *Zonaria*, and *Conus* (albeit single ones) in the fauna of Georgia indicates very warm-water and polyhaline conditions of the sea (data of Iljina in Popov et al., 2005).

Veselyanka beds. The change of the hydrological regime of the Late Konkian (Veselyanka) Sea resulted in the disappearance of many polyhaline species and spread of euryhaline mollusks throughout the Eastern Paratethys, which played only a subordinate role (if they were ever present in the Early Konkian and Badenian seas), being displaced into freshened areas. The composition of marine mollusks became much poorer in Veselyanka beds. At that time, endemic species, such as *Parvivenus konkensis*, *Acanthocardia andrussovi*, *Parvicardium scyoticum*, *Donax dentiger*, *Macra basteroti konkensis*, *Abra reflexa*, and *Dorsanum neutrum*, also appeared or spread widely throughout the water body (Popov et al., 2005).

Boundary of the Konkian and Sarmatian stages. In most of the sections of the shallow water zone, the base of the Sarmatian lies onto the underlying deposits with erosion; therefore, the continuous transition is rarely observed. It can probably be traced in sections near the Dubrovaya Hill (Zhgenti, 1991; Goncharova

and Golovina, 2007). Here, *Ervilia trigonula*, *Donax dentiger*, *Mytilaster volhynicus buglovensis*, *Macra basteroti*, and *Poittapes vitaliana* are dominant in sands under Lower Sarmatian deposits; *Cerastoderma praeplicatus*, *Obsoletiformes obsoletus*, *Varicorbula gibba*, *Barnea praeustjurtensis*, *B. ?ustjurtensis*, *Alveinus* cf. *nitidus*, *Ervilia pusilla*, and *Gomphomarcia secunda* occur sporadically. Among Sarmatian elements, single *Plicatiformes plicata* were recorded. The presence of *Mytilaster volhynicus buglovensis*, *Macra basteroti*, *Alveinus* cf. *nitidus*, and *Barnea* sp. determines the age of these deposits most likely as Konkian. Judging from the good preservation of fragile *Macra* and *Alveinus* shells, it is unlikely that they were washed out and redeposited. In addition to the depletion of the assemblage, dominance of euryhaline species, and decrease in the size and thickness of *Macra basteroti* valves, unstable conditions during the transition to the Sarmatian are also evidenced by a significant variability of *Ervilia trigonula*, whose shell size increased during its transition to the Sarmatian *E. dissita*.

Approximately the same assemblage of bivalves was recorded in sections of the Chekist quarry, in Vorovskoleskaya settlement, the core of the Belomechet syncline, in ravines on the right bank of the Belaya River near the settlement of Tulsy (Goncharova and Golovina, 2007), and on the Kuzhora River. Thin-walled *Macra basteroti* and *Alveinus nitidus* are also sharply dominant here; *Ervilia trigonula* also occurs here. *Gomphomarcia secunda*, *Ervilia pusilla*, *E. dissita*, and *E. trigonula* sometimes occur in sections of the Podvesnaya and Chumnaya gullies.

The possible new appearance of marine fauna in the uppermost strata of the Konkian in Ciscaucasia is indicated by finds of *Gomphomarcia secunda* shells (Goncharova and Golovina, 2007) together with gastropods of the genera *Natica* and *Turritella* (Il'ina, 2000a, 2000b). It should be noted that *G. secunda* is not established below in the Veselyanka section. As suggested by Iljina (2000b), this invasion may correspond to the level with marine species in the section near the city of Novocherkassk (Bogachev, 1905), from which *G. secunda* was first described, and to the upper strata of the Veselyanka beds in Georgia in a section near the village of Nasperi (Bidzinashvili, 1974). Zhgenti (1991) called this interval the Dubrov substage.

At the same time, it is difficult to rule out the redeposition of mollusks in sandy facies. Thus, fragments and single shells of *Acanthocardia* sp., *Chlamys* sp., *Varicorbula gibba*, *Loripes dentatus*, *Barnea* sp., and *Apporhais alatus* were found in a section on the Kuzhora River in the right slope of the Vertepka gully, also in transitional beds from the Konkian to the Sarmatian, with macras and ervilians being sharply dominant (based on our collections and determinations). *Cardita calyculata* and *Anadara* sp. were found in old collections at this level. Konkian species (*Natica mil-*

lepunctata and *Turritella pythagoraica*) were also found again at this section, 25 m above these finds, at the level above the appearance of typical Sarmatian cardids, with *Macra*, *Gibbula*, and *Ervilia* (which are common for the Sarmatian) being still sharply dominant. Undoubtedly, these are not lifetime assemblages; however, it is not always possible to differentiate synchronously redeposited forms from those which were washed over from the underlying beds by the degree of preservation.

Sarmatian Regional Stage

Mollusks in the Sarmatian were dominated by representatives of marine euryhaline families: Cardiidae, Mactridae, Veneridae, Mesodesmatidae, and Scrobiculariidae among bivalve mollusks (Kolesnikov, 1935; Iljina et al., 1976; Paramonova, 1994). Gastropods were dominated by Trochidae, Rissoidae, and Nassariidae (Kolesnikov, 1935; Kojumdzieva, 1969; Iljina, 1998, etc.). The total number of marine bivalves of the Sarmatian was about 110 species of 20 genera from 13 families. About 120 species of 23 genera from 17 families are known among marine gastropods. Brackish-water forms were rare, represented by only seven known species (*Congerina*, *Neritina pictus*, *Brotia*, etc.). An accelerated speciation occurred in the Early Middle Sarmatian basin, resulting in the appearance of new genera. The Late Sarmatian reservoir was even more desalinated and almost completely enclosed and its malacofauna was extremely depleted.

Early Sarmatian. The Early Sarmatian malacofauna had a much more depleted family and generic composition than the preceding Konkian–Badenian and was characterized by a greater endemism. In total, representatives of 45 bivalve species of 21 genera from 13 families and more than 75 gastropod species of 25 genera from 18 families lived in the Early Sarmatian Eastern Paratethys (Popov et al., 2005). Twenty-six endemic bivalve species and 50 gastropod species were recorded in the Early Sarmatian; endemic genera *Cryptomactra*, *Planacardium*, and *Sinzowia* originated during this period, which reached their main flowering in the Middle Sarmatian.

In terms of the origin, the Early Sarmatian mollusks included both individuals that passed from the Konkian basin and those which appeared in the Sarmatian reservoir itself. The first group included 20 bivalve species of 19 genera and 11 gastropod species of nine genera. The group of invaders can be subdivided into Mediterranean species and species that appeared in the earlier basins of the Paratethys. The former include nine bivalve species of eight genera and four gastropod species of four genera. Among them, cardids, mytilids, *Macra eichwaldi*, *Abra reflexa*, and *Donax dentiger* spread widely in the Early Sarmatian basin and gave rise to many endemic species. The proportion of endemic species was about 40% of bivalves

and not less than 80% of gastropods. The ratio of the number of species to the number of genera is 2.1.

Middle Sarmatian. In total, representatives of 78 marine bivalve species of 17 genera from 11 families and not less than 75 gastropod species of 10 genera from eight families lived in the Middle Sarmatian basin. Thirty bivalve species and about 50 gastropod species passed from the Early Sarmatian basin; 48 bivalve species and more than 40 gastropod species appeared (Popov et al., 2005). Brackish-water species remained rare. The Middle Sarmatian malacofauna is richer than the Early Sarmatian one. Its composition was replenished with new endemic taxa: the genera *Avicardium* and *Kubanocardium* and species of the genera *Obsoletiformes*, *Macra*, and *Politiitapes* among bivalves; genus *Barbotella* and species of the genera *Gibbula*, *Dorsanum*, *Hydrobia*, and *Mohrensternia* among gastropods. About 60% of new endemic species appeared among Trochidae and over 65% among Nassariidae.

Compared to the species composition, the family and generic composition was even more depleted than that for the Early Sarmatian. Four genera (24%) were endemic among bivalves and two genera among gastropods (20%). The percentage of endemic species was 24 for bivalves and about 90 for gastropods.

Late Sarmatian. The malacofauna of the Late Sarmatian basin, which had an unstable salinity with a high deviation from the normal level, was extremely depleted. Bivalves were represented by only eight endemic species of three genera from two families. There were almost no gastropods except exotic finds of the genus *Pirenella* (Iljina, 1998).

Maeotian Regional Stage

The beginning of the Maeotian Age was marked by the appearance of euryhaline malacofauna of Mediterranean origin. In total, marine bivalve mollusks were represented by 14 species of 12 genera from eight families. Marine gastropods included 38 species of 22 genera from 14 families. Only about half of species were common with the Miocene Mediterranean: seven of the 14 bivalve species and 11 of the 18 gastropod species. Among them, three bivalve species and four gastropod species were endemic subspecies (Popov et al., 2005).

Early Maeotian. There were few true endemics that appeared in the Early Maeotian basin. Among them are *Coelacanthia quadrispinosa* and *Rissoa subangulata*. In the second half of the Early Maeotian, fairly polyhaline species (*Rissoa ventricosa*, *Alvania montagui*, *Gibberula philippii*, and *Ruditapes decussatus*) entered the Maeotian basin as a result of the expansion of communication with open waters; however, they did not become widespread here. The percentage of endemic species was about 50 for bivalves and about 45 for gastropods. One gastropod genus (*Coelacanthia*)

was endemic. The ratio of the number of species to the number of genera was 1.2 for bivalves and 1.5 for gastropods; i.e., the speciation was insignificant (Popov et al., 2005).

Late Maeotian. The Late Maeotian reservoir was dominated by species of the brackish-water genus *Congeria* among bivalves and *Theodoxus*, *Caspihydrobia*, *Turricaspia*, and *Pseudamnicola* among gastropods. Most of them originated from species that lived in the Early Maeotian sea. Marine species (*Macra superstes*, *Thracia* cf. *papyracea*, and *Sphaeronassa mutabilis andrusovi*, according to Popov et al., 2016) were exotic, rare, and represented by single specimens. The Maeotian basin had no direct communications with the Pannonian, although some species of brackish–freshwater gastropods were common, which probably spread in the rivers.

Pontian Regional Stage

Most Pontian bivalves are represented by new species of the endemic brackish-water genera *Pseudocatillus*, *Paradacna*, *Pontalmyra*, *Eupatorina*, *Euxinocardium*, and *Prosodachnomya*, which were alien to the Maeotian fauna. The latter three of them were not recorded in the Pannonian basin but are known from the Late Messinian closed Aegean basin (Popov and Nevesskaya, 2000). Only a small part of malacofauna consisted of species that passed from the preceding Maeotian basin (two species of *Congeria*, *Dreissena*, and *Abra*).

Early Pontian. The taxonomic composition of the molluscan assemblage was depleted at the very beginning of the Pontian. Bivalves were dominated by brackish-water genera *Eupatorina* and *Pseudocatillus* and a little later by *Euxinocardium*, *Paradacna*, *Congeria*, and *Dreissena*. Of euryhaline marine mollusks, *Parvivenus widhalmi* and rare *Abra tellinoides* are present. Gastropods included representatives of the genera *Valenciennius*, *Viviparus*, *Theodoxus*, *Melanopsis*, “*Hydrobia*”, *Lithoglyphus*, *Turricaspia*, and some others (works by Eberzin, 1947, 1967, etc.; Taktakishvili, 1987; Pontien, 1989, etc.; for more details, see Nevesskaya et al., 1997). In total, there were 27 species of 12 genera from three families among the bivalves. The ratio of the number of species to the number of genera is 2.3; i.e., the speciation was quite intensive. No new genera appeared in the Early Pontian Eastern Paratethys.

There were few species common with the fauna of the Late Pannonian reservoir: only one species, *Paradacna abichi*, for the Euxinic, Caspian, and Aegean basins. Five common species were recorded only for the Dacian basin immediately adjacent to the Pannonian basin. The similarity of the malacofauna of the Dacian, Euxinic, and Caspian basins was very great. Thus, only two endemic species were recorded among lymnocyprids in the Dacian basin, four endemic species in the Euxinic basin, and one endemic species in

the Caspian basin; in addition, these species are usually not abundant.

Late Pontian. At the beginning of the Late Pontian period (Andrusov’s *Congeria subrhomboidea* Beds), the difference between the bivalve assemblages from the Eastern Paratethys and Pannonian basin was smoothed out as a result of the penetration of Pannonian forms (*Phyllocardium*, *Plagiodacna*, *Arpadicardium*, and *Bosphoricardium*); at the same time, differences were still preserved at the species level (Nevesskaya et al., 2001). Several other new genera appeared in the Eastern Paratethys (*Chartoconcha*, *Prosodacna*, and some others). Among gastropods, the generic composition did not change.

In total, representatives of 72 bivalve species of 21 genera from the families Cardiidae and Dreissenidae lived in the Late Pontian basin. The ratio of the number of species to the number of genera was 3.4. The differences in bivalve assemblages also increased in different parts of the Eastern Paratethys (Nevesskaya et al., 2001): in the Dacian basin, half of 70–75 lymnocyprid species are endemic forms (30–35) and only 26 species were common with the Euxinic basin (Papaianopol, 1992, 1995). In the Euxinic Basin, 12 of the 43 species were endemic; however, it is quite possible that these differences may also be determined by the use of different approaches to species identification.

The Caspian basin, which actually already became isolated at the beginning of the Late Pontian, was characterized by a depleted generic and species composition of bivalves. Four lymnocyprid genera lived here (among them, the genera *Nargicardium* and *Schirvanicardium* were endemic) and two dreissenid genera (17 of the 22 species were endemic).

Kimmerian Regional Stage

Mollusks that lived in the Dacian and Euxinic basins were genetically related to Pontian forms, and the Caspian basin became a closed freshwater reservoir, where brackish-water forms became extinct. In the former basins, species belonging to the families Cardiidae (Lymnocypridae) and Dreissenidae continued to prevail among bivalves. In the Kimmerian basin, lymnocyprids were very diverse and numerous. Among dreissenids, species of the genera *Dreissenomya* lived here (Eberzin, 1931, 1947, 1960, 1967; Taktakishvili, 1987, etc.; for more details, see Nevesskaya et al., 1997).

Seven genera and one subgenus (*Moquicardium*, *Limnodacna*, *Stenodacna*, *Macradacna*, *Oxydacna*, *Prionopleura*, *Panticapaea*, and *Pachydacna* s. str.) and 89 species appeared in the Kimmerian basin (Nevesskaya et al., 1986, 1997). The Kamysh-Burun (Early Late Kimmerian) malacofauna was characterized by a large size of many bivalve species from the genera *Pontalmyra*, *Macradacna*, *Prionopleura*, *Pteradacna*, and

Prosodacna. In total, representatives of 119 bivalve species from 27 genera lived in the Kimmerian reservoir. The percentage of lymnocardiin genera and species specific only to the Kimmerian was 29 and 60.5% in the basin and that of endemic genera and species was 37 and 81%, respectively.

Both the descendants of Pontian species of the genera *Prosodacna*, *Plagiodacna*, *Pseudocatillus*, *Euxinocardium*, and some others and, probably, those from the Kimmerian basin (*Limnodacna*) lived in the Dacian basin, which existed simultaneously with the Kimmerian basin and was located in a trough before the front of the Southern Carpathians. Species of the genera *Prosodacnomya*, *Prosodacna*, *Zamphiridacna*, *Psilodon*, *Horiodacna*, *Plagiodacna*, *Pachydacna* (*Parapachydacna*), *Pseudocatillus*, *Euxinocardium*, *Dacicardium*, and *Limnodacna* prevailed here. Along with cardiids, dreissenids (*Dreissena*) also lived in this basin (Papaianopol, 1992, 1995, etc.). Three genera (*Zamphiridacna*, *Horiodacna*, and *Ecericardium*) appeared here. In total, 54 bivalve species from 19 genera inhabited the Dacian basin.

Among gastropods, species of the brackish-water genera *Valenciennius*, *Melanopsis*, *Viviparus*, *Melanoides*, *Theodoxus*, *Lithoglyphus*, and *Zagrabica*, which are genetically related to Pontian species, were recorded both in the Dacian and Kimmerian reservoirs (data of Iljina in *Neogenovaya sistema*, 1986; Papaianopol, 1995). All the Kimmerian and Dacian species belonged to brackish-water genera; marine forms were completely absent. The ratio of the number of bivalve species to the number of genera is 4.4 for the Kimmerian basin and 3.5 for the Dacian basin; i.e., the speciation was very intensive.

Akchagylian Regional Stage

The brackish-water Kuyalnikian basin with fauna inherited from Kimmerian forms continued to exist in the Euxinic area. In the Caspian area, a sharp pre-Akchagylian regression and the formation of the freshwater Balakhanian water body led to a transgression, which resulted in the appearance of a huge semimarine Akchagylian basin, inhabited by euryhaline mollusks of marine origin.

Akchagylian. After the onset of transgression, few mollusks entered the basin: one species from each of the genera *Cerastoderma*, *Aktschagylia* (Mactridae), and "*Clessiniola*" from gastropods. Five genera of the subfamily Lymnocardiinae descended from the first of these genera: *Raricardium*, *Acobaecardium*, *Andrusoviacardium*, *Avicardium*, and *Miricardium*; mactrids gave rise to four endemic genera: *Kirghizella*, *Andrussella*, *Avimactra*, and *Caspiomactra*. The total number of species is more than 54. Brackish-water bivalve mollusks were represented by the genus *Dreissena* (Paramonova, 1994; Danukalova, 1996; Nevesskaya et al., 1997).

Among gastropods, species of the genera *Potamides* (*Pirenella*) (a marine euryhaline form) and brackish-water *Turricaspia*, *Micromelania*, and *Caspia* lived at the beginning of the Akchagylian and *Pyrgula* and the endemic genus *Avardaria* also appeared here from the middle of Akchagylian; *Theodoxus*, *Valvata*, *Viviparus*, etc., lived in desalinated areas. In total, 11 genera from nine families were recorded among gastropods (Il'ina in *Neogenovaya sistema*, 1986; Nevesskaya et al., 1986).

The short-term regression in the middle of the Akchagylian was followed by a maximum transgression. At that time, there was an outbreak of speciation and new cardiid and mactrid genera appeared. The richest and most diverse mollusk assemblages were recorded in Azerbaijan and western Turkmenistan. The percentage of endemic and specific genera is 85; the proportion of endemic species in the total number of species is 98%; the ratio of the number of species to the number of genera is 4.2; i.e., the speciation was very intensive. Ten genera and 53 species appeared throughout the Akchagylian time (1.7 Ma).

The composition of mollusks was poor in desalinated northern areas: a few species of *Dreissena*, *Cerastoderma*, and *Aktschagylia* were dominant here; these species were also able to penetrate into the Azov-Black Sea Bay.

Kuyalnikian. In total, 42 brackish-water bivalve species of 18 genera from two families are known from the Kuyalnikian reservoir (Nevesskaya et al., 1997). The richest assemblages of mollusks were encountered in western Georgia. The composition of bivalves was much poorer in the more northern areas: here, few species of the genera *Pseudocatillus*, *Pachydacna*, *Euxinocardium*, *Dreissena*, and *Unio* prevailed among lymnocardiins and lagoon species. About 60% of the genera were endemic to the Eastern Paratethys. No new genera appeared, and the number of newly formed species was 17. All the lymnocardiin species were endemic to the Eastern Paratethys; 36% of species were specific to the Kuyalnikian and the other species were found in the Kimmerian. The ratio of the number of species to the number of genera is 2.8.

The composition of gastropods was the same as that in the preceding Kimmerian basin; the new species included only freshwater ones of the genera *Valvata*, *Planorbis*, and *Planorbarius*, which indicates a further decrease in salinity.

Some of the genera were extinct in the second half of the existence of the Kuyalnikian reservoir; representatives of *Euxinocardium*, *Ecericardium*, *Moquicardium*, *Pachydacna*, *Pontalmyra*, *Pseudocatillus*, *Charutoconcha*, and *Prosodacna* survived.

Ichthyofauna

A. F. Bannikov

The ichthyofaunal assemblages of the Eastern Paratethys were generally buried at considerable depths in facies of the open sea with hydrogen sulfide contamination of bottom layers, where sediment bioturbation was absent. Therefore, the cooccurrence of fish remains and benthic fauna is extremely rare.

Upper Maikopian

A rich and rather diverse assemblage of marine fishes was found in the Upper Maikopian of the Caucasus and Crimea. Late Maikopian fishes were found in a number of localities in the North Caucasus and Azerbaijan; however, the most representative collections were taken from four localities (Bannikov, 2010): in an outcrop to the west of Cape Tarkhan on the northern coast of the Kerch Peninsula; on the left side of the ravine on the left bank of the Pshekha River, 1.5 km southwest of Shirvanskaya settlement (Krasnodar Region); on the Chernaya River near the city of Vladikavkaz (Republic of North Ossetia–Alania); and on the bank of the Sumgait River near the village of Perekishkyul and on the slopes of the Islamdag Hill (northern Azerbaijan). Although exact stratigraphic data on these localities are not yet available, most of them are presumably dated to the Sakaraulian; in Azerbaijan, they may also be dated to the Caucasian (see above). The fish assemblage differs in different localities (for instance, *Bregmacerina antiqua* was found only in two Northern Caucasian localities, while *Priacanthus longispinus* is, on the contrary, abundant in the Crimea and Azerbaijan, but was not found to date in the North Caucasus); however, the general features of the assemblage are the same. Some differences in the composition of Late Maikopian fish assemblages from different localities led to the assumption that they were of different ages and attempts to date them to the Upper Caucasian (Bannikov, 1985) (or Aquitanian: Popov et al., 2004a; Sytchevskaya, 2005) and Sakaraulian (Bannikov, 1985) (or Burdigalian: Popov et al., 2004a; Sytchevskaya, 2005), respectively. However, taking into account the dominance of common forms, it is more logical to assume that they are of the same age, namely, of the Sakaraulian age (Bannikov, 1990, 2010), and explain the differences in the composition of assemblages by their different facial confinement.

On the whole, the Late Maikopian assemblage has the following composition (Bannikov and Parin, 1997; Bannikov, 2010): *Maicopiella brevicauda*, *Pomolobus antiquus*, *Alosa genuina*, *Glossanodon adolescens*, *Merluccius lednevi*, *M. errans*, *Palaeomolva smirnovi*, *P. monstrata*, *Bregmacerina antiqua*, *Onobrosmius sagus*, *O. parvus*, *O. oligocaenicus*, *Lophius* sp., “*Belone*” *crior*, *Holocentridae* gen. et sp. indet., *Aeoliscus apscheronicus*, *Aulostomus fractus*, *Syngnathus*

altus, *Nerophis gracilis*, *Priacanthus longispinus*, *Lednevia oligocenica*, *Echeneis urupensis*, *Seriola* sp., *S. smithvanizi*, *Scomberoides spinosus*, *Selar fedotovi*, *Alepes pin*, *Caranx quietus*, *Decapterus praegracilis*, *D. fusiformis*, *Leiognathoides minutus*, “*Sparus*” sp., *Spicara islamdagica*, *Caucasisciaena ignota*, *Mugil latus*, “*Blennius*” sp., *Bestiolablennius eugeniae*, *Gobiidae* gen. et sp. indet., *Caprovesposus* sp., *Gempylidae*: gen. et sp. indet., *Hemithysites maicopicus*, *Anenchelium lednevi*, *Scomber gnarus*, *Sarda memorabilis*, *Pinichthys fractus*, *Arnoglossus distinctus*, and *Buglossidium apsheronkiense*.

In addition, very rare teeth of the shark *Carcharias cuspidata* are known from the Upper Maikopian of the Caucasus and Crimea (identified by T.P. Malyshkina). With respect to the number of finds, the ichthyofauna is generally dominated by herrings (*Maicopiella brevicauda*), hakes (*Merluccius errans*), bluefishes (*Lednevia oligocenica*), and mackerels (*Scomber gnarus*). The localities of Late Maikopian fishes differ in the systematic composition and relative number of finds of different species and were definitely formed in different environments. The Chernaya River in North Ossetia, Urup River in Krasnodar Region, and Cape Tarkhan (upper beds of the *Bathysiphon* Formation) in the Crimea, dominated by Syngnathiformes (*Aeoliscus apscheronicus* and *Syngnathus altus*), are localities with pronounced coastal–shallow-water facies. Other localities, such as Shirvanskaya in Krasnodar Region and Cape Tarkhan (the lower beds of the *Bathysiphon* Formation), are characterized by the almost complete absence of coastal shallow-water forms; pelagic Clupeidae, Merlucciidae, Gadidae, Pomatomidae, and Scombridae are dominant there. Therefore, a local regression of the basin is observed in the outcrop at Cape Tarkhan, which confirms the general regressiveness of the Sakaraulian basin of the Eastern Paratethys (Popov et al., 1993b). The composition of the fish fauna indicates a nearly-tropical climate in the Late Maikopian (the presence of the genus *Aeoliscus*). Most of the fishes are definitely pelagic; however, benthic blennies (Blenniidae) and gobies (Gobiidae) appear for the first time in the Eastern Paratethys in Sakaraulian fauna; flatfishes (Bothidae and Soleidae) become relatively abundant; however, they are generally represented by pelagic larvae, similarly to the coral surgeon fish *Caprovesposus* sp. Most of the species taxa of the Early Miocene fishes of the Eastern Paratethys belong to the stenohaline genera and could not resist significant freshening.

The later Early Miocene assemblage inherited only five fish genera from the Caucasian assemblage: *Merluccius*, *Aeoliscus*, *Caprovesposus*, *Scomber*, and *Sarda*. Pelagic fishes (mainly neritic fishes) also prevailed there, while typical meso- and bathypelagic fishes were absent, except very rare finds of the Trichiuridae and Gempylidae. The Early Miocene fauna is characterized by a high occurrence of the hake *Merluccius errans*; however, its finds were also recorded in clearly

shallow water facies; therefore, it can hardly be assumed that it lived at great depths. Apparently, the level of the anaerobic zone of the Eastern Paratethys in the Early Miocene was close to that of the modern Black Sea (i.e., about 150–200 m), where hake also lives. Hypoxia during the death of fishes is confirmed by the open mouths of most of their specimens collected from the localities: the mass mortality of the fishes was apparently caused by the upwelling of waters contaminated with hydrogen sulfide.

The Late Maikopian assemblage shows a significant similarity in the generic composition with the probably coeval fish fauna of the Upper Dysodilic layers of the Romanian Carpathians, where species of the genera “*Sardinella*”, *Merluccius*, *Syngnathus*, and *Scomber* also predominate in the Pietricica locality near the town of Piatra Neamt (Ciobanu, 1977; author’s data). The supposed connection of the Caucasian–Kopetdag province of the Eastern Paratethys with the Eastern Turkish and Iranian basins in the Sakaraulian (Popov et al., 2005) is confirmed by the presence of the Indo-Pacific horse mackerel genera *Scomberoides* and *Alepes* in this area.

Tarkhanian–Chokrakian

In the Tarkhanian and first half of the Chokrakian, the Eastern Paratethys is again characterized by the marine or semi-marine regime. In Tarkhanian deposits, mesopelagic lightfishes (the genus *Vinciguerrria* from the family Phosichthyidae) appear for the first time after the Early Oligocene both in the Ciscaucasian and Transcaucasian parts of the basin and in the Crimea, which indicates a significant lowering of the boundary of the lifeless zone compared to the Upper Maikopian.

Fish finds are confined to deep-water Tarkhanian and Chokrakian facies (“*Spirialis* Clays”), where the boundary of these regional stages is controversial (see above). The main localities of the Tarkhanian fishes are on the northern coast of the Kerch Peninsula near the Kamyshlak place and on the Pshekha River near Shirvanskaya settlement (the lower strata of the Lower North-Shirvanskaya Subformation: Beluzhenko, 2002). Fishes from *Spirialis* Clays occur in several Caucasian localities; however, the most abundant collections have been collected from the left bank of the Sumgait River (Azerbaijan). On the whole, the Tarkhanian–Chokrakian assemblage of marine fishes from the Limacina (= *Spirialis*) deposits of the Eastern Paratethys includes the following taxa (Bannikov and Parin, 1997; Bannikov, 2010, 2020; with additions): cf. *Karaganops* sp., *Sardina prisca*, *Pseudohilsa brevicauda*, *Vinciguerrria merklini*, *Bregmaceros* cf. *B. filamentosus*, *Palaeogadus atropatanus*, *Palaeomolva andrussovi*, *P. tarchanica*, *Merluccius* sp., Hemiramphidae (?) gen. et sp. indet., *Myripristis sorbinii*, *Priacanthus fortis*, “*Lednevia*” sp., *Scomberoides spinosus*, *Selar weileri weileri*, *S. weileri ampliscutulatus*,

Decapterus abbreviatus, *Sciaenidae* gen. et sp. indet., *Landinisciaena popovi*, *Mugil* sp., *Parasphyraena apsheronica*, *Blenniidae* gen. et sp. indet., *Myoblennius fraudulentus*, *Ammodytes* sp., “*Diplogrammus*” sp., *Gobiidae* gen. et sp. indet., *Lepidopus lateralis*, *Scomber collettei*, *Sarda* (?) sp., *Ariomma* (?) sp., *Pinichthys shirvanensis*, *Arnoglossus sumgaiticus*, and *Archaeotetraodon jamestyleri*.

The strictly Tarkhanian species from this list are presumably *Vinciguerrria merklini*, *Palaeomolva tarchanica*, *Landinisciaena popovi*, *Mugil* sp., *Scomber collettei*, *Sarda* (?) sp., *Ariomma* (?) sp., *Pinichthys shirvanensis*, and *Archaeotetraodon jamestyleri*. With respect to the number of finds, *Vinciguerrria merklini* and herrings predominate in the Tarkhanian. Since the “*Spirialis* Clays” are deep-sea facies of the Tarkhanian and Chokrakian, coastal–shallow-water Syngnathiformes (Syngnathoidei) are not yet known from there. The composition of the fish fauna indicates a nearly tropical climate in the Tarkhanian–Chokrakian time (the presence of the genus *Bregmaceros*). Most fishes are definitely pelagic, but there are also finds of demersal Blenniidae, Ammodytidae, Callionymidae, Gobiidae, and Bothidae, which, however, are represented mainly by the juveniles. Most of the species taxa of Tarkhanian–Chokrakian fishes of the Eastern Paratethys belong to stenohaline genera and could not resist significant desalination. The generic composition of fishes from the Tarkhanian–Chokrakian basin significantly changed compared to that from the Late Maikopian basin: the Tarkhanian–Chokrakian fishes inherited only the genera *Palaeomolva*, *Priacanthus*, *Scomberoides*, *Selar*, *Decapterus*, *Arnoglossus*, and, probably, *Lednevia* from the Sakaraulian fish assemblage. Pelagic, mainly neritic fishes also prevailed here; at the same time, typical meso- and bathypelagic fishes of the genera *Vinciguerrria* and *Lepidopus* also appeared here. Most of the Tarkhanian–Chokrakian species are endemic to the Crimea and Caucasus; the only exception is *Decapterus abbreviatus*, which was also found in the Turkish Thrace (Pinarhisar) (Rückert-Ülkümen, 1995; Bannikov, 2010). The Chokrakian basin of the Eastern Paratethys was connected with open waters in the southeast (Popov et al., 2005); among fish, this is confirmed only by the find of the Indo-Pacific genus *Scomberoides* in the “*Spirialis* Clays” of Azerbaijan (Bannikov, 1984). The relatively small number of currently known taxa indicates that the biodiversity of Tarkhanian–Chokrakian fishes only slightly reflects the true biodiversity of the ichthyofauna of that time.

Karaganian and Konkian

In the semi-marine Karaganian basin, fishes are known mainly from two localities: northern Azerbaijan (the outcrop on the Islamdag Hill) and Western Ciscaucasia (Pshekha River upstream to village of Tsurevsky, lower strata of the Middle Tsurevsky Sub-

formation, according to Beluzhenko, 2002). The latter locality is strongly dominated by *Karaganops*; *Mugil* is not uncommon and *Atherina* is rare there. Endemic euryhaline herrings (*Karaganops perratus*), atherinas (*Atherina prima*), mullets (*Mugil karaganicus*), and scald-fishes (*Arnoglossus ovalis*) are known in the Azerbaijan assemblage. The barracuda *Parasphyraena apsheronica* is inherited from the Chokrakian fauna.

The same depletion is characteristic of the composition of the fish assemblage from the outcrop on the Psekups River near the southern outskirts of the town of Goryachy Klyuch; however, the assemblage of *Karaganops*, *Mugil*, and *Atherina* is supplemented with the blennies Blenniidae gen. et sp. indet. Despite the clearly Karaganian appearance of the ichthyofauna, rare finds of mollusks date the locality on the Psekups River to the beginning of the Konkian (Popov, oral communication).

Undoubtedly, Konkian fishes are still very poorly studied. From the Konkian of the Taman Peninsula are known herring *Clupeonella* sp., mullet *Mugil finitimus* (Danil'chenko, 1986), and dragonet *Protonymus gontsharovae* (Sychevskaya and Prokof'ev, 2007). The fauna of Konkian bony fishes (including 30 species) was described from the Mangyshlak peninsula (Karagaily) based on the otoliths (Bratishko et al., 2015). The predominance of cod (Gadidae) and goby (Gobiidae) otoliths indicates the coastal internal-neritic environment of the Karagaily locality.

Sarmatian

Sarmatian fishes of the Eastern Paratethys are better known than the Karaganian and Konkian fishes. Certain finds of teleosts from the Lower–Middle Sarmatian deposits are known from different places in the Northern Caucasus, Crimea, Ukraine, and Moldova; however, Sarmatian fishes were systematically collected by members of the PIN only in two Lower Sarmatian localities: on the Pshekha River in Krasnodar Region and in the north of Moldova (the township of Naslavcea) (Bannikov, 2009, 2019). The fish assemblages recorded in these areas significantly differ in their systematic composition. The following fish species were collected on the left bank of the Pshekha River near the village of Tsurevsky (upper strata of the Middle Tsurevsky Subformation: Beluzhenko, 2002) (Carnevale et al., 2006; Bannikov, 2009, 2010, 2019): *Sarmatella tsurevica*, *Sardina tarletskovi*, *Palimphemus* sp., Belonidae gen. et sp. indet., *Hyporhamphus* (*Reporhamphus*) *tatjanchenkoi*, Syngnathidae gen. et sp. indet., Scorpaenidae gen. et sp. indet., Carangidae gen. et sp. indet., *Pshekharus yesinorum*, *Mullus* sp., *Mugil minax*, *Trachinus* sp., “*Diplecogaster*” sp., *Callionymus* cf. *macrocephalus*, *Pomatoschistus* sp., *Proantigonia* sp., *Scomber* aff. *caucasicus*, *Bothus* sp., and *Soleidae* gen. et sp. indet. The herring species *Sarmatella tsurevica* is dominant; the cod *Palimphemus* sp. and juveniles of lefteye flounder *Bothus* sp. are also abun-

dant. Unlike the Northern Caucasian assemblage, the Sarmatian fish assemblage of Moldova bears clear signs of confinement to the lagoonal environment (there, the fish are buried in several mass mortality layers) and characterized by the dominance of *Atherina suchovi*, while herrings (*Moldavichthys switshenskae*) are at best second in terms of the number of finds; benthic gobies (Gobioidei) are unusually diverse there. Only two genera (*Mullus* and *Mugil*) are common for the two assemblages; the latter genus is represented by a clearly different species (Bannikov, 2019).

Based on data on bivalves, the Early–Middle Sarmatian basin of the Eastern Paratethys was classified as semi-marine (mixomesohaline) basin occasionally connected with open waters (Nevesskaya et al., 2005). The fish fauna generally confirms this classification, being clearly depleted in systematic composition and dominated by euryhaline taxa. At the same time, *Bothus*, *Mullus* and, apparently, *Proantigonia* are stenohaline genera that do not tolerate significant desalination; and some euryhaline genera (*Mugil*, *Hyporhamphus*, and *Scomber*) need marine environments for the completion of their life cycle, even though they can live in incompletely saline waters for a long time. Therefore, with respect to the fish composition, the Early Sarmatian Eastern Paratethys can be classified as a mixopolyhaline basin with a salinity above 18‰ (the upper salinity limit of mesohaline basins). The chemical properties of the waters of the Sarmatian basin was characterized by an increased alkalinity and supersaturation with carbonate (Pisera, 1996; Carnevale et al., 2006); the latter is indicated by the preservation in situ of the otoliths in all Sarmatian fishes (Bannikov, 2009, 2010, 2019). Therefore, the depletion of the systematic composition of the Early Sarmatian fishes of the Eastern Paratethys is explained not so much by the low salinity of waters as by their unfavorable chemical properties.

In addition to the Tsurevsky and Naslavcea assemblages, Sarmatian fishes were also recorded from different localities of the Northern Caucasus, Crimea, Azerbaijan, Moldova, and Ukraine (Amvrosievka: Bogachev, 1955); however, systematic excavations have not been made there. Noteworthy is the presence of finds of Sciaenidae in the Sarmatian of the Amvrosievka locality and in the vicinity of the city of Grozny, which are not yet known from the better studied Tsurevsky and Naslavcea assemblages. A find of a caproid species of the genus *Proantigonia* in Dagestan is also interesting; this genus is typical for the Sarmatian of more western regions (Croatia, Austria, and Romania) (Baciu et al., 2005); several finds of *Proantigonia* sp. are also known from the Tsurevsky assemblage. On the whole, the Early Sarmatian basins of the Eastern Paratethys are characterized by a high fish species endemism.

Downstream from the Tsurevsky locality, closer to the confluence of the Golyshka River on the Pshekha River, an assemblage of the Middle Sarmatian fishes is known (Upper Tsurevsky Subformation: Beluzhenko, 2002); this assemblage is more depleted in systematic composition and confined mainly to the several thin layers with evidence of mass mortality of fishes. Reliable finds of the Late Sarmatian fishes are not yet known.

Maeotian, Pontian, and Pliocene

The Maeotian fishes are so far very poorly studied: Bogachev (1942) recorded two forms of herrings and the problematic *Lepidopus* from the Maeotian of the Eastern Paratethys and briefly described (without images) four new species: *Matarchia* (= *Scomber*) *spuria*, *Chrysophrys* (= *Sparus*) *diatomacea*, *Merluccius maeoticus*, and *Labrax* (= *Morone*) *vogdti* (the first three of them are from the environs of the Taman Peninsula and Cape Zhelezny Rog and the latter is from Guria (Georgia)). Despite their incompleteness, the presence of the marine genera *Sparus* and *Merluccius* in the Maeotian of Taman can be confirmed by and supplemented with three other forms: *Mugil* sp., *Sciaenidae* gen. et sp. indet., and *Carnevalella* (?) *tmutarakanica* (Bannikov, 2013). Apparently, Bogachev (1942) rightfully believed that the Maeotian fishes were migrants from open waters rather than being inherited from the Late Sarmatian faunas.

Marine fish faunas are unknown from the younger deposits of the Eastern Paratethys; freshwater and brackish-water fishes are poorly studied. A brackish-water fish assemblage was described from the Pontian (Upper Miocene) of Abkhazia (Gabelaya, 1976; Danil'chenko, 1980); this assemblage consists of five species of Clupeidae as well as *Atherina colchidica* (Atherinidae), *Mugil editus*, *M. nodosus*, *M. ordinatus* (Mugilidae), and *Carnevalella impropria* (Sciaenidae). Three species of brackish-water herrings characterize the Akchagylia deposits of Azerbaijan and Turkmenistan (Danilchenko, 1980).

Terrestrial Vegetation

M.A. Akhmetiev

Unfortunately, data on the terrestrial vegetation cover of the continental framing of the Eastern Paratethys are very inequivalent for its different parts. It is possible to trace changes in floras and the transformation of the vegetation cover from the beginning of the Miocene to the Pleistocene only in the Carpathian and Caucasian regions. Floristic data on the northern and eastern the surrounding land of the Paratethys relate mainly to the Middle Miocene. Paleocarpological and palynological data make it possible to assess the development of the Late Miocene and Pliocene vegetation cover in the southern and southeastern parts of the Russian Platform.

The characteristic features of the development of the Paratethys were a gradual expansion of areas drained from the sea and an uplift of mountain ranges in its southern frame, which led to an increase in the differentiation of vegetation cover and the appearance of mountain vegetation belts. With respect to the features of the geological and paleogeographic features of the development of the Eastern Paratethys, the author distinguishes four main stages of development of the vegetation cover: Late Maikopian, Tarkhanian—Middle Sarmatian, Late Sarmatian—Pontian, and Pliocene stages.

The great transformation of the flora occurred in the Late Miocene as a result of active uplifts of Alpine mountain structures, including the Greater Caucasus, as well as due to the liquidation of the sea strait near the Dzirulsky massif and Eastern Georgia. This change was accompanied by climate cooling and drying and the formation of new types of small-leaved hard-leaved maquis vegetation. In the second half of the Late Miocene, heterogeneous floristic elements of East Asian and North American affinity were actively replaced by Macaronesian elements, which have been preserved to the present on the Canary Islands.

Due to the progressive climate cooling, the boundary between the largest phytochoria shifted to the south in latitude by no less than 20° by the end of the Neogene. Subtropical conditions were preserved until the middle of the Pliocene only in the Transcaucasian and Turkmenian provinces.

Early Miocene

The knowledge of the composition of the flora and pattern of vegetation of the Early Miocene of the Russian Platform and Scythian Platform is based on palynological data. L.A. Panova (in *Prakticheskaya palynostratigrafiya*, 1990) recognized a single palynoassemblage with *Pinus*, *Corylus*, and *Momipites punctatus* in the spore—pollen palynoassemblages of Ciscaucasia and the Black Sea region. Assemblages were dominated by the pollen of conifers, mainly *Pinus* and less often *Tsuga*, *Sciadopitys*, and *Cedrus*; by the second half of the Early Miocene, the pollen of Taxodiaceae acquires became increasingly more significant. The pollen of Betulaceae (*Betula*, *Corylus*, *Carpinus*, and *Alnus*) was dominant in the angiosperm group and pollen of *Platycarya*, *Engelhardia*, and *Momipites* among Juglandaceae. As in Central European floras, the pollen of subtropical angiosperms is also diverse here: Palmae, Sapindaceae, Myricaceae, Proteaceae, and *Laurus*. In palynofloras of the Northern Caucasus, a significant contribution is made by herbaceous plants (Liliaceae, Gramineae, and *Sparganium*).

As the climate began to acquire seasonal features in the Aralian time, beech forests in uplands and birch—walnut forests in lowlands began to be gradually replaced by pine—oak forests in Ustyurt, the Aral Sea

region, and Turgay. Unlike the Oligocene palynoassemblages, herbs and shrubs with a relatively small amount of tree species became increasingly important in Early Miocene palynoassemblages. From the beginning of the Miocene, judging by the appearance of pollen of cereals and other herbaceous, biochoria arose, from which steppe associations subsequently began to develop; the composition of *Ephedra* became more diverse (data from N.I. Zaporozhets et al.).

Sedimentation on the Turanian Plate occurred under conditions of seasonal precipitation, which reaches the maximum level in winter (as now in the Mediterranean). Landscapes significantly changed under conditions of dry hot summer, although the lowland lacustrine plains still continued to be poorly drained by the hydrographic network. The near-shore forests of the gallery type began to acquire the status of island forests and maquis and herbaceous cenoses occupied the main position in zonal vegetation. The most elevated areas and southern slopes were occupied by thorny legume and heather bushes. The warm climate of the Burdigalian Age in Kazakhstan is indicated by finds of pollen from palm and other thermophilic woody plants in the upper beds of the Aral Ustyurt Formation with a simultaneous high content of *Ephedra* and herb pollen.

The Early Miocene floras of the Ukrainian Carpathians are quite rich (Baikovskaya, 1953; Il'inskaya, 1960) and reflect forest vegetation with laurels and other evergreen plants, as well as deciduous broad-leaved plants (*Alangium* and *Platanus*).

The characteristics of the vegetation cover in Northern Ciscaucasia at the beginning of the Miocene (the Alkun, Zelenchuk, and Early Karadzhalga epochs) were close to the features of the vegetation cover in the Black Sea region (*Neogenovaya sistema*, 1986) and differed only in a greater role of subtropical elements.

In the second half of the Early Miocene, forest formations continued to dominate in the Black Sea region (the Chernobaevskoe epoch) and Ciscaucasia (Late Karadzhalga and Olginskaya epochs); however, the increase in the number and diversity of subtropical plants in these time indicates a significant warming of the Burdigalian. Areas occupied by herbaceous cenoses appeared here for the first time in the Cenozoic (data from Zaporozhets et al.).

In Transcaucasia, deposits of the Upper Caucasian (Uplistsikhe Formation) and Sakaraulian are characterized by assemblages of evergreen subtropical hard-leaved forests, which reflect a hot dry climate (Dzhaparidze, 1982). The Uplistsikhe flora also differs from Ciscaucasian floras in the presence of coniferous and coniferous-mountain subtropical forests formations with evergreen woody forests, which indicate the ruggedness of the relief of the Lesser Caucasus. With respect to the composition, the Uplistsikhe palynoflora is closer to the floras of the Western Para-

tethys, in particular, the Upper Egerian of Hungary (data of L.A. Panova in *Prakticheskaya palinostratigrafiya*, 1990).

In the Sakaraulian, palynoassemblages show that the subtropical forest flora remained the dominant formation here; however, the proportion of Taxodiaceae increased among conifers and that of Juglandaceae and Fagaceae (*Quercus* and *Castanopsis*) increased among woody families; the proportion of *Ulmus* and exotic subtropical taxa with tricolpate pollen, which are indeterminate by natural system, also increased.

The Kozakhurian palynoflora of Western Georgia also remained subtropical, similar to the Sakaraulian palynoflora; however, the role of conifers somewhat decreased in it (*Prakticheskaya palinostratigrafiya*, 1990).

In Mangyshlak, the deposits of the Kashkarata Formation, containing the pollen of palms, laurels, myrtles, and other thermophilic plants, correspond to the warmest conditions (Neogenovaya sistema, 1986). In the south of Turkmenistan, there were saltwort—wormwood—mixed herbs deserts in Cheleken, as evidenced by the palynological data.

In Central Asia, the activation of tectonic processes in the Alpine—Himalayan belt led to an increase in the vertical differentiation of the vegetation cover. As Tibet and the Pamir-Alai were uplifted, forest formations began to play an increasingly prominent role, along with savannah-like formations. Broad-leaved forests with walnut, beech, and other broad-leaved trees were common in the middle-altitude part of the rising mountain ranges.

Rare finds of leaf flora involving palynological data make it possible to reconstruct the main belts of vegetation in the mountain framing of the Tajik Depression and in the Pamirs. In lowlands that became free from the sea, a tugai assemblage with Juglandaceae and Salicaceae was formed at the turn of the Oligocene and Miocene. The lower mountain belt was occupied by savannah alternating with maquis. Higher up, there was a clearly defined belt of broad-leaved forests with transitions to savanna at the lower boundary of the belt and coniferous forests near the ridges.

Climate cooling, which began at the end of the Chattian, continued in the Early Aquitanian, which was determined by a decrease in average winter temperatures at an average annual precipitation of up to 1000–1500 mm (Akhmetiev et al., 2005). The maximum warming occurred in the Burdigalian and its manifestation was equal both to the north and south of the Paratethys Basin. The difference with the average annual and average winter temperatures of the Aquitanian was about 4–6°C. Mangrove vegetation spread along the southern sea coast of the Paratethys in the Burdigalian; its presence was recorded in Hungary and Georgia. It is noteworthy that remains of Mastixiaceae fruits, which are characteristic components of the

modern tropics of Southeast Asia, were recorded in laurel-leaved Burdigalian and Early–Middle Miocene floras.

Tarkhanian

In the Black Sea region, the first half of the Middle Miocene was characterized by humid broad-leaved forests dominated by moderately thermophilic deciduous flora with a significant proportion of evergreens, which was characterized mostly by the presence of Ulmaceae, Fagaceae, and Juglandaceae species and a slight involvement of conifers (*Prakticheskaya palinostratigrafiya*, 1990).

Palynoassemblages of Western Georgia characterize a very rich and diverse subtropical forest flora with elements of warm-temperate taxa (different species of *Juglans*, *Carya*, *Pterocarya*, *Salix*, *Alnus*, and *Betula*, as well as *Myrica*, *Nyssa*, and *Engelhardtia* among evergreens and Lauraceae).

According to palynological data, the Tarkhanian floras of Transcaucasia are also known in Armenia (Leie, 1968). In this region, lush warm-temperate coniferous–broad-leaved forests with different conifers and dominant oaks and Castanopsis and an equal participation of other evergreen and deciduous forms were widespread at high hypsometric elevations under conditions of a dissected mountainous relief.

Chokrakian

In most of the areas of the Black Sea and Ciscaucasia, the Chokrakian palynoassemblage is characterized by rich forest associations dominated by Pinaceae among conifers and Ulmaceae and Fagaceae (*Quercus*) among angiosperms. The proportion of Betulaceae, *Salix*, and Juglandaceae decreased compared to the Tarkhanian (*Prakticheskaya palinostratigrafiya*, 1990). The role of herbaceous plants (in particular, Chenopodiaceae) increased, which indicates a more dried climate.

In the Chokrakian time, the differentiation of the vegetation cover in Transcaucasia proved to be even more significant than that in the Tarkhanian. Humid subtropical forests occupied not only the coastal zone but also the low-mountain belt in some places. Higher up, they were replaced by broad-leaved deciduous forests. Aridization in the Chokrakian epoch is unevenly recorded in different regions of Transcaucasia, in particular, in Azerbaijan, where the amount pollen of herbs increased in palynoassemblages (15–55% of the sum spores and pollen). In Talysh and the Middle Kura depression, the content of pollen *Ephedra* increased to 30–35%, while Cupressaceae pollen was dominant among gymnosperms.

Karaganian

For the south of the Russian Platform (the northern Cis-Azov region, lower reaches of the Don, and Ciscaucasia), it is possible to reconstruct a more complete dynamics of the development of vegetation in the Neogene, starting from the Karaganian, based on two dozens of localities of plant megafossils and seed floras of different ages, as well as on palynological data of E.N. Ananova (1974) from sections of numerous wells and separate outcrops in this area.

In the Karaganian, oak–laurel–ulmus forests with very little involvement of conifers (pines) and deciduous amentaceous species (birch and alder) were widespread everywhere except the sea coast. The periodically drained sea coast was inhabited by Chenopodiaceae and abundant coastal–aquatic plants, including herbaceous ones. Finds of the leaves and carpoids of subtropical plants, in particular, in Ciscaucasia, are supplemented with the presence of pollen from *Sapindus*, *Broussonetia*, *Eucommia*, *Buxus*, *Altingia*, *Parrotia*, *Pistacia*, *Ilex*, etc. In Karaganian localities, leaves of Lauraceae and evergreen stiff-leaved oaks were encountered in collections by S.V. Popov (Belaya and Pshekha rivers), Yu.O. Gavrilov (Eastern Ciscaucasia), A.S. Tesakov, and M.A. Akhmetiev, and leaves of pinnate palm and plain leaves of laurels family were described from Karaganian deposits of Dagestan by T.N. Baikovskaya. As in the Tarkhanian–Chokrakian, the flora remained small-leaved, which indicates a greater similarity of the natural environment of the Karaganian with the Tarkhanian–Chokrakian period, rather than with the Konkian–Middle-Sarmatian time. Against the background of the dominance of pollen broad-leaved plants, the proportion of tree and shrub xerophytes, as well as herbaceous plants (Chenopodiaceae, Compositae, Dipsacaceae, *Ephedra*, etc.), was also significant in the palinospectra. The climate was similar to the modern Mediterranean one, being seasonal, with warm summers and precipitation, most of which fell in the autumn–winter period.

The composition of the flora and vegetation of Moldova in the Karaganian and Konkian epochs was reconstructed only from palynological data (Mitsul, 1973). In the Podolsk Formation of the Belgorod–Dnestrovsky area (presumably of Karaganian age), the pollen of tree prevails in the palynospectra, the proportion of herbaceous species is 17%, and that of moss spores is 8%. Pine pollen is dominant (more than 60%). The pollen *Quercus*, *Ulmus*, and *Carpinus* is often recorded, while that of *Betula*, *Carya*, and *Corylus* is less common. Dwarf-shrub and herbaceous plants are represented by Chenopodiaceae (16%) and Compositae (1%).

Floras of the Karaganian Regional Stage and Pholadidae or Kartvelian beds of the Konkian Regional Stage were studied by G.S. Avakov (1970) in the valleys of the Medzhuda (southern Ossetia) and Kvirila (the west of Central Georgia) rivers. These

floras are reconstructing the forest vegetation of the central part of the southern mountain slope of the Miocene Caucasian Island and Dzirulsky massif. There are three main groups of plant formations that existed in the mountain relief with absolute elevations up to 2000 m: (1) stiff-leaved forest on dry slopes, (2) humid subtropical (laurel-leaved) forest, and (3) deciduous summer-green forest growing under variable humid climate conditions. Acacias and other small-leaved species with hard leather-like leaves (*Myrica*, *Castanopsis*, *Cotinus*, *Myrtus*, and *Callistephyllum* species, as well as *Hakia* and *Banksia*, which are close to Proteaceae) grew on dry slopes. Laurel-leaved forests were characterized by relatively high humid conditions typical for the fog belt. This is the taxonomically richest group of trees and shrubs (ivy, *Engelhardia*, *Helicia*, *Magnolia*, *Litsea*, *Cinnamomum*, *Ocotea*, *Persea*, *Ilex*, *Sapindus*, *Sabia*, *Combretum*, etc.). The formation of summer-green forests included both moisture-loving *Castanea* and more dry- and light-loving species (*Comptonia*, *Carpinus*, *Cotinus*, etc.). The formation of riverine forests was represented by various willow, poplar, elm, and plane-tree (Avakov, 1970).

For the lower zone of hard-leaved forests, Avakov assumes the average annual temperature of +18 to +20°C at an average annual relative humidity of 63%. It could reach 80% at altitudes from 600 m above sea level, which was favorable for the existence of humid subtropical forests at an average annual temperature of +14°C. In mountains at altitudes up to 1500–2000 m, the average annual temperatures decreased to +9°C.

Other natural conditions developed in Armenia at that time. According to palynological data, mesophilic deciduous forests with Juglandaceae (*Carya* and *Pterocarya*), elm species, mulberries, oak, chestnut, birch, waxberries, sweetgum, and Hamameliaceae, rather than subtropical forests existed during the accumulation of the Oktembrian Series of the Prierevansky area (lower strata of the Middle Miocene) and Hrazdan formation (Sarmatian).

In most of Azerbaijan, temperate thermophilic forest vegetation in the Karaganian and Early Konkian time formed a complex assemblage with subtropical vegetation, which tended to colonize sea coasts and gradually lost its influence, in particular, in the Konkian age. The role of the pollen of herbaceous plants and *Ephedra* was much less significant in the Karaganian and Konkian than in the Chokrakian epoch. Avakov (1970) and other Transcaucasian paleobotanists emphasized that the extreme forms of vegetation of all three vertical zones or belts (warm dry, warm humid, and moderately warm climates) originated from different, ecologically isolated areas and were floristically hardly related to each other.

Konkian

Floras of the northern coast of the Eastern Paratethys within the south of the Russian Platform were monographically described from the Krynka (Krishtofovich and Baikovskaya, 1965) and Amvrosievka (Pimenova, 1941, 1954) localities in Eastern Donbass and from Gruzsky Elanchik and Mariupol (Teslenko, 1957) and near Mariupol (Koval, 1955) in the northern Cis-Azov region. To date, it has been fairly reliably established that these floras are Konkian, since the flora-bearing beds are overlain by beds of the Early Sarmatian fauna everywhere (sometimes with unconformity and less often gradually) and Konkian mollusks were found directly in Beds with plant remains.

Megafossil assemblages are similar in composition and usually contain not less than 20–26% of environmentally identical common species. They are represented by tree and shrub deciduous broad-leaved and less often small-leaved species with evergreens (up to 5%), oaks (*Quercus neriifolia* and *Q. ilex*), laurels family (*Laurus*, *Cinnamomum*, and *Sassafras*), Magnoliaceae (*Magnolia* and *Schizandra*), Sapindaceae, Lorantheae, Ilicaceae, and Moraceae (*Ficus*). The main forest-forming species of mesophilic broad-leaved forests were beeches, oaks, chestnuts, Juglandaceae, and Betulaceae. The lush underbrush was formed by Rosaceae (*Physocarpus*, *Spiraea*, *Rubus*, *Rosa*, *Prunus*, *Laurocerasus*, *Pyros*, *Photinia*, *Cotoneaster*, *Crataegus*, etc.) with Fabaceae (*Cercis*, *Wistaria*, *Genista*, etc.). In the Krynka flora, the proportion of swamp cypress and Taxaceae was significant in the vegetation cover. Leaves of *Cercidiphyllum*, *Quercus alexeevii*, and some other plants, which flourished in the western regions of Central Eurasia during the Oligocene, were recorded in the Mariupol and Amvrosievka floras.

The studied floras on the northern coast of the Paratethys are among the youngest floras, in which the role of evergreen subtropical plants is still noticeable, which increases in more western Ukrainian–Carpathian floras. Remains of subtropical plants, including evergreens, were found in almost all collections from Konkian deposits (Amvrosievka, Krynka, Gruzsky Elanchik, etc.), as well as in palynospectra. From the pollen of the most thermophilic plants were represented by single specimens of *Parrotia*, *Sterculia*, *Engelhardia*, and *Eucommia*. A variety of Lauraceae (avocado, benzoin, laurel, *Daphnogene*, *Cinnamomum*, etc.), magnolias, hard-leaved evergreen oaks, Hamamelidaceae, legumes, soap tree, persimmon, etc., were found among megafossils. *Altingia*, *Symplocos*, *Firmiana*, etc., were recorded in palynospectra.

Konkian palynospectra differ from Karaganian ones in a greater proportion of pollen from several pine species (65–75%) and no more than 1% from other conifers. Among them are *Sequoia*, swamp cypress (bald cypress) and *Chamaecyparis*, and hemlock (represented by several species), as well as *Cryptomeria*,

Podocarpus, *Pseudotsuga*, *Cedrus*, etc. Some of the representatives of these genera are unknown in younger deposits. The spectra of flowering species are dominated by *Quercus* and *Ulmus* pollen, which is characterized by various species. The pollen of shrubs and herbs is represented by *Ericaceae*, *Chenopodiaceae*, *Compositae*, *Poaceae*, and *Sparganium* species. In the palynoassemblages, the proportion of *Ulmaceae* and *Betulaceae* species decreased markedly as a result of a significant increase in the amount of coniferous pollen. The Late Konkian is characterized by two peaks of herbaceous—shrub pollen (pollen of *Chenopodiaceae*, *Asteraceae*, etc.), which probably reflects two short-term drying phases during the regressive phase of the sea basin.

The wide range of conifers and large leaved of flowering plants indicate a warm, humid climate close to the subtropical type. The climate became moderately warm towards the north (Tambov oblast), which is confirmed by a noticeable increase of the role of coniferous pollen, as well as by a large proportion of deciduous broad-leaved plants in megafossil assemblages along with the presence of evergreens (data from E.N. Ananova et al.).

In the eastern framing of the Paratethys, the floras of Asian district Russia and adjacent regions of Kazakhstan and Central Asia have not yet been sufficiently studied. V.V. Lavrov suggested that the uplift of the mountain structures of the Kopetdag and Tien Shan system was accompanied by a migration of plant communities ahead of the front of these mountain structures, resulting in the succession of forest, forest-steppe, steppe, and even semidesert vegetation to the north of the mountain structures.

Flora on the developing mountain ranges of Central Asia contributed to the formation of numerous endemic plants in the Neogene, which determine the peculiarity of the composition of the floras and modern mountain ranges of these regions in Asia. The pattern of the vegetation cover of Southern Kazakhstan and Central Asia can be assessed by the taxonomic composition of floras from deposits of intermountain depressions (Karkara, Tekes, Kochkor, Issyk-Kul, Ferghana, and Ile depressions), as well as by the Neogene floras of the Northern Aral Sea region and Turgay (Kutuzkina, 1957; Kornilova, 1966; Akhmetiev, 1993). The main edificators of stunted sparse forests in river valleys in almost all Middle—Late Miocene and Early Pliocene floras of the above-listed depressions were poplars of the subgenus *Turanga*, which were accompanied by narrow-leaved willows and small-leaved elms. The presence of birch and walnut species with broad-leaved trees (linden, chestnut, maple, and zelkova), as well as ailanthus and *Periploca*, combined with a variety of herbaceous plants (Typhaceae (*Sparganium*), chenopodiaceous, fabaceous, and Asteraceae taxa), was established in the composition of riparian forests using the palynological method.

The vegetation cover of Turkmenistan was a link between the regions of Eastern Transcaucasia and Tajikistan; as is now, it differed in an even wider distribution plants of arid climate. The average annual precipitation varied from 100 to 400 mm. Slonchaks and the first deserts appeared; however, their areas often changed from the Middle of the Miocene and the periods of marine transgressions (the Konkian and Sarmatian ones) decreased. This is established by the ratio of pollen of xerophyte (indices of aridity) and hygrophytes plants in palynoassemblages.

The terrigenous Miocene molasse of the Tajik Depression is subdivided into the lower redbeds (Baldzhuan and Khengous formations) and the upper grey-colored (Tavildara Formation) parts. The Middle Miocene palynospectra of the upper part of redbeds sediments are characterized by a decrease in the amount of *Ephedra* pollen and a simultaneous increase in the amount of herbaceous pollen. Slope groups were formed by mixed polydominant mesophilic forests with spruce, pine, *Cedrus*, *Tsuga* birch, alder, and elm. Juniper forests developed independently in terms of their cenotic value, judging from a high content of *Juniperus* pollen in the red beds of the Khengous Formation; in the Tavildara time, open areas were occupied by steppe and semidesert vegetation. Steppe cenoses were formed by *Poaceae*, *Asteraceae*, and *Chenopodiaceae*, while the composition of tugai groups can be assessed based on finds of small- and narrow-leaved *Populus mutabilis* and *Salix angusta* in the basal beds of the Tavildara Formation (Akhmetiev, 1993).

Early—Middle Sarmatian

The assemblages of megafossils, spores, and pollen in the Early Sarmatian and first half of the Middle Sarmatian are similar and complete the Middle Miocene stage of flora and vegetation development. This stage is a natural continuation of the preceding Konkian Stage, since evergreens were still preserved in the first half of the Sarmatian in the south of the Russian Platform against the background of the dominance of deciduous trees and shrubs. The most significant changes in the composition of the flora occurred at the end of the Middle Sarmatian.

A distinctive feature of the composition of the flora and vegetation of the Cis-Azov region and lower Don reaches in the first half of the Sarmatian is the dominance of coniferous pollen (70–80%), in particular, pollen from pine of both subgenera (*Haploxylon* and *Diploxylon*) and almost all sections of this genus (*Strobus*, *Cembra*, *Banksia*, *Eupitys*, etc.), in palynoassemblages. As in the Konkian, epoch, pinaceous and taxodiaceous taxa pollen significantly contributes to the pollen spectra; the role of *Tsuga* and *Abies* also markedly increased in the vegetation cover. The accessory part of pollen spectra reflected a wide variety of representatives of other gymnosperm genera: *Keteleeria*,

Sciadopitys, Taxaceae, Podocarpaceae, *Ginkgo*, etc. Angiosperms (up to 20%) are represented by the pollen of oaks, elms, and betulaceous taxa (the main forest-forming species of riparian and low-slope associations). Juglandaceous taxa still played a significant role in the composition of forests. The underbrush cover was dominated by ferns, as well as by ericaceous and chenopodiaceous taxa. The proportion of representatives of the genera *Rhododendron* and *Vaccinium* is noticeable only from the beginning of the Middle Sarmatian, when there were significantly fewer evergreens. Finds of Lauraceae (*Laurus* and *Cinnamomum*) were recorded among megafossils and a few specimens of *Lithocarpus*, *Liriodendron tulipifera*, *Pittosporum*, *Nyssa*, *Althingia*, *Buxus*, *Ilex*, etc., were found in pollen spectra. The pollen of *Trachycarpus* (a palm resistant to light frosts) occurs rarely.

Palynological data on the entire south of the Russian Platform from Moldavia to the Caspian Sea region indicates a very uniform composition of forest vegetation dominated by pines in watershed habitats and oak–elm–birch forests on plains to the north of the sea basin. The role of evergreens noticeably decreased in the vegetation cover, which indicates a further southward shift of the boundary of the Boreal zone. The flora of the first half of the Sarmatian is large-leaved, which reflects a humid warm-temperate climate with a uniform distribution of precipitation throughout the year.

Sarmatian leaf floras have been most fully studied and monographically described; these are floras of the Bursuk (Negru, 1969, 1970; Shtefyrtza, 1972, 1974, 1999), and Naslavcea (Yakubovskaya, 1955) localities of the Lower Sarmatian and Middle Sarmatian flora of Ghidighici (Yakubovskaya, 1955).

The flora of the village of Bursuk (Kamensky district, northeastern Moldavia) was described from the remains of leaves and fructifications. It originates from the middle part of the basal horizon of Lower Sarmatian carbonate–terrigenous member with an abundant mollusk fauna overlain by Badenian deposits, which also contain a rich mollusk fauna. In the “leaf” flora, A.G. Shtefyrtza indicates few prints of leaves and feathers of ferns (*Pteridium* and *Osmunda*), single specimens of conifers (*Pinus*, *Sequoia*, and *Taxodium*), and one leaf of fan palm *Chamaerops humilis*, identical to that described by A.A. Kolakovskii (1964) from the Miocene flora of Abkhazia. Monocotyledons are represented by *Smilax* and *Dioscorea* leaves. The dominants and subdominants of the flora are deciduous plants: *Carpinus*, *Ulmus*, *Zelkova*, *Parrotia*, *Podogonium*, *Cotinus*, and *Acer*. A characteristic feature of Bursuk flora is that taxa common to the Sarmatian floras of Central and Eastern Europe (*Salix*, *Populus*, *Pterocarya*, *Juglans*, *Carya*, *Alnus*, *Corylus*, *Fagus*, *Platanus*, *Tilia*, etc.) were not found in megafossils and only a small part of them is compensated by finds of single specimens of seed flora (*Carpinus*, *Tilia*,

and *Pterocarya*). It is characteristic that the proportion of leaves of subtropical plants (*Chamaerops* and *Smilax*) is extremely insignificant in imprints, although many of deciduous species have a distant subtropical affinity. The Bursuk flora is related to the coeval floras of Central Europe by its small leaves, which are usually observed even in mesophilic *Liquidambar* and *Parottia*. This distinguishes it from floras with larger leaves in the south of the Russian Platform. According to carpological data, the flora is characterized by a mixture of subtropical (Moraceae, Buxaceae, Rutaceae, Sapindaceae, Alangiaceae, and Staphyleaceae) and warm-temperate species. Formationally, the Bursuk flora reflects a subxerophytic broad-leaved formation that forms its main core with *Celtis*, *Ampelopsis*, *Ailanthus*, *Swida*, *Aralia*, and *Prunus*. It included many herbaceous ground-cover plants (*Portulaca*, *Arenaria*, *Chenopodium*, *Hypericum*, etc.). The leading phytogeographic elements of the Bursuk flora were Atlantic–North American, Ancient Mediterranean, and East Asian. Judging from the composition of the flora, its climate parameters varied within the following limits: average annual temperature, +13 to 16°C, average winter temperature, +3 to 10°C, and average annual precipitation, up to 800 mm.

The flora of Naslavcea on the right bank of the Dniester near the city of Mogilev-Podolsky (Yakubovskaya, 1955) is also confined to the basal clay member of the Lower Sarmatian. In addition to plants, remains of mollusks, fishes, and insects were found in this flora. Remains of brown algae (*Cystoseira*) were recorded. The composition of catkin-bearing plants (juglandaceous, betulaceous, and fagaceous taxa) is diverse in the absence of ferns and conifers. Imprints of *Castanea* leaves prevail; they are accompanied by *Zelkova*, *Acer*, *Ulmus*, and *Rhus*. Similarly to Bursuk, the flora of Naslavcea is characterized by its xerophilicity and extremely low proportion of evergreens in the composition of megafossils. T.A. Yakubovskaya notes that the composition of the Naslavcea flora is similar to that of the coeval floras of Poland and Hungary, although the Sarmatian floras of the latter (Andreansky, 1959) contain much more evergreens, including laurels.

The flora of Ghidighici in the vicinity of Kishinev (Yakubovskaya, 1955) is of Middle Sarmatian age and represented by remains of *Platanus* (43%), *Populus*, *Ulmus*, and *Liquidambar*, which reflects the composition of the riparian formation. This flora has only four species common with the Naslavcea flora and is more closely related to the younger floras of Ukraine, even those of the Maeotian age. This flora could exist at greater summer aridity and an average annual precipitation of up to 600–700 mm.

The small-leaved floras of the Middle Sarmatian of Ciscaucasia and the Black Sea coast are well distinguished by their xerophytic appearance and involvement of various evergreens in the composition and

were distributed throughout Western Ciscaucasia and the Black Sea coast from Western Georgia and Abkhazia to Taman. This allowed N.V. Gur'ev (1987) to combine the floras of Krymsk and other localities of Ciscaucasia with similar floras of Western Georgia and Abkhazia (Goderdzi, Dzindza, Kodor, etc.) into a single floristic region differing from the North Azov area.

In comparative terms, the flora of the Krymsk area is most indicative. Subtropical plants, including Lauraceae, Magnoliaceae, Myrsinaceae (*Rapanea*), *Sapindus*, *Berchemia*, etc., were repeatedly described by G.D. Pashkov (1959, 1965). N.V. Gur'ev (1987) monographically characterized the flora of the *Cryptomactra* beds of Krymsk. Based on the fauna of mollusks, he dated this flora to the first half of the Middle Sarmatian age and indicated more than 50 plant species, most of which belong to evergreens. He noted finds of brown algae (*Cystoseirites*, *Cystophyllum*, and *Sargassum*), *Osmunda* and subtropical *Cyclosorus* ferns, three *Magnolia* species, representatives of eight genera and ten species of laurels [*Actinodaphne*, *Apolonias*, *Daphnogene*, *Cinnamomum* (hundreds of specimens), *Lindera*, *Litsea*, *Ocotea*, and *Persea*]. Remains of hard-leaved *Myrica*, *Diospyros*, *Rapanea*, *Sterculia*, *Sapindus*, *Rhus*, Ilicaceae, *Schefflera*, *Viscum*, *Berchemia*, bamboo, and other subtropical plants recorded in this flora characterize the flora of Krymsk as the youngest among the known subtropical floras of the Neogene of Russia. At the same time, it lacks the most important representatives of Neocene catkin-bearing plants: betulaceous, fagaceous, and juglandaceous taxa. Most of the modern analogs of Krymsk flora grow in Southeast Asia and Macaronesia, as well as on the American continent, including Central and South America (*Rapanea*, *Sterculia*, and *Litsea kubanensis*). According to the Gur'ev opinion (1987), the mountain laurel forests of Macaronesia at altitudes of 700–1600 m above sea level are a phytocenotic analog of the Sarmatian forest of the Krymsk assemblage and the climate of the Canary Islands with a February temperature of +12.8°C and an average minimum temperature of –3.4°C is a climate analog. He estimates the average August temperature to be +22°C at an average maximum value of +40 to +41°C. The average annual precipitation is 580 mm; the maximum precipitation level (130 mm) is observed in December.

The Sarmatian floras of Sary Krym contain much pine pollen, which reflects the vegetation of watershed areas. In Upper Sarmatian floras, there are signs of aridization everywhere in the south of Russia, since the amount of *Artemisia* pollen increases to 20% in the spectra.

Mesophilic and hygrophilic components are mixed in forests of Volhynian epoch (Early Sarmatian) of the Carpathians. The main forest-forming taxa were coniferous, juglandaceous, and fagaceous. In mountain paleocenoses, an increase in the role of hygro-

phytes is recorded in the Middle Volhynian time. At the end of the Early Sarmatian and in the first half of the Middle Sarmatian, the proportion of evergreens continued to decrease in the vegetation cover and in coniferous–broad-leaved forests; *Carya*, *Quercus*, and *Castanea* were the forest forming taxa. The distribution of hygrophytes in mountain floras became limited.

The generic composition of the Early Sarmatian floras of the Carpathians correlates them with the modern flora of Talysh. The climate was also close to that of Talysh, differing from it only in a lower humidity in summer. The Lukovo flora and vegetation cover of the Early Sarmatian were monographically described by S.A. Molchanov (2002). The composition of lowland forests was formed by *Pteris*, *Ulmus*, *Zelkova*, *Carpinus*, *Buxus*, *Acer*, *Berchemia*, *Gleditschia*, *Wistaria*, and *Ligustrum*. Forests with *Castanea* and *Quercus* were widespread in the lower mountain belt and beech forests in the upper mountain belt. According to malacological data, flora-bearing beds were formed at the end of the Early Sarmatian. The average temperature is estimated by S.A. Molchanov to be +23.5°C in July and +5°C in January at an average annual precipitation of 900 mm.

Sarmatian floras of Western Georgia and Abkhazia are characterized by a variety of evergreen flowering plants (inhabitants of areas with humid subtropical climate) in combination with exotic conifers (*Cathaya* and *Colchidia*). In the Middle Sarmatian, in particular, in Late Sarmatian floras, there are many hygrophilous warm-temperate deciduous species, as well as representatives of haemoxerophytic flora. The flora of the southern areas of Western Georgia is poorer than the Abkhazian flora; however, it is more diverse in the composition of plants of humid subtropical climate. These are primarily Lauraceae, represented by species of six genera, as well as five or six hard- and narrow-leaved subtropical fagaceous species. There are close relationships between fossil species and representatives of the recent East Asian flora with a significantly lower diversity than the taxa of North American and Macaronesian affinity. The East Asian elements of flora prevail among floras of the mountain range and North American elements—riparian floras. The floras of Western Georgia differ from the Sarmatian floras of the northern areas of the Caucasus both ecologically and phenocenotically. The feature of the climate of the Sarmatian of Western Georgia was that this place provided a longer existence not only for a large number of evergreen flowering plants but also for a number of more ancient relic flora species known from the Paleogene.

Late Sarmatian

The fundamental change in the composition of the flora and plant associations began in the second half of the Middle Sarmatian and was completed by the end of the Late Sarmatian. The progressive aridization and

cooling of the climate led to a consistent reduction of coniferous and broad-leaved trees pollen in the paly-nospectra and their replacement by Chenopodiaceae, Asteraceae, and Poaceae, which indicated a wide development of open landscape. Changed of phytolandscapes with the development of poorly differentiated forest-steppe and steppe vegetation covered the entire flat area to the north of the Paratethys.

Small-leaved subxerophyte floras of Ciscaucasia, the Late Sarmatian age of which was determined based on mollusk assemblages from plant-bearing beds, was described from different localities: leaf floras from sections near the city of Armavir (Kutuzkina, 1964) and Labinskaya settlement on the Kuban River (Pashkov, 1959), as well as near the city of Apsheronsk (Kutuzkina, 1974), where leaf imprints were supplemented with a rich collection of seed flora processed by P.I. Dorofeev (1964). The forest-formers in the Late Sarmatian were *Fagus*, *Castanea*, *Carpinus*, and *Platanus*. In the Late Sarmatian flora of Armavir, *Pterocarya*, Fabaceae, and Hamamelidaceae taxa played a significant role; single finds of *Laurus* and *Cinnamomum*, pomegranate, and *Loranthus* were also recorded. Forests preserved some taxa known from the Paleogene vegetation cover (*Ginkgo*, *Cercidiphyllum*, and *Liquidambar*), as well as a number of modern Transcaucasian relicts (*Zelkova* and *Parrotia*). The generic composition of floras is very close to floras which were common on the Russian Platform and in the northern Cis-Azov region and Eastern Ukraine in the Konkian epoch.

The Apsheronsk flora, also dated to the Late Sarmatian, is widely represented by a number of taxa previously unknown or extremely rarely occurring in the floras of this age in Ciscaucasia (*Phyllerea pschechen-sis*, *Punica paleogranatum*, *Quercus cerris* var. *caucasica*, *Populus apscheronica* (Kutuzkina, 1974)). The composition of the seed flora is much richer, which indicates the inclusion of a wide range of deciduous species [*Fagus*, *Carpinus*, *Pterocarya*, *Betula* (sect. *Costatae*), *Juglans*, *Acer*, *Eucommia*, *Fraxinus*, *Styrax*, and *Viburnum*] in the forest communities. This flora also includes some southern representatives of deciduous floras (*Meliosma*, *Moroidea*, *Eurya*, and *Ampelopsis*), as well as other southern species plant that were correlated by Dorofeev with recent species (*Prunus spinosa*, *Buxus* spp., *Kenranthus* spp. *rubber*, and *Atriplex* spp.). Forests of the high mountain belt were formed by *Tsuga*.

In the southwest of Ukraine, Middle and Late Sarmatian seed floras were studied by P.I. Dorofeev (1955) in the valleys of the Yuzhny Bug and Tiligul rivers. Taphocenoses are formed mainly by herbaceous plants of wetland and open coastal habitats (*Azolla*, *Salvinia*, *Marsilea*, *Lemna*, *Ceratophyllum*, *Caldesia*, *Carex*, etc.), as well as by groups of dry slopes (*Polygonum*, *Runex*, *Euphorbia*, *Physalis*, *Potentilla*, and *Cleome*). Representatives of dendroflora (*Morus*)

occur only occasionally in these southern floras. They are mostly represented by fruiting shrubs or lianas (*Myrica*, *Ampelopsis*, *Sambucus*, and *Aralia*). It can be assumed that the vegetation cover of the Ukraine was dominated by forest-steppe and open landscapes inhabited by herbaceous plants from the second half of the Sarmatian. The Late Sarmatian climate of Ciscarpathia was more arid and, at the same time, had lower average annual temperatures (not higher than +11°C).

In southwestern Georgia, Late Miocene floras of different ages are known from the volcanogenic Goderdzi Formation. Flora-bearing beds are basal and confined to the tuffaceous member in the middle part of the formation. The basal member is exposed near the town of Vale, near the border with Armenia in the south of the Akhaltsikhe depression. It overlies a variegated formation, presumably of Oligocene age, over an unconformity (Chelidze, 1965). The flora from the tuffs of the middle part of the Goderdzi Formation (Uznadze, 1946; Takhtadzhyan, 1963) was collected near the Goderdzi mountain pass, as well as near the village of Utkhisubani 134 km from the city of Batumi. Near the Goderdzi pass, plants "on the vine" were completely buried by ash falls and represented not only by leaf imprints and fructifications but also by fossil wood remains.

The flora of the Vale locality is represented by evergreen and deciduous plants, slightly dominated by the former (dwellers of dry subtropical climate). The flora is small-leaved and hard-leaved. Most of the descendants of plants of the Vale flora still live on the dry mountain slopes of the Caucasus, although there are also plants of American, Macaronesian, Asia-Minor, Anatolian, and East Asian affinity. In addition to the remains of ferns (*Polypodium*, *Adiantum*, and *Vandenboschia*), fan palms, and pines, a riparian deciduous element (willows, poplars, bayberries, hornbeams, alders, and zelkovas) is also widely represented, dominated by the evergreen *Myrica lignitum*. The evergreen component is also represented by several species of narrow-leaved hard-leaved oaks: *Quercus elaeagnifolia*, *Q. ilex*, *Q. neriifolia*, etc., various Lauraceae (*Cinnamomum*, *Persea*, and *Laurus* species), and stunted tree and shrub legumes (*Cassia*, *Sophora*, *Robinia*, *Colutea*, *Dalbergia*, and *Podogonium*), which makes similar the Vale flora with the Late Miocene floras of the Vienna Basin (Berger, 1954). Deciduous shrubs are also represented in the flora: *Spiraea*, *Sorbus*, *Rosa*, *Laurocerasus*, *Mahonia*, and *Ligustrum*. Among evergreens, there are also single finds of *Ilex*, *Sapindus*, *Zyziphus*, *Myrtophyllum*, *Bumelia*, *Ficus*, etc. Despite the wide ecological range of fossil species, most of them are characteristic of maquis vegetation and stunted trees and shrubs thickets of mountain habitats.

The Late Sarmatian age of the Vale flora is confirmed by its taxonomic proximity and physiognomic similarity with other coeval small-leaved floras of the

Paratethys and Western Mediterranean (Armavir, Apsheronsk, and Krymsk floras) and Late Miocene floras of Italy (Senigallia and Piedmont), Anatolia (Mangilica), Serbia (Bela Stena), Bulgaria, and Transcarpathia.

Maeotian

At the beginning of the Maeotian, the climate became wetter and colder and, at the same time, remained warm-temperate. There was a recovery of forest vegetation formed by a wide range of catkin-bearing genera (fagaceous, betulaceous, and juglandaceous taxa), while conifers were almost completely absent. The role of shrubs formed by Rosaceae and Fabaceae significantly increased. Open areas were occupied by Chenopodiaceae and Compositae, in particular, *Artemisia* species. An important role was played by grasses. The diversity of herbs and dwarf shrubs was not limited to the above-mentioned families. In the Maeotian, it noticeably increased and the presence of two or three species of *Ephedra* pollen, as well as pollen of Polygonaceae species, *Aesculus*, *Delphinium*, *Euphorbia*, etc., was recorded in almost all palynological samples from the Maeotian deposits and pollen of *Sparganium*, *Lotus*, water-lily, *Trapa*, and *Salvinia* water fern among coastal aquatic plants. This was confirmed by the determinations of seed floras by Dorofeev (1951) and P.A. Nikitin.

In the second half of the Maeotian, the climate retained its winter humidity and, at the same time, became more arid. The pollen of herbaceous plants in open areas is up to 90% of palynospectra. In the south of the Russian Plain, treeless landscapes became dominant and were replaced by mixed forests only in the middle region. Pine forests with *Picea*, *Abies*, and *Tsuga* grew in the north of the region.

The climate significantly dried in northeastern Bulgaria from the second half of the Middle Sarmatian to the middle of the Maeotian (Ivanov, 1995). Xerophytic herbaceous cenoses with Chenopodiaceae, *Artemisia*, and Caryophyllaceae reached the maximum development. The main forest-forming species in mountain forests were *Ulmus*, *Quercus*, and *Carya*.

In the Late Maeotian and Pontian (the Akmanaian and Novorossian substages), the proportion of shrub—herbaceous cenoses and evergreens decreased due to the continued climate cooling and humidity. The increased role of hygrophites plants was reflected in a wide development of *Alnus* in the vegetation cover. The proportion of *Fagus*, *Carpinus*, and *Betula*, as well as conifers (*Picea* and *Abies*) increased in mountain forests; however, the main position was occupied by *Castanea*, *Quercus*, and *Ulmus*.

In contrast to the floras of the second half of the Sarmatian, the Maeotian seed flora from the Odessa region (Dorofeev, 1951, 1955) characterizes forest vegetation with a variety of woody angiosperms (*Carpi-*

nus, *Liriodendron*, *Morus*, *Acer*, *Betula*, *Salix*, *Prunus*, *Crataegus*, etc.) and conifers (*Picea*, *Abies*, and *Tsuga*). At the beginning of the Maeotian, the herbaceous—shrub xerophytic vegetation of the Late Sarmatian was replaced by taiga-shaped forests. The Maeotian climate was more humid and characterized by warm summers and harsher winters.

According to paleocarpological data (Negro, 1986), the flora of the Maeotian of Moldavia has a more diverse composition and is characterized by the richness of conifers and absence of taxodiaceous and an even greater reduction in the number of evergreens. The dominant role was played by the forest vegetation of broad-leaved summer-green and dark-coniferous—broad-leaved formations. Compared to the Sarmatian, the diversity of herbaceous forms noticeably increased: Caryophyllaceae, Lamiaceae, Urticaceae, Violaceae, Capparaceae, Asteraceae, etc. The Maeotian climate was warm and humid at an average annual temperature of about +12°C and an average annual precipitation of not less than 900–1000 mm.

The Maeotian floras of Western Georgia are poorer than the Sarmatian ones; however, they are very closely related to them. The core of the floras was formed by warm-temperate species of humid climate at that time; however, many evergreens (Lauraceae) were still preserved. They were particularly diverse in the south in Guria, where they were accompanied by ferns, including arborescent, as well as conifers. The number of representatives of mountain forests noticeably increased compared to the Sarmatian. With respect to the species composition, the Maeotian flora of Western Georgia is close to the South European floras of Italy and the Balkan Peninsula.

Pontian

In the Pontian palynoassemblages of the Cis-Azov region and lower Don reaches, the content of herb pollen increases to 90–95%. Chenopodiaceae, Compositae (including *Artemisia*), and Poaceae, were dominant. The proportion of the pollen of trees plants is no more than 10% of the composition of spectra; among them, the content of *Pinus* subgen. *Diploxylon* was minimal (up to 4%) and the pollen of dark conifers (*Picea*, etc.) was absent. The pollen of trees angiosperms is represented by *Betula* sect. *Albae*, *Corylus*, and *Quercus* and, more rarely, by *Myrica*, *Juglans*, etc. A great similarity of Pontian palynoassemblages with Late Maeotian assemblages dominated by herbaceous pollen is noteworthy. Their composition becomes more diverse in the Pontian; there are significantly more Poaceae and *Artemisia*, while the proportion of chenopodiaceous pollen decreases. According to palynological data from sections of the Ukraine, the northern coastal belt of the Paratethys was more forested, in particular, in the Late Pontian (Ananova, 1974).

In the Pontian, the latitudinal differentiation of the vegetation cover is even more pronounced. Sagebrush—pigweed dry steppes extended in the southeast of the Russian Plain; at the beginning of the Pontian, they were replaced by more hygrophilous groups with grasses and forbs from the middle of the Pontian. Leafy forests spread along river valleys. In the Ukraine, steppe vegetation was gradually replaced by shrubs with acacia and other fabaceous taxa from east to west. This was accompanied by the simultaneous appearance of spots of pine and mixed forests.

In the Pontian flora of the Izmail region, many elements of Maeotian flora except dark conifers were preserved against the background of the preservation of forest vegetation. The Pontian floras of Moldavia are poorer than the Maeotian ones (Negro, 1986). Their feature is the absence of dark coniferous and typical broad-leaved subtropical forms against the background of a significant enrichment with plants of warm-temperate flora, similar to modern ones. Phytogeographically, the flora is rich in Holarctic and European—Turanian elements. The vegetation was forest-steppe. The climate of the Pontian was subarid, with an average annual temperature of up to +11°C and an average annual precipitation of up to 600 mm.

The richest floras are the Pontian floras of Abkhazia, studied by A.A. Kolakovskii (1964). Thus, not less than 180 plant species were recorded in the Pontian flora of Kodor; a significant part of them were new species. According to the data of this researcher, mountain and lowland swamp forests became widely developed in Abkhazia. Riparian and low-slope formations were formed by monodominant communities with *Quercus neriifolia*. Independent groups were represented by species *Quercus*, *Carya*, *Alnus*, *Salix*, *Platanus*, and *Liquidambar* in combination with *Populus*. The main edificator species were *Quercus codorica*, *Carya denticulata*, *Alnus subcordata*, *Salix varians*, *Platanus platanifolia*, *Liquidambar europaeum*, and *Populus populina* in this case. The forest vegetation of the lower belt was formed by humid and hemixerophilous forests, the initial types of which were humid subtropical forests transformed under the effect strengthening the cooling and continentality of the climate.

A feature of these forests was the presence of relics of more ancient European mastixioid floras: some ferns, Fagaceae, Araliaceae, Lauraceae, and palms. The appearance of hemixerophyte cenoses is recorded as early as the Sarmatian. The vegetation of this type is reflected in the distribution of hard-leaved forests with maquis elements. Separate formations were formed by hard-leaved oak forests with *Quercus sosnowskii* as well as forests of *Quercus* sect. *Roburoides* and pine. The middle and upper mountain belts were occupied by broad-leaved deciduous forests dominated by *Fagus*, with *Carpinus*, *Carya*, *Castanopsis*, *Castanea*, *Quercus*, etc. The dominants of mixed and coniferous forests

were firs, pines, beeches, and birchs (Kolakovskii, 1964).

The composition of the Pontian floras of Guria and Megrelia is known from palynological data. The subtropical element is more widely represented these floras than in floras of Abkhazia. The presence of *Pandanus* and *Sterculia* pollen additionally emphasizes their close relationship with floras of humid subtropical regions.

In western Turkmenistan, finds of megafossils are known from the Cheleken Formation of the Late Miocene—Pliocene. In addition to grasses, tугai groups were formed by *Populus ariana*, *P. diversifolia*, and *Periploca graeca*. Red sediments are dominated by Atripliceae pollen; *Ephedra*, *Artemisia*, and Poaceae are recorded here. At the end of the Miocene, the open phytolandscapes of Cheleken were very similar to the modern ones.

However, forests in Central Asia were also partially preserved in the Late Miocene; against the background of the activation of the Tien Shan and Pamir uplifts, the areas occupied by vertically differentiated forest vegetation expanded again. Deciduous forests with walnut, *Pterocarya*, sweetgum, and legumes were common in the lower stage and coniferous forests were widespread in the upper mountain zone.

Pliocene

In the Pliocene, zones that existed in the Miocene were preserved in the framing of the Paratethys; however, their vegetation types changed. In the northern zone, forest floras continued to actively degrade and treeless areas occupied by forest-steppe and steppe vegetation were formed. Polydominant forests with coniferous, broad-leaved, and small-leaved woody flowering trees were formed to the north of the forest-steppe zone; they at higher latitudes were replaced by south-taiga type forests. Broad-leaved forests with species close to modern species of Central and South European forests developed in some places.

Kimmerian

Several hundreds of species of tree and shrub plants were found in floras from the Kimmerian to the Pleistocene. In Kimmerian floras, there are three assemblages corresponding to the main subdivisions of this regional stage. The most diverse flora is the Middle Kimmerian flora. In the first half of the Kimmerian, steppe and sometimes semidesert vegetation spread again in the south of the Russian Platform under conditions of an even hotter and drier climate. The boundary of its range roughly coincides with the modern boundary of the steppe region of southern Eurasia.

On the northern outskirts of the Paratethys (Donbass and the Cis-Azov region), the composition of Pliocene floras can be reconstructed only from paly-

nological and paleocarpological data. The seed floras of the lower Don reaches were described by Dorofeev (1957). They have been studied from Beds with Levantine fauna and are represented by herbs and dwarf shrubs, including aquatic and coastal aquatic species with a few tree forms (*Salix*, *Betula*, *Morus*, *Ampelopsis*, and *Sambucus*). The presence of some pre-Akchagylia species (*Salvinia*, *Azolla*, *Potamogeton*, *Najas*, *Dilichium*, *Decodon*, *Myriophyllum*, etc.) forms the archaic aspect of the flora. Remains of herbs (*Scirpus*, *Demasonium*, *Rumex*, *Bunias*, etc.) are typical for open areas and include some coastal aquatic forms.

The Early Pliocene palynoassemblages of “Ergeni sands” can be conditionally dated to the Kimmerian age based on the established “leaning” of Upper Pliocene Akchagylia sands against these assemblages. The dominance of herb pollen in the palynospectra indicates the preservation of open landscapes directly to the north of the Paratethys. There were some changes among the leading taxa compared to the Pontian Age: Chenopodiaceae become the main group again, while the total proportion of Poaceae and *Artemisia* is no more than 10% of the volume of pollen spectra. It should be noted that Lower Pliocene deposits require additional study, since the sands contain extremely little pollen and no megafossils.

The pre-Akchagylia floras of the Kinel Formation in the Middle Volga, Bashkortostan, and Voronezh regions are of forest type and similar to southern taiga floras and include conifers (pine, spruce, larch, and juniper). In the Trans-Volga region, this list is supplemented with fir and *Tsuga*. There are numerous remains of reproductive organs of catkin-bearing species (*Betula sect. Albae*, willows, and alders) and the finds of fruiting rowan, *Andromeda*, bayberry, and *Daphne* suggest the development of not only southern-taiga but also deciduous forests with rich underbrush. Relics were preserved in trans-Volga Kinelian forests: Amur cork tree, mulberry, *Actinidia*, *Weigela*, and *Stefanandra*. There are many relics, as well as plants with European and Central Russian relationships, among herbaceous plants (Dorofeev, 1957). Kinelian floras are closer to Miocene floras than to Akchagylia and Apsheronian ones.

At that time, relic subtropical forests still continued to exist in Western Georgia; however, in the Early and, in particular, Late Kimmerian epoch, the major role was played by deciduous tree–shrub forms. By the end of the Kimmerian time, laurel forests completely lost their significance and were preserved only as relics in broad-leaved forests formed by heat-loving deciduous forests: *Carya*, *Quercus*, *Zelkova*, and *Juglans*.

The richness of the Kimmerian flora of Abkhazia can be assessed by the diversity of mosses (more than 30 species), including extinct species, the descendants of which are common in tropical and subtropical regions (Indo-Malesian and Macaronesian regions). The core of the Middle Kimmerian flora of Western

Georgia (38%) was formed by taxa, the transformed descendants of which are known from East Asia, mainly from areas of monsoonal subtropical and warm temperate climates. About 18% of the flora was formed by the North American refugial element. The proportion of the Palearctic and Holarctic element was no more than 10%. Different refugial-geographical elements differ not only cenotically and ecologically, but also in origin: there is a combination of plants that appeared in the Paleogene and those which are known only from the Neogene. The latter include some Lauraceae, alders, and *Actinidia*. Comparison of the Kimmerian flora of Western Georgia and Abkhazia with the more ancient Miocene flora suggests that the Kimmerian flora proved to be enriched in a greater number of previously unknown species, although many taxa of the Miocene did not pass into this flora.

For the Kimmerian epoch of Western Georgia, N.K. Ratiani (1975) reconstructed several types of forest vegetation associated with the zonality of its cover and climate factors characteristic of mountain areas. Lake-swamp plants, consisting mainly of monocotyledons, were widespread in the partially swamped coastal strip. The composition lower swampy riverine forests included *Glyptostrobus europaeus*, *Taxodium* sp., *Platanus platanifolia*, *Nyssa dessiminata*, *Quercus neriifolia*, *Carya serrifolia*, *Pterocarya castanaefolia*, *Myrica lignitum*, *Liquidambar europaeus*, etc. They were accompanied by palm trees. The gorge slopes located above were occupied by evergreen forest vegetation with Lauraceae and *Castanopsis*. Ferns of subtropical and even tropical affinity grew in the ground cover.

The lower hypsometric level was formed by riparian forests common in drained depressions and river valleys. They were gradually replaced by foothill forests, which covered placodes. The foothill belt was formed by broad-leaved mesophilic forests with conifers and hemixerophytes. Wetter biotopes were represented by *Fagus attenuata*, *Zelkova zelkovifolia*, *Eucommia ulmoides*, and *Magnolia* (several species). The underbrush consisted of stunted trees, shrubs, and lianas (*Deucia kimmerica*, *Hamamelis kryshstofovichii*, *Schizandra grossheimii*, *Vitis silvestris*, *Ampelopsis* spp., *Sambucus* sp., *Styrax* spp., etc.). Conifers were represented mainly by *Cryptomeria*. Poplars, elms, and juglandaceous taxa spread along river valleys. The grass cover consisted of ferns. *Quercus sosnovskiyi*, *Acer monspessalanum*, and *Celtis* occurred in drier habitats and *Carpinus ex gr. orientalis*, *Phyllirea*, *Ceanothus*, *Viburnum*, and *Pistacia* were recorded in underbrush (Ratiani, 1975).

Two upper belts were formed by mid-mountain and high-mountain forests, since the height of the watershed of the Greater Caucasus was not less than 2500 m as a result of Late Sarmatian uplifts. Mountain ranges along its periphery also reached significant absolute

elevations. Various deciduous broad-leaved and coniferous trees were widespread in the mid-mountain belt. The main components of these forests were *Fagus*, *Carpinus*, *Castanea*, and *Amur* cork tree. Mixed and coniferous forests consisted of *Cryptomeria*, *Thuja*, and *Tsuga*. All of them did not survive Late Pliocene and Pleistocene cooling. The composition of the underbrush was especially rich; it included *Corylus*, *Buxus*, *Viburnum*, *Actinidia*, etc. Willows, poplars, and elms spread along the banks of the rivers. The forests of the upper mountain belt were formed by the same coniferous forests as middle-mountain forests and also included pines. The most cold-loving woody flowering plants, including birch, were common in the underbrush.

The Goderdzi flora reflects a stage of short-term warming, most likely in the Kimmerian epoch, when the climate became humid subtropical in southern Georgia for a short time. This is confirmed by finds of remains of evergreens from the upper part of Goderdzi tuffs (Uznadze and Tsagareli, 1979). The flora of the Goderdzi pass (Uznadze, 1946; Takhtadzhyan, 1963) is characterized by large-leaved plants. It is represented mainly by evergreen woody tree, including laurels (*Cinnamomum*, *Actinodaphne*, *Litsea*, and *Neolitsea*), *Magnolia* spp., and palms (including *Livistona*, which is sensitive to moisture and heat). The composition of heat-loving ferns preferring wet habitats is diverse: *Woodwardia*, *Pteridium*, *Cyclosorus*, etc. Coniferous (*Pinus* and *Podocarpus*) are among plants of the mountain range.

The climate of the Kimmerian time in lowlands and foothills of Western Georgia and Abkhazia was closer to the humid subtropical type with an average temperature of not less than +8 to 9°C in the coldest month, an absolute minimum of –3 to –4°C, an absolute maximum of +24 to +26°C, and annual precipitation of 1500–2000 mm. In the Kimmerian, the zonation of the vegetation cover corresponded with the climatic zonation.

Akchagylian/Kuyalnikian

During the period of Akchagylian transgression, the forest vegetation in the middle latitudes of Eastern Europe and in the Lower Volga region was replaced by steppe vegetation, which was replaced by forest deciduous vegetation again towards the Northern Caucasus. The Neogene flora of the Russian Plain changed little by the time of the first Akchagylian transgression. After the second transgression (in particular, after its maximum phase), most relicts were eliminated from the vegetation cover, while the main composition of conifers and herbs was preserved. *Epipremnum crassum* and *Decodon globesum* continued to occur until the Apsheronian epoch. *Caldesia* and *Teurnefortia* were still present before the Wurm stage. The post-Akchagylian (Apsheronian) seed floras of the Russian Plain differed little from modern ones. In middle latitudes,

these are typical forest floras containing almost no exotic species. However, many Pliocene species were preserved in “nunataks” even during the period of maximum Pleistocene glaciations. The study of seed floras made it possible to discover many Pliocene relicts in Quaternary sediments, as well as plants of boreal–arctic association, which became widespread during glaciations.

The composition of palynoassemblages and seed flora was established only for the Middle and Late Akchagylian. It differs in more southern and northern areas, since the Akchagylian sea basin stretched in the meridional direction for many hundreds of kilometers. The revealed differences are determined by the latitudinal zonation of the vegetation cover, as well as by changes in the ratio of tree and herbaceous pollen and the composition of the latter, while the content of tree pollen remains almost constant throughout the meridional sea water body. The latter is probably explained by a high pollen productivity of tree plants and a wider wind and water transport of their pollen. The composition of palynospectra is poor, and many plants of the Neogene flora (*Sciadopitys* and other Taxodiaceae, *Nyssa*, *Liquidambar*, *Weigelia*, etc.) disappear from the vegetation cover by the Late Pliocene and boreal elements became completely abundant. In northern regions (Tatarstan), the proportion of coniferous pollen (in particular, pine and spruce) noticeably increased (up to 40–60%); at the same time, its diversity significantly decreased in the south: in the Akchagylian time Caspian Sea region, its content was no more than 10%. The pollen of white birch, alder, hazel-nut, wych, elm, oak, hornbeam, and sometimes juglandaceous taxa constantly occurs. Under conditions of dominant woody vegetation in the northern regions, the ground cover in the forests was formed by herbaceous plants, which almost completely displaced ferns. On the whole, the Akchagylian assemblages have a mosaic pattern. Their composition changed not only from south to north but also from west to east, where there is more pollen from plants adapted to the subarid conditions of the continental climate. The composition of palynoassemblages was relatively constant only in the Late Akchagylian.

In the Kuyalnikian, which is an age analog of the Akchagylian in the Euxinic part of the basin, the previously single Transcaucasian province was divided into two provinces: the western Colchis–Guria province (which had a higher of moisture supply and preserved subtropical relicts) and eastern Apsheron–Talysh province (which had a lower level of moisture supply and had a winter-humid climate and a subxerophytic flora). In Western Georgia and Abkhazia, there were polydominant coniferous and coniferous–broad-leaved forests with a dense herb–ferny cover formed by plants that have been now hardly preserved in the region. Although subtropical plants still occurred in these forests, their taxonomic composition was significantly lower here. The role of dark

coniferous groups increased significantly and mesophilic elements became more significant in Gurian forests, which led to their dominance at the end of the Late Pliocene and beginning of the Pleistocene. The Late Pliocene flora can only be reconstructed based on palynological data, since the localities of plant megafossils are almost completely unknown. Kuyalnikian forests were significantly poorer in their species composition (in particular, in subtropical species and the most thermophilic deciduous species in humid habitats) than Kimmerian forests. These changes were associated not only with climate changes but also with the transformation of other physical and geographical conditions. North American elements almost completely disappeared from the flora, while many of its components of East Asian affinity were preserved.

Liquidambar, *Carya*, *Nyssa*, *Pterocarya*, *Corylus*, and *Periploca* became widespread in the Late Pliocene forests of the lower belt. Bald cypress was preserved until the end of the Pliocene. *Cinnamomum* and magnolias, which survived cooling, appeared in the vegetation cover closer to the foothills. They were represented by separate groups in broad-leaved forests in the warmest and most humid habitats. Foothill forests were formed by broad-leaved woody plants with an admixture of hemixerophilous plants (*Castanea*, *Parrotia*, *Carpinus*, walnuts, *Zelkova*, etc.). Tree plants requiring less moisture included oaks, laurels, sumacs, etc. These forests also included conifers (*Cryptomeria* and *Podocarpus*). They were the main components of the high-mountain forests. The grass cover was formed by ferns. *Fagus*, *Carpinus*, *Castanea*, *Acer*, and *Tilia* were the dominant woody plants in the middle mountain belt. These forests also included conifers (fir, cedar, spruce, pine, and *Tsuga*) and Taxodiaceae and, possibly, *Sequoia* or *Metasequoia*. The understory was formed by *Euonymus*, *Ilex*, and *Corylus*. At the beginning of the Pleistocene, most subtropical plants (most of the Taxodiaceae and *Cryptomeria*) were extinct due to further cooling. A number of *Pinus*, *Thuja*, and *Tsuga* species, many Hamameliaceae, Araliaceae, Fabaceae and *Parrotia*, some hard-leaved oak species, etc., disappeared in the Pleistocene. The extinction was gradual, and it is difficult to determine certain lines of elimination.

A humid, warm-temperate climate, colder than the Kimmerian one, became dominant in the Kuyalnikian time. Within the ranges of dominant elements of the flora, the climate was characterized by the following parameters: the average January temperatures varied from -5 to $+5^{\circ}\text{C}$ at an absolute minimum of -8 to -9°C . July temperatures were $+23$ to $+25^{\circ}\text{C}$. The annual amount of precipitation was not less than 1100–1800 mm. Mountain forests existed under temperate climate conditions. January temperatures were about -10°C here; the absolute minimum could fall to -25°C . The annual precipitation was not more than 1300–1500 mm.

Paleobotanical Data on the History of the Greater Caucasus

Paleobotanical data on the Caucasus region make it possible to assess the direction of orogenic movements in the Neogene based on the identification of the most probable time intervals of Greater Caucasus uplifts. The criteria for such conclusions are as follows: an increase in the content of coniferous remains in macro- and microfossil composition, which indicates an increase in the vertical differentiation of the vegetation cover and the appearance or expansion of mid- and high-mountain vegetation belts. The simultaneously greater proportion of pollen of xerophyte plants in palynocoassemblages indicates a moisture deficit due to an increased shielding role of mountain ranges with the formation of a “rain shadow” beyond the front of growing mountain structures, which are natural barriers for directional moisture transfer. In the Caucasus, the humid air flow significantly decreases from south, i.e., from the ocean area.

Therefore, it is highly probable that the most significant uplifts of the Greater Caucasus occurred during the phases of climate aridization in the Early Miocene and continued in the Karaganian and, partly, Konkian time. The most active uplifts occurred in the Late Sarmatian—beginning of the Maeotian and successively continued at the end of the Miocene and in the Pliocene; however, they were gradual and had no signs of sharp increase.

REVISION OF THE MIOCENE–PLIOCENE MAGNETOSTRATIGRAPHIC SCALE OF THE EASTERN PARATETHYS

The magnetostratigraphic scale of the Neogene of the Eastern Paratethys began to be formed in the 1950s (Khranov, 1958, 1960). The initial object of study included Miocene–Pliocene deposits from Turkmenistan and Azerbaijan (publications by A.N. Khranov, Asadullaev, and Pevzner, 1973; Trubikhin, 1977, etc.), Ciscaucasia, Transcaucasia and the Kerch–Taman region (Pevzner and Chikovani, 1978; Zubakov and Kochegura, 1984; Gruzinskaya et al., 1986, etc.), and Ukraine (Semenenko and Pevzner, 1979).

There were serious technical problems in developing the Paratethys geomagnetic polarity scale, mainly due to the special characteristics of magnetic carriers in the deposits. Deposits of this inland water body with a sharp stratification of the water mass were often formed under oxygen-depleted conditions, which led to the formation of paramagnetic iron sulfides (pyrite) and iron carbonates (siderite and ankerite) or greigite (iron sulfide with strong magnetic properties), the formation of which was associated with diagenetic processes. Since it was documented that greigite in Paratethys was authigenic and formed during sedimentation (Vasiliev et al., 2004), its use in magnetostratigraphic dating was resumed, although

the presence of iron sulfides still imposed some limitations. For instance, thermal demagnetization could be applied in a limited temperature range (below 420°C to prevent pyrite oxidation to magnetite) and demagnetization in alternating fields required special techniques to prevent field-induced effects (to prevent the gyroremanent behavior of greigite in strong alternating fields). These technical limitations and the rarity of continuous sections are the main reasons why the magnetostratigraphic pattern for the Maikopian anoxic facies of the Oligocene–Early Miocene is still under development.

Paleomagnetic Scale of the Paratethys

Preliminary data on the geomagnetic polarity of the Paratethys sediments were established by the mid-1980s; however, it soon became apparent that there were serious problems and inconsistencies in the correlation with the chrons of the global geomagnetic polarity time scale (GPTS). Many problems were due to inconsistencies between magnetostratigraphic age models and the existing biostratigraphic correlations of the endemic Paratethys biota with Mediterranean and oceanic time scales. The awareness of these contradictions made it possible to abandon some unreliable biostratigraphic markers (e.g., Beds with Rzehakia, which proved to be diachronous, or identifications of *Ceratolitus acutus* in nannoplankton (Golovina et al., 2019)).

In other cases, magnetostratigraphic data contradicted the correlation of trends of Paratethys development (such as sea level fluctuations or stratigraphic divisions) with global ocean trends. Due to a limited connection or disconnection, the Paratethys region was characterized by trends unrelated to the evolution of the global ocean for long time periods (Popov et al., 2010), which makes the correlations possible only in limited time intervals.

In some cases, the development of magnetostratigraphic models revealed large differences in the understanding of the ranges of regional stages and their boundaries between sub-basins due to the existing ecological or paleogeographic differences. For instance, the boundaries between the Pontian and Dacian in the Dacian Basin and between the Pontian and Kimmerian in the Kerch–Taman region are defined at different levels, although they have similar faunal characteristics.

These differences made it difficult to develop basinwide age models and reflected the practical issues that had to be solved during the creation of a magnetobioisotope stratigraphic scale adapted to the Paratethys. The biostratigraphic correlations had to be revised and unreliable correlations with global events were abandoned.

Miocene

The Miocene interval of the Paratethys magnetostratigraphic scale has until recently been the most problematic due to its complex correlation, the predominance of anoxic facies, and rare continuous sections. The problems of correlation and comparison of scales have only recently been partly solved thanks to the accumulation of paleomagnetic data and advances in phytoplankton and isotopic stratigraphy.

Lower Miocene. Since the magnetostratigraphic scale of the Miocene in the Paratethys was developed from younger to older deposits, the Lower Miocene remains the least studied and has no established polarity scale. The currently available paleomagnetic data are insufficient for the reliable characterization of the Caucasian, Sakaraulian, and Kozakhurian stages. According to the opinion of Trubikhin, the deposits of the Sakaraulian Stage in the stratotype area (Kartli depression) are characterized by a normal polarity at the base and a long interval of reversed polarity in the upper part (Trubikhin, 1998; *Unifitsirovannaya...*, 2004). Kozakhurian deposits are successively represented (from bottom to top) by a normal polarity zone, an interval of reverse magnetization of rocks, and, again, by a normal polarity horizon at the top. Similar paleomagnetic characteristics are determined for deposits correlated with Sakaraulian–Kozakhurian deposits in Kopetdag (Voronina et al., 1993) and northern Ustyurt (Kazanskii, 1988). However, biostratigraphic data show that the Caucasian, Sakaraulian, and Kozakhurian intervals correspond to the Early Miocene, i.e., to the time interval characterized by more than 30 magnetic polarity reversals, which requires higher resolution studies for determining reliable correlations.

Middle Miocene. The Tarkhanian Regional Stage is very short. The lower boundary is determined in most sections as the end of the anoxic facies of the Maikopian Group and their replacement by lighter calcareous clays with malacofauna. This boundary is correlated with the lower part of subchron C5Bn.1n or descends slightly lower into a short reversed polarity subchron, C5Bn.1r, and is dated to 14.85–14.9 Ma (Fig. 19). The upper part of the Tarkhanian is often disturbed and characterized by mass transport deposits (MTB) or unconformities, which can be traced in many of the studied sections; therefore, accurate data on this part are not yet available. The entire Tarkhanian presumably corresponds to the interval of 14.85–14.9 Ma (Palcu et al. 2019a).

The Chokrakian Stage has now been quite completely characterized. The lower boundary of the Chokrakian overlies the disturbed Upper Tarkhanian and, in some cases (e.g., the Pshekha River in Western Ciscaucasia), also contains reactivated Tarkhanian olistostromes. Due to this instability, the boundary is tentatively marked at the end of short normal-polarity subchron C5Bn.1n and has an age of about 14.77–

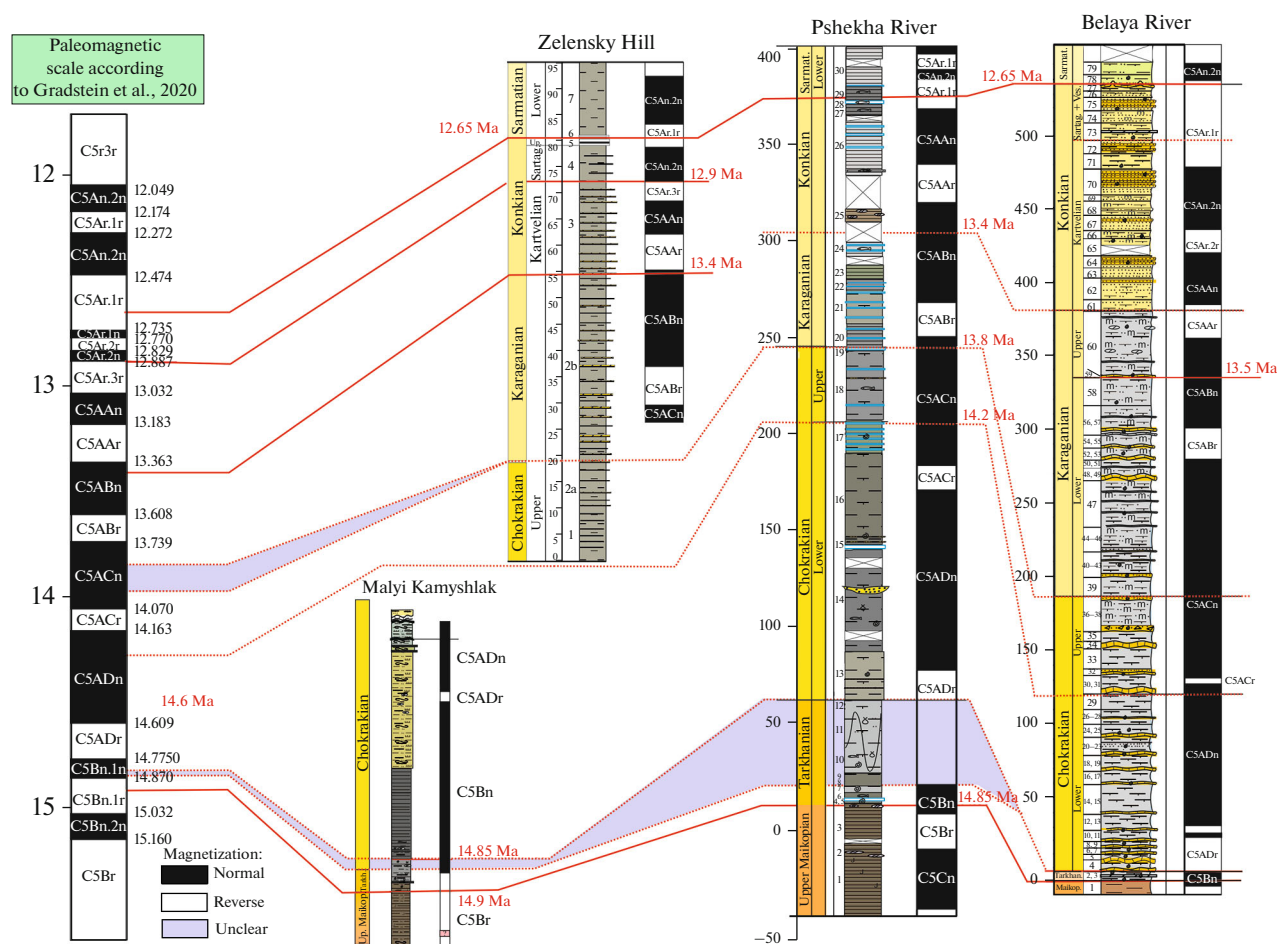


Fig. 19. Paleomagnetic characteristics of the Middle Miocene reference sections.

14.8 Ma (Palcu et al. 2019a). The boundary between the Upper and Lower Chokrakian substages has not been completely determined. In the section of the Belaya River in Western Ciscaucasia, where this boundary is faunistically well dated, it passes in the upper part of Chron C5ADn (Fig. 19) and has an age of about 14.2 Ma, while it is marked only tentatively in the adjacent section of the Pshekh River (in the lower half of Chron C5ACn) and, consequently, has an age of about 14 Ma. This contradiction is probably caused by the inaccuracy of the determination of this boundary in the Pshekh section, where the fauna is sparse due to a deeper bathymetric regime.

The Karaganian Regional Stage is fully characterized by paleomagnetic data. The lower boundary of the Karaganian lies in the upper or middle part of normal polarity chron C5ACn and its age is estimated at 13.8–13.9 Ma (Palcu et al., 2017). The boundary between the Upper and Lower Karaganian substages in the section of the Belaya River, where it is characterized by mollusk fauna, is in the middle part of chron C5ABn and is thus dated at about 13.5 Ma.

The base of the Konkian Regional Stage, which is assumed to be at the base of the Kartvelian Beds in this study, is at the top of chron C5ABn and its age is estimated at 13.4 Ma (Palcu et al., 2017, 2019a). The subdivisions of the Konkian Stage have also been quite fully characterized by paleomagnetic data: the boundary between the Sartaganian + Veselyanka and Kartvelian Beds, which is faunistically well dated based on foraminifers and nannoplankton in the section of the Zelensky Hill in Taman, almost completely coincides with the boundary of subchron C5Ar.2n/C5Ar.3r and is thus dated to 12.9 Ma. The lower boundary of the Kartvelian beds of this section is defined in the upper part of chron C5ABn and has an age of 13.4 Ma.

The Sarmatian Stage (s.l.) was one of the most difficult stratigraphic subdivisions of the Paratethys for paleomagnetic studies. The base of the Sarmatian (both in a narrow and broad sense) was dated in the Central and Eastern Paratethys using biomagnetostratigraphic methods and corresponds to subchron C5Ar.1r and its age is estimated at 12.65 Ma (Palcu et al., 2015, 2017). The chronostratigraphy of the Sarmatian stage has been almost completely resolved to

date, except the boundary between the Lower and Middle Sarmatian (Vollhynian/Bessarabian), which corresponds to 11.9–12 Ma, according to biostratigraphic estimates (Harzhauser and Piller, 2004); however, this chronostratigraphy has been still not dated by paleomagnetic or isotopic methods.

Upper Miocene. The Middle/Upper Miocene boundary passes within the Sarmatian Stage and has recently received much attention owing to its paleogeographic and paleoclimatic significance. The key event marking the separation of the Pannonian–Transylvanian region from the Eastern Paratethys coincides with the boundary between the Sarmatian s. s. and Pannonian and is dated to 11.6 Ma in reversed polarity subchron C5r.3r, slightly above the geomagnetic excursion of C5r.3r-1n (ter Borgh et al., 2013). This event roughly corresponds to the boundary between the Middle Miocene and Upper Miocene and is therefore correlated with the eustatic fall of ocean level. This boundary was initially considered diachronous according to the earlier age (11.3 Ma) recorded in the Transylvanian Basin (Vasiliev et al., 2010); however, later reassessments (studies by I. Magyar and A. de Leeuw) suggested that the boundary corresponded to 11.6 Ma.

It is difficult to date the boundary between the Middle and Upper sarmatians s.l. (Bessarabian/Khersonian) due to a depositional gap and the absence of continuous sections for this stratigraphic interval. On the Taman Peninsula, these deposits are completely exposed and characterized by fauna and phytoplankton (diatoms) in the Panagia section. In this section, the Bessarabian/Khersonian boundary is in the reversed polarity chron correlated with chron C4Ar and dated to 9.6 Ma (Palcu et al., 2021). The data from previous researchers (Trubikhin in *Unifitsirovannaya...*, 2004) and study results for the Panagia section (Fig. 20) indicate that most of the Middle Sarmatian s. l belongs to the normal polarity zone correlated with long chron C5n, which is fully consistent with the new age model for this section.

The Sarmatian s.l./Maeotian boundary was estimated over a wide age range (11.6 Ma according to Moghadam, 2013; 9.8 Ma according to Semenenko et al., 2009; Gozhyk et al., 2015; 9.5 Ma according to Nevesskaya et al., 2003; 8.85 Ma according to Andrews, 2009; 8.6 Ma according to Vasiliev et al., 2011; and 7.6 Ma according to Trubichin, 1989; Radionova et al., 2012). A regional magnetobiostratigraphic study (Palcu et al., 2019b) has shown that the boundary interval is a gradual diachronous filling of the partially dried Eastern Paratethys (Fig. 20). The boundary lies in the interval of both direct and reversed polarity and is dated at 7.65 to 7.4 Ma. The oldest dates of the Sarmatian s.l./Maeotian boundary (the beginning of the transgression) were established in the deepest parts of the basin and correlate to chron C4n.1r, which corresponds to 7.65 Ma in the Cerna and Cernișoara sections of the western depression of the Dacian Basin, while younger age estimates were

found in the more marginal parts of the basin: 7.5 Ma (chron C3Br.3r) in the Rusavatu and Putna sections and about 7.4 Ma (chron C3Br.2r) in the Badislava section in the same basin. Recent studies have provided similar results: 7.65 Ma (C4n.1r) in the Panagia section of the Taman region (Palcu et al., 2021) and 7.6 Ma (chron C4n.1n) in Slanicul de Buzau (Lazarev et al., 2020).

The boundary between the upper and lower parts of the Maeotian in the Taman sections is close to the boundary between chron C3An and C3Ar; however, it is often disturbed by slope instability and characterized by mass-transport deposits or erosional gaps. In the most complete sections (Zhelezny Rog), it lies in the upper strata of chron C3Ar and has an age of about 6.75 Ma. Similar anomalies, marked as an intra-Maeotian event (IME), were described in the Dacian Basin and correlated with the same chron C3Ar; however, the preliminary estimate of their age was slightly higher (about 6.9 Ma) (Palcu et al., 2019b). Due to IME-related disturbances of sedimentation, the age pattern for this event requires more careful study; however, it is likely that the IME event is traced throughout the Paratethys.

Deposits of the base of the Pontian Regional Stage overlie the Maeotian and begin in the normal polarity interval in chron C3An.1n; they are dated to 6.1 Ma (Vasilev et al., 2004, 2011; Krijgsman et al., 2010; Stolica et al., 2013; Chang et al., 2014; Lazarev et al., 2020). Paleogeographic changes associated with the Messinian salinity crisis (MSC) occurred in subsequent reversed polarity interval C3r, which led to the fragmentation of the Eastern Paratethys and establishment of different conditions in the Kuban–Black Sea, Caspian, and Dacian basins. Therefore, the top of the Pontian is differently assessed in these basins and corresponds to different stratigraphic units, which reflect the specific paleoecological history of each of the sub-basins, requiring a separate description.

Pliocene

Euxinic Basin. In the Euxinic Basin, the upper boundary of the Pontian Regional Stage with Azov Kimmerian beds in the stratotype Kerch–Taman region lies almost at the top of a long reversed magnetized interval correlated with chron C3r (Trubikhin, 1998; Filippova and Trubikhin, 2009). In Azov beds, there is a normal polarity subchron correlated with subchron C3n.4n (Thvera). Based on these data, the age of the upper boundary of the Pontian of the Euxinic Basin is estimated to be close to 5.3 Ma, since the base of subchron C3n.4n in GPTS2020 is dated to 5.235 Ma (Gradstein et al., 2020). The alternative age of 5.6 ± 0.1 Ma (Krijgsman et al., 2010) was proposed for the Pontian–Kimmerian boundary based on bio-magnetostratigraphic correlations between the Dacian and Euxinic basins.

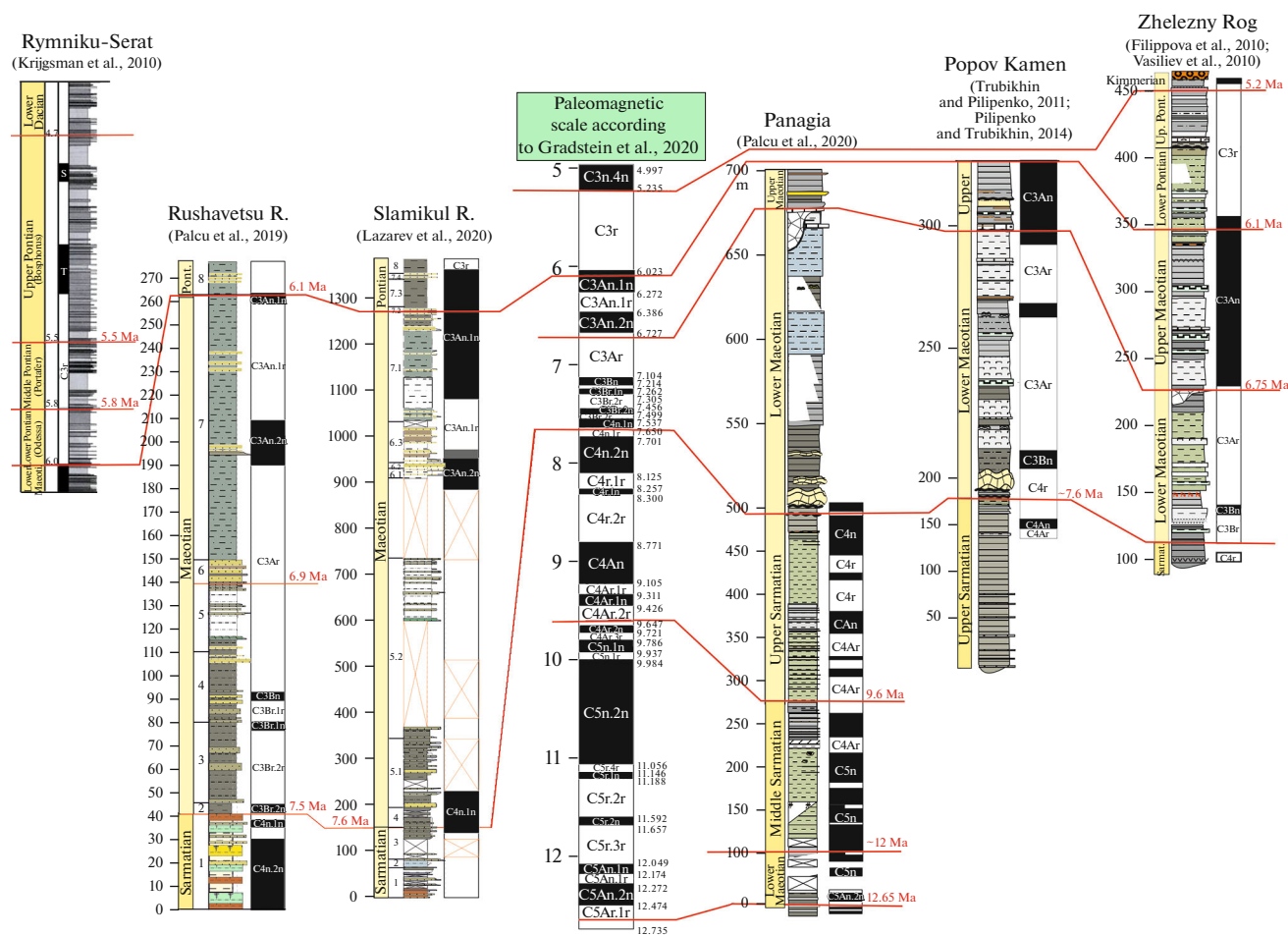


Fig. 20. Paleomagnetic characteristics of the Upper Miocene reference sections.

The Lower Pliocene (Kimmerian Regional Stage) is characterized mainly by a reversed polarity interrupted by four intervals of normal polarity (see Fig. 9); it is correlated with the uppermost sub-units of chron C3r—lower sub-units of C2Ar, including the entire chron C3n (Khranov, 1958; Semenenko and Pevzner, 1979; Zubakov and Kochegura, 1984, etc.). The Lower Kimmerian (Azov beds) includes normal polarity subchron C3n.4n (Thvera) and the lower boundary of Azov beds is close to the base of this subchron. The normal polarity interval at the base of the Kamysh-Burun beds of the Middle Kimmerian is correlated with subchron C3n.3n (Sidufjall), which makes it possible to roughly date the boundary between the Lower and Middle Kimmerian substages at 4.9 Ma. The next normal interval, correlated with subchron C3n.2n (Nunivak), also falls into the Middle Kimmerian, while the uppermost normal interval in the Kimmerian is correlated with subchron C3n.1n (Cochiti) and the end of the Kimmerian is in reversed magnetized chron C2Ar (Fig. 21).

Dacian Basin. Pontian deposits in the Dacian Basin differ significantly in their paleomagnetic char-

acteristics: here, they also begin in normal polarity subchron C3An.1n and include reversed magnetized chron C3r; however, the “upper Pontian” includes two intervals of Gilbert normal polarity (C3n.4n (Thvera) and C3n.3n (Sidufjall)). Therefore, according to the paleomagnetic characteristics, the “Upper Pontian” of the Dacian basin would correspond not only the Azov beds of the Kimmerian Stage of the Kerch–Taman region but also the lower part of Kamysh-Burun Kimmerian beds and the subsequent Dacian Regional Stage corresponds to the upper strata of the Middle Kimmerian and lower strata of the Upper Kimmerian (Fig. 21).

Pliocene–Pleistocene deposits of the Dacian basin are dated in detail in the section of the Slanicul de Buzău River, where the outcrops are continuous and well exposed (Vasiliev et al., 2004; Van Baak et al., 2015a; Jorissen et al., 2018). The Dacian Regional Stage of the Slanicul de Buzău section shows the predominance of reversed magnetic polarity interrupted by two magnetozone with normal polarity. These intervals of normal polarity are interpreted as paleomagnetic subchrons C3n.2n (Nunivak) and C3n.1n

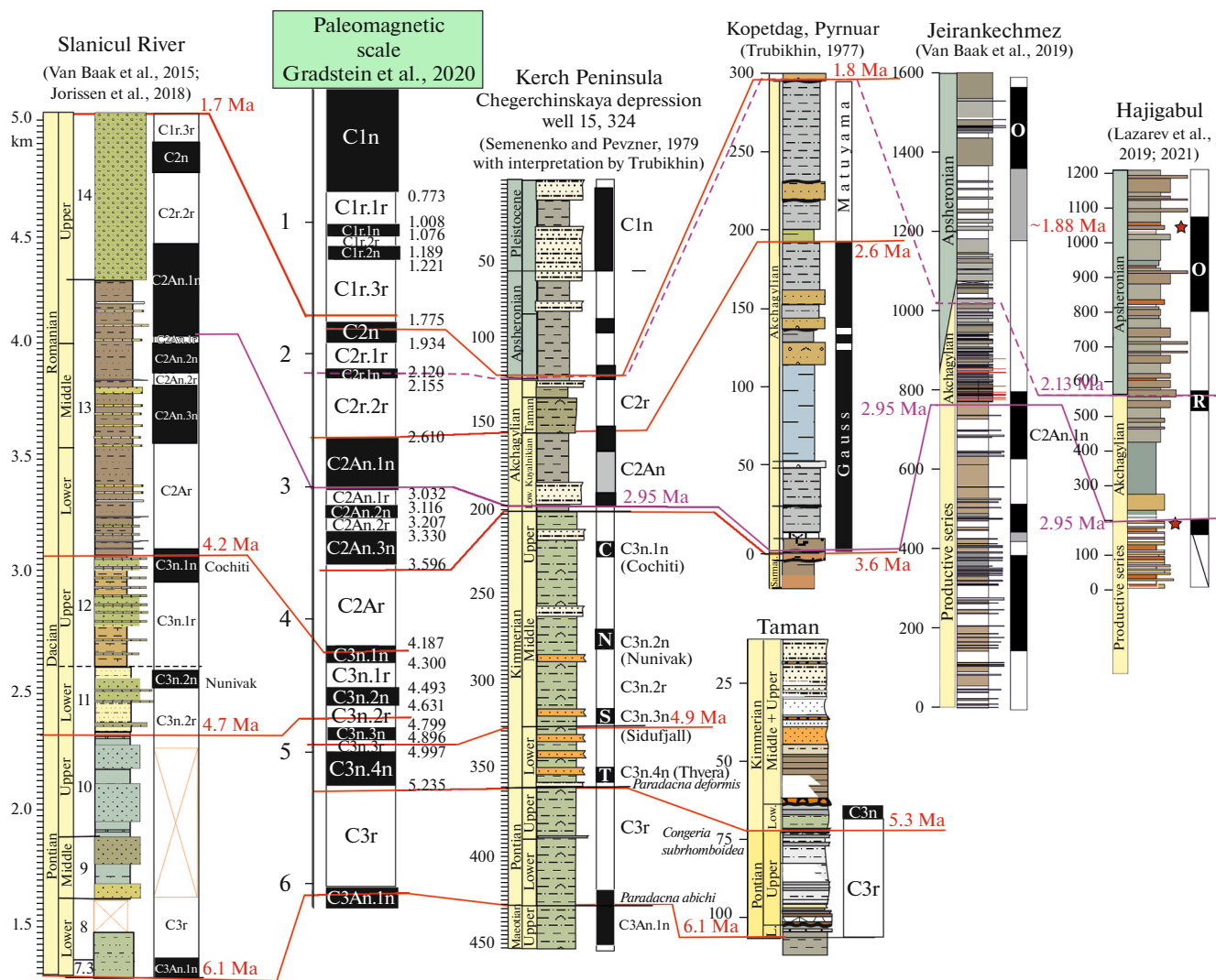


Fig. 21. Paleomagnetic characteristics of the Pliocene reference sections.

(Cochiti) (Fig. 21). According to the underlying and overlying deposits, the age of the Dacian Stage is 4.8 to 4.2 Ma (Vasiliev et al., 2004; Van Baak et al., 2015a; Jorissen et al., 2018).

The Romanian Regional Stage was studied in detail in the lectostratotype section of Slanicul de Buzău. The lower boundary of the stage is in the normal polarity interval corresponding to the upper part of subchron C3n.1n (Cochiti) and is dated at 4.2 Ma. The upper boundary of the stage roughly corresponds to the top of chron C2n (Olduvai) with an age of 1.775 Ma and is dated to 1.7 Ma (Van Baak et al., 2015a).

Caspian Basin. In the Caspian Basin, the Pontian Regional Stage also corresponds to the long reversed polarity interval correlated with chron C3r and the upper boundary of the Pontian with a Productive Series is dated to 5.38–5.23 Ma in the upper part of reversed chron C3r (Van Baak et al., 2017), which is

close to the estimates of the age of the Pontian/Kimmerian boundary in the Euxinic region.

The Productive Series, which is widespread in the Kura depression of the Caspian basin, corresponds to the long episode of a strong fall of the Caspian Sea level during the Pliocene. On the southeastern coast of the Caspian Sea (Turkmenistan), continental deposits of the Toronglinsk Formation (Balkhan) and Red Colour Formation (Krasnovodsk Peninsula) correspond to the productive strata (Trubikhin, 1977; *Stratigraphicheskii...*, 1982). The top of the Productive Series, which is transgressively overlain by Akchagylia deposits, is correlated with the lower part of Chron C2An.1n (Fig. 21, Van Baak et al., 2019).

Akchagylia magnetostratigraphy is based on the study of the South Caspian region, where active tectonics contribute to a good exposure and a good duration of geological sections. Based on data on the sections of Turkmenistan and the Kura depression, it is

possible to distinguish two main age models: the models of the so-called “long” Akchagylian and “short” Akchagylian (Krijgsman et al., 2019).

The “long Akchagylian” model is based on a magnetostratigraphic study of a series of sections on the eastern coast of the South Caspian: the Krasnovodsk Peninsula and Kopetdag (Trubikhin, 1977). Here, the base of the Akchagylian lies within a long normal chron which is followed by a long reversed polarity interval above (Fig. 21); these chrons are interpreted as the Gauss and Matuyama chrons, respectively (Trubikhin, 1977). One or two short intervals of reversed (or indeterminate) magnetization were also found in several sections (Gokchaladze, Issu, Kushuldzha, Orumeldzha, Diodzhi, Pynuar, Zau, and Khalats) within the Gauss chron and interpreted as Kaena (C2An.1r) and Mammuth (C2An.2r) subchrons. The base of the Akchagylian was thus correlated with the base of subchron C2An.3n (Lower Gauss), which was 3.3 Ma according to the Cox scale (Cox, 1969) used at that time, while the top was correlated with the base of the Gilsa subchron and dated to 1.79 Ma (Trubikhin, 1977, Fig. 30). According to GPTS 2020, the “long Akchagylian” model has an age range of 3.6–1.8 Ma (from the base of C2An.3n to the middle part of Chron C2n), which is currently accepted in regional stratigraphic schemes of the Caspian region (Trubikhin, 1977; Semenenko and Pevzner, 1979; Molos-tovskii and Khramov, 1997; Nevesskaya et al., 2004).

The “short” Akchagylian model was partially proposed back in the 1960s (Khramov, 1960; Gurarii, 2015) and has been developed in the last decade based on interdisciplinary and magnetobiostratigraphic data from sections of the Kura depression (Van Baak, 2015; Van Baak et al., 2019; Lazarev et al., 2019). The base of the Akchagylian in the Kura depression was also found within a long normal chron, followed by a long reversed magnetized interval towards the upper strata. This shift was also interpreted as a Gauss–Matuyama magnetic polarity reversal. However, studies of the Adzhiveli and Babazan sections have shown that most of the Gauss Chron (including the reversed magnetized Mammuth and Kaena subchrons) belong to the upper part of the Productive Series, while the transgressively overlying Akchagylian deposits are correlated within the Upper Gauss (C2An.1n) (Van Baak et al., 2015a). The dating of volcanic ashes from the lower part of the Akchagylian in the Lokbatan and Jeirankechmez sections at an age of about 2.7 Ma confirmed this magnetostratigraphic correlation and was proposed as the age of the Akchagylian base (Van Baak et al., 2019). The upper boundary of the Akchagylian was studied in the Hajigabul section, where the first Apsheronian mollusks were found within the first short, normally magnetized subchron after the Gauss–Matuyama boundary, interpreted as the Reunion (Feni) subchron (Lazarev et al., 2019). Therefore, the age of the Akchagylian top was dated to 2.13 Ma (Fig. 21).

A new unified age model of the Akchagylian Regional Stage was proposed to resolve the contradictions between the two age models (Lazarev et al., 2021); this model is based on new data on magnetostratigraphy, $^{40}\text{Ar}/^{39}\text{Ar}$ dating, and the biostratigraphy of the Kvabebi, Kushkuna, Hajigabul, and Lokbatan sections, as well as on the revision of data on 20 sections of Turkmenistan and the Kura depression. According to the new model, the Akchagylian Regional Stage consists of three intervals:

(1) Initial Akchagylian transgression, followed by freshwater–mesohaline conditions, which are dated together at 2.95 to 2.75 Ma, within normal chron C2An.1n;

(2) Meso-euhaline or “marine” Akchagylian, between 2.75–2.45 Ma, which covers the upper part of normal chron C2An.1n and lower part of reversed magnetized subchron C2r.2r;

(3) The oligohaline upper interval between 2.45 and 2.13 Ma, with the Akchagylian–Apsheronian boundary within the Reunion subchron (C2r.1n).

ASTRONOMICAL TUNING OF THE MIDDLE-UPPER MIOCENE SEDIMENTS OF THE EASTERN PARATETHYS

Introduction

The term *cyclostratigraphy* is interpreted in different ways. It is often understood as a subdiscipline of stratigraphy that uses the cyclicity of sediments to subdivide and correlate sedimentary strata (Gladenkov, 2004). The cyclicity of deposits is usually determined by the alternation of different rock types, including rhythmic. This cyclicity includes cycles of various origin; among them are cycles reflecting the regressive and transgressive stages of the development of the paleobasin, which allows the correlation of adjacent sedimentary successions; however, this does not make it possible to date rocks. In another understanding, 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 (Hilgen et al., 2004). 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 amount of sunlight and radiation reaching the Earth’s surface over long periods of time, known as 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. The term cyclostratigraphy was discussed in this sense during the session of the Global Program for Sedimentary Geology at a conference in Perugia (Italy) and Digne (France) in 1988 (Fischer et al., 1988). Based on this technique, an Astronomical Time Scale was developed for some stratigraphic subdivisions, taking into account astrochronological data (Laskar et al., 2004), with an order determination accuracy of 0.02–0.4 million years, which is higher than the resolution of the International Geologic Time Scale with a dating error of about 1–5 million years (Hinnov et al., 2007).

One of the features of these cyclostratigraphic studies is the possibility to analyze also monotonic successions, in which there is no clear alternation of different rock types. The identification of astronomical cycles that influenced long-term climate fluctuations and were reflected in the geological record during the accumulation of sediments makes it possible to calculate the sedimentation rates and duration of formation of the sedimentary successions. For these cyclostratigraphic studies, a generally accepted methodology has been developed (Weedon, 2003). Astronomical cyclicity is recognized using different characteristics (usually geochemical and geophysical characteristics) of sediments, which involve the magnetic susceptibility of rocks. Sedimentary successions with minimum or absence hiatuses, such as deep-water sediments, are the best objects for studying astronomical cyclicity.

Taking into account the wide understanding of the term “cyclostratigraphy,” some researchers suggest using the term “astrostratigraphy” to refer to studies concerning the identification of orbital cycle records in sediments (Gladenkov, 2004).

There are numerous publications on the cyclostratigraphy of Mio–Pliocene sediments. Many of these papers represent the results of studies of the Neogene sediments of the Mediterranean and Central Paratethys. (Hilgen, 1991; Abdul Aziz et al., 2003; Hilgen et al., 2003; Abels et al., 2005; Lirer et al., 2005, 2009; Hu sing et al., 2007; Hohenegger et al., 2009a; Bache et al., 2012, etc.). For example, the boundary between the Miocene and Pliocene (Hilgen, 1991) and between the Badenian and Sarmatian, as well as the base of the Pannonian, have been dated based on the identification of astronomical cyclicity in these sediments (Lirer et al., 2009). Cycles corresponding to the periods of fluctuations in the angle of inclination of the Earth’s axis (obliquity), precession, and eccentricity were established in the studied sediments (Lirer et al., 2009; Gunderson et al., 2012, etc.).

The Neogene sediments of the Eastern Paratethys are much less studied by cyclostratigraphic methods. Many such papers present the results of studies of the Neogene sediments of the Romania (Van Vugt et al., 2001; Vasiliev et al., 2004; Popescu et al., 2006), as well as the Konkian sediments of the Eastern Georgia

(Rostovtseva et al., 2020). A few publications (Rostovtseva and Rybkina, 2014, 2017; Rybkina and Rostovtseva, 2014; Chang et al., 2014; Rybkina et al., 2015) consider the results of cyclostratigraphic studies of the Middle and the Upper Miocene sediments exposed in the key sections of the Taman Peninsula. In this part, the astronomical cyclicity of the Miocene sediments of the Eastern Paratethys 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.

Material

The objects of cyclostratigraphic studies were the Konkian, the Maeotian and the Pontian sediments, which were exposed in key sections of the Taman Peninsula and previously studied in detail both by paleontological and paleomagnetic as well as by lithological methods (Andrusov, 1903; Trubikhin, 1989; Popov and Zastrozhnov, 1998; Filippova, 2002; Pevzner et al., 2003; Rostovtseva, 2009b, 2009c; 2012; Vasiliev et al., 2011; Radionova et al., 2012; Popov et al., 2016). The Konkian sediments were studied in the Zelensky section, sediments of the Lower Maeotian in the Popov Kamen section, and sediments of the Upper Maeotian and Pontian in the Zhelezny Rog section. Relatively deep-water sediments of the Miocene, composed mainly of clays, are exposed in these sections.

According to paleomagnetic data, the studied Konkian sediments, including Kartvelian, Sartagan, and Veselyanka beds, are characterized by the presence of three intervals of reversed and normal polarity (Palcu et al., 2017). In the studied sections, the Lower Maeotian sediments generally have reversed rock magnetization; most of the Upper Maeotian sediments are characterized by normal polarity (Trubikhin, 1989; Trubikhin and Pilipenko, 2011; Vasiliev et al., 2011; Radionova et al., 2012). In the Popov Kamen section, the Lower Maeotian sediments with reversed polarity contain the short intervals of normal polarity, located in the lower and upper parts of these sediments (Trubikhin and Pilipenko, 2011). Pontian sediments are characterized by reversed polarity (Trubikhin, 1989; Vasiliev et al., 2011; Radionova et al., 2012). In the transition layers between the Maeotian and Pontian, the change of intervals from the normal to the reversed polarity is correlated with the C3An and C3r chron boundary (Trubikhin, 1989; Vasiliev et al., 2011; Radionova et al., 2012), corresponding to 6.023 Ma (Gradstein et al., 2020). According to Trubikhin and Pilipenko (2011), and Radionova et al. (Radionova et al., 2012), the reversal of the sign of rock polarity between the Lower/Upper Maeotian corresponds to the C3Ar and C3An chron boundary, dated to 6.727 Ma (Gradstein et al., 2020). This determination

of the age of the Lower/Upper Meotian boundary is consistent with the data on the appearance of diatoms *Nitzschia miocenica* (FO 7.1 Ma) and *Thalassiosira convexa* (FO 6.7 Ma) (Radionova et al., 2012).

The main minerals carrying of primary magnetization were magnetite in the studied Konkian deposits (Palcu et al., 2017) and iron sulphide in the Maeotian and Pontian sediments (Trubikhin and Pilipenko, 2011; Vasiliev et al., 2011). According to Vasiliev et al. (2011) and L. Chang et al. (2014), the main mineral carrying of primary magnetization among iron sulphides is greigite.

Methods

The astronomical tuning of studied sediments was determined based on measurements of the magnetic susceptibility of rocks. Measurements were made every $20 \pm 1\text{--}2$ cm across the strike of the layers using a KM-5 magnetic susceptibility meter (Geofyzika BRNO, Czech Republic). In total, about 4383 determinations have been obtained (three measurements at each point).

The average values of measurements at each point were used in statistical data processing. The average values of the magnetic susceptibility of rocks were transformed using the functions of logarithm and detrend analysis. The resulting data were processed using the PAST software (Hammer et al., 2001), which makes it possible to obtaining Lomb–Scargle and REDFIT periodograms and perform a wavelet analysis (Schulz and Mudelsee, 2002). The Lomb–Scargle and REDFIT periodograms were then transformed with the conversion of the frequency values to the length of cycles in meters.

The frequency values of the Lomb–Scargle and REDFIT periodograms were used as targets for a Gaussian bandpass filter with the AnalySeries programme (Paillard et al., 1996). The Gaussian bandpass filter data were compared with long-term insolation changes at the end Miocene (Laskar et al., 2004), considering the available age (bio- and magnetostratigraphic and radiological) dating of the studied sediments.

In these studies, the sedimentation rates were calculated without taking compaction effects into account. The reduction of the core volume through compaction is not deemed significant (up to 20% of the original volume) for the Middle–Upper Miocene sediments, based on shallow burial diagenesis by the presence of amorphous biogenic silica (skeletal opal) (Rostovtseva and Kosorukov, 2012). A.I. Rybkina, A.N. Kern, E.O. Goncharov, E.V. Filina, and A.Yu. Rylova were involved in these studies.

Results and Discussion

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, as well as the correlation of the Maeotian and Pontian to the Messinian, are particularly debated.

The presence of nannoplankton of the undivided zones NN6–NN7 (according to the Martini scale (1971)) in Konkian sediments suggests that this regional stage of the Middle Miocene Eastern Paratethys corresponds to the lower part of the Serravallian of the Mediterranean and the Upper Badenian (Kosovian) of the Central Paratethys. (Nevesskaya et al., 2004; Popov et al., 2013a). The age of the boundaries of the Konkian Regional Stage has not been precisely determined. It is assumed that Konkian sediments might accumulate between 13.8–13.4 to 13.0–12.1 Ma (Nevesskaya et al., 2004; Popov et al., 2013a; Palcu et al., 2017). According to Trubikhin (*Unifitsirovannaya...*, 2004), the Veselyanka and Sartagan beds of Konkian sediments correspond to chron C5An (a time interval of about 0.425 Ma, from 12.474 to 12.049 Ma) of the general magnetostratigraphic scale. According to Pevzner (1986) and Molostovskii (Molostovskii and Khramov, 1997), the Konkian Regional Stage corresponds to the intervals of Chron C5AB. According to new data (Palcu et al., 2017), the upper and lower boundaries of the Konkian Regional Stage (including the Kartvelian beds) are dated to 12.65 and 13.4 Ma, respectively. The Veselyanka and Sartagan beds accumulated for about 0.240 Ma (approximately from 12.89 to 12.65 Ma).

At the end of the Miocene, paleographic conditions sharply changed in the Mediterranean basin due to the onset of the Messinian salinity crisis. The determination of the reflection of this event in the Eastern Paratethys is a subject of much debate. In the latest edition of the Neogene stratigraphic scale for the southern regions of the European part of Russia (Nevesskaya et al., 2003; *Unifitsirovannaya...*, 2004), the Maeotian corresponds to the upper part of the Tortonian and the Pontian corresponds to most of the Messinian (Fig. 22). New data on the stratigraphy of Maeotian and Pontian sediments have been obtained. According to the results of integrated stratigraphic studies performed in recent years, the age of the lower boundary of the Pontian is dated to about 6.1–6.03 Ma (Krijgsman et al., 2010; Radionova et al., 2012). According to most scientists, the age of the upper boundary of the Pontian may correspond to 5.3–5.2 Ma (Trubikhin, 1989; Nevesskaya et al., 2003; Radionova et al., 2012) or 4.7 Ma (Krijgsman et al., 2010). According to these views, the Pontian Regional Stage is correlated with the upper part of the

Polarity	Gradstein et al., 2020	Ma	Mediterranean region	Eastern Paratethys				
			Gradstein et al., 2020	Nevesskaya et al., 2003	Semenenko et al., 2009; Gozhuk et al., 2015	Krijgsman et al., 2010; Vasiliev et al., 2011	Trubikhin, 1989; Trubikhin and Pilipenko, 2011	Radionova et al., 2012; Popov et al., 2013a
	C2Ar	4	Zanclean 5.33	Kimmerian Panticapean Kamysh–Burun Azovian	Kimmerian	Kimmerian 5.6	Kimmerian 5.4–5.2	Kimmerian 5.2
	C3n	5						
	C3r	6	Messinian 7.25	Pontian Bosphorian Portaferian Novorossian	Pontian	Pontian 6.04	Pontian 6.15	Pontian 6.1
	C3An	7				Maeotian Akmanai Bagerovian ~8.6–8.2	Maeotian Akmanai 6.7 Bagerovian ~7.6	Maeotian Akmanai 6.7 Bagerovian ~7.6
	C3Ar	8	Tortonian 11.63	Maeotian Akmanai Bagerovian	Maeotian Akmanai Bagerovian			
	C3Br	9						
	C4n	10		Sarmatian (s.l.)	Sarmatian (s.l.)	Sarmatian (s.l.)		
	C4r	11						
	C4A	12						
	C4Ar	13						
	C5n		Serravallian					
	C5r							
	C5An							
	C5Ar							

Fig. 22. Scheme of correlation of the Upper Miocene divisions of the Eastern Paratethys with the Mediterranean stratigraphic scale, according to the different researchers.

Messinian and, possibly, partially corresponds to the lower part of the Pliocene. In this case, the maximum onset of the Messinian salinity crisis, which caused the formation of an erosional surface (MES) in the Mediterranean from 5.6 to 5.5 Ma (CIESM, 2008), corresponds to the Pontian of the Eastern Paratethys.

The age of the lower boundary of the Maeotian is estimated differently. According to Vasilev et al. (2011), the lower boundary of the Maeotian may correspond to 8.6–8.2 Ma. In this case, the duration of the Maeotian is about 2.2–2.6 Ma. According to Trubikhin, Pilipenko (2011), and Radionova et al. (2012), the lower boundary of the Maeotian may correspond to about 7.6 Ma; consequently, the duration of the Maeotian is no more than 1.5 Ma and the Maeotian is almost completely correlated with the lower Messinian.

The study of the cyclicity of the Konkian, Maeotian, and Pontian sediments, reflecting the influence of astronomical processes, can contribute to the solution of existing problems.

Konkian Sediments of the Zelensky Section

Results. 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), Sartagan (about 2–2.5 m), and Veselyanka (about 4–4.5 m) beds (Vernigorova et al., 2006; Palcu et al., 2017). Cyclostratigraphic studies revealed that the magnetic susceptibility (K) of these rocks was characterized by values from 0.06 to 0.24×10^{-3} SI units (average 0.15×10^{-3} SI units). Sediments in the lower part of the section are generally characterized by higher K values (Fig. 23). In total, about 345 measurements of the magnetic susceptibility of rocks were obtained.

A spectral analysis of equidistant sets of the magnetic susceptibility data of Konkian rocks allowed to distinguish two sharp peaks (Fig. 24). One of these peaks exceeds the interval of spectral noise on the REDFIT periodogram with a 99% confidence level, the validity of the orbitally calibrated record. This peak corresponds to the 3.3 m cycle. Another peak value, which exceeds the spectral noise interval on the REDFIT periodogram with a 95% confidence level, corresponds to the 14.3 m cycle.

The peak values were determined based on statistical processing of the magnetic susceptibility data both for the whole section and for a sample of measurements characterizing the sediments of the Veselyanka and Sartagan beds as well as the top of Kartvelian beds. The spectral analysis of the K values determined during the study of sediments from the lower part of Kartvelian beds did not reveal a strong periodicity. In this part of the section, along with clays, there are

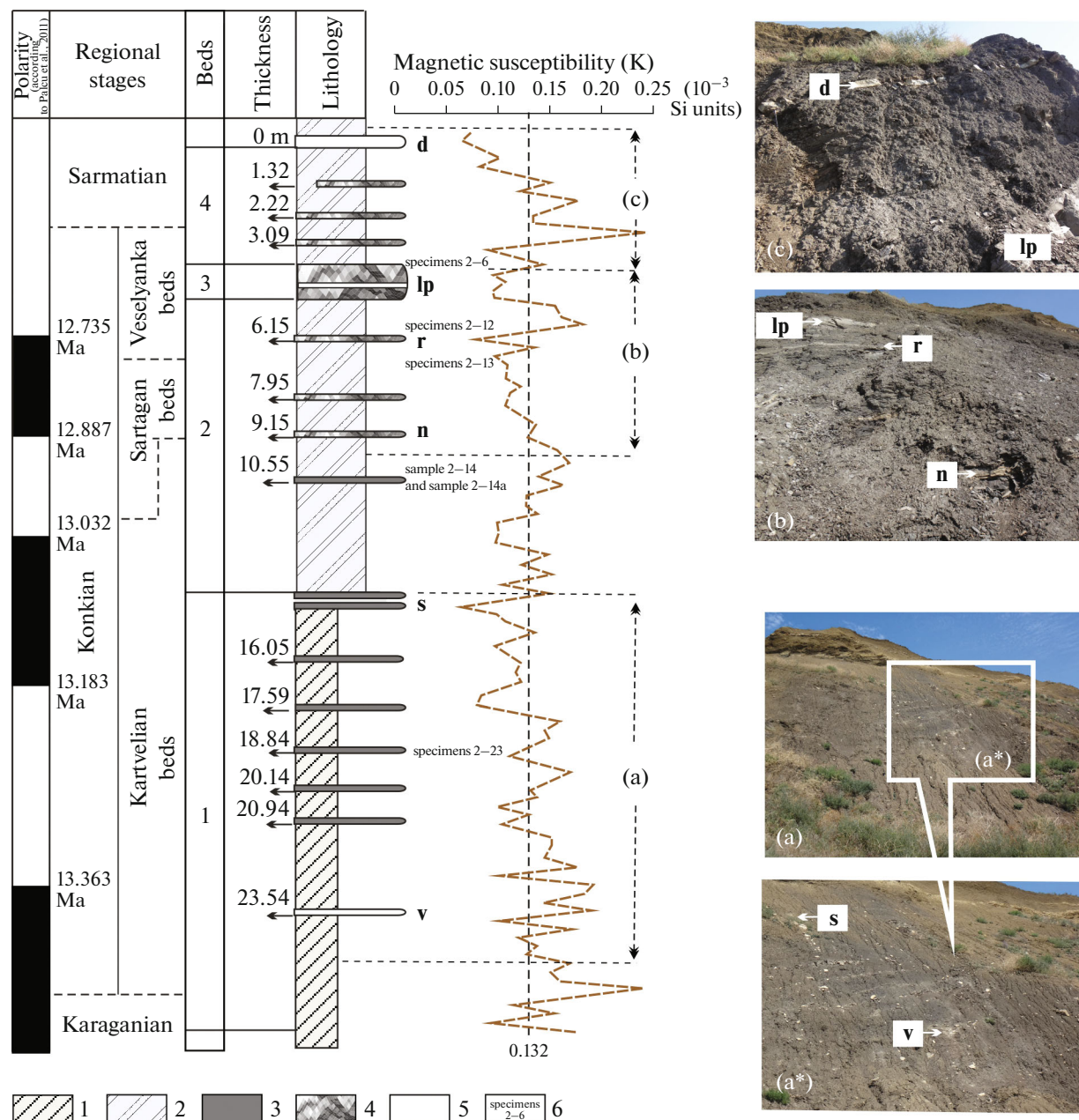


Fig. 23. Lithological structure, variability of the remanent magnetization of rocks (K), and general view of Konkian deposits exposed in the Zelensky Hill section on the Taman Peninsula. Stratigraphic subdivision, age dating, and polarity of rocks according to (Palcu et al., 2017): (1)–(2) weakly calcareous (1) and calcareous (2) clays; (3)–(5) carbonates: microbial (3), coccolith (4), and strongly dolomitized (5) carbonates; (6) sites of carbonate sampling for microscopic analysis. Letter abbreviations (v, s, n, r, lp, and d) designate separate beds that are shown both in the lithological column and in the photographs of different parts of the section.

microbial carbonate interlayers associated with the development of benthic cyanobacterial communities (Rostovtseva et al., 2019). Sediments of Veselyanka and Sartagan beds are characterized by the presence of carbonate interlayers composed mainly of nannoplankton. Different sedimentation regimes of the identified types of carbonate rocks, which also differ from the sedimentation regime clay, may be reflected in the features of the orbitally calibrated record present

in the studied sediments (Fig. 25). Taking this into account, it is assumed that the data related to the upper part of the section (to the Sartagan and Veselyanka beds) are the most validity to estimate the duration of accumulation of the studied sediments by cyclostratigraphic methods. The ratio between the observed periodicities (signals at 3.3 and 14.3 m) is 1 : 4 (1 : 4.3), which correlates with long-term insolation variations associated with 100-kyr and 24-kyr cycles (eccentric-

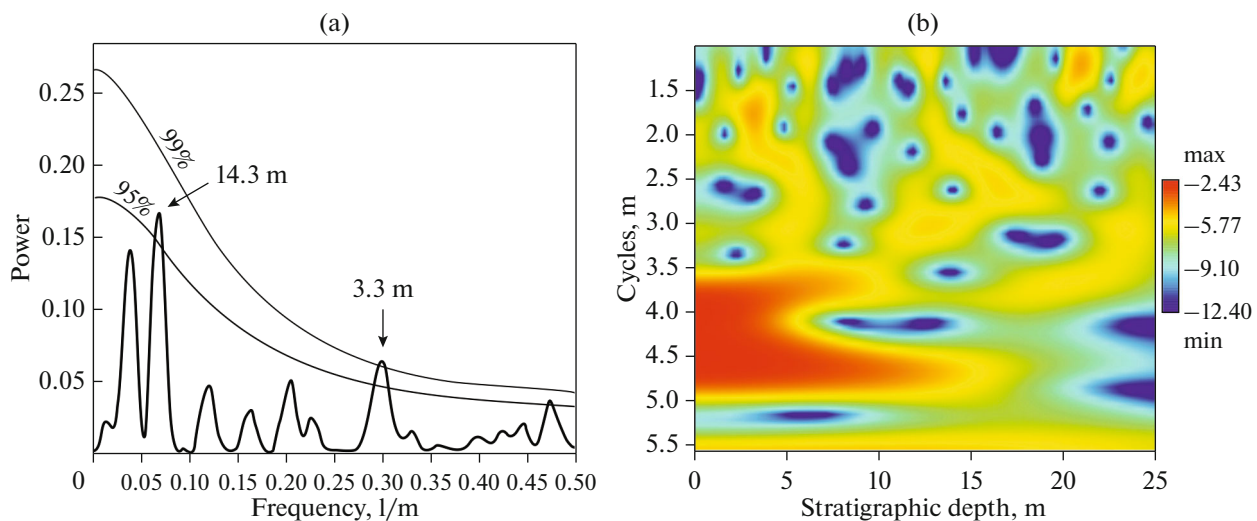


Fig. 24. Results of the REDFIT (a) and Wavelet (b) analysis of data on the magnetic susceptibility of Konkian rocks exposed in the Zelensky Hill on the Taman Peninsula.

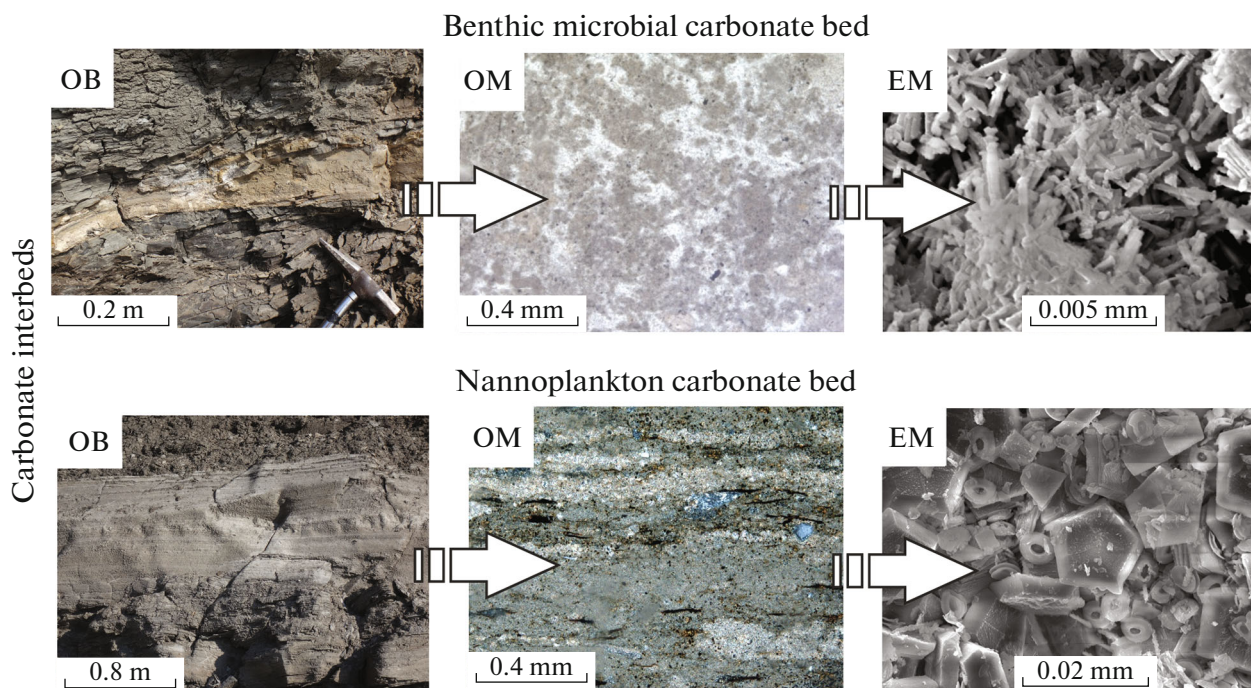


Fig. 25. Lithological types of carbonate rocks of the studied Konkian deposits: OB, general view of carbonate interbeds, OM, carbonates in thin sections, EM, carbonates under an electron microscope.

ity and precession) or 100-kyr and 400-kyr cycles (eccentricity only). If the signal at 3.3 m corresponds to the 24-kyr precession cycle, the duration of accumulation of Sartagan and Veselyanka beds with the total thickness of about 6–7 m is about 50 ka. In this case, the sedimentation rate was about 13–14 cm/1000 years. If we consider this signal as a record of 100-kyr eccentricity cycle, the Sartagan and Veselyanka beds were deposited at an average rate of

3.3 cm/1000 years for about 200 ka. In the latter case, the obtained values are well consistent with the data on the duration of the formation of Sartagan and Veselyanka beds in the studied section over the period of about 240 ka at sedimentation rates of about 2.16 cm/1000 years (Palcu et al., 2017).

Discussion. Cyclostratigraphic studies revealed a record of astronomical cyclicity in Konkian sediments of the Zelensky section. It was found that the forma-

tion of these rocks occurred with repeated changes in sedimentation regimes, providing accumulation of clayey and different (benthic and planktonic) carbonate sediments. The carbonate and clayey sediments accumulated at different rates, which should be taken into account when interpreting the cyclostratigraphic data. Estimates of the duration of the Konkian Regional Stage by cyclostratigraphic methods also involve some difficulties due to a still existing sharp debate about the volume and subdivision of this regional stage. According to Nevesskaya et al. (2004), the Konkian Regional Stage includes Sartagan and Veselyanka beds, which reflect the stage-by-stage onset of marine transgression. According to a number of scientists (Andrusov, 1917a; Merklin, 1953; Popov et al., 2016; Palcu et al., 2017, etc.), the Konkian Regional Stage should also include Pholadidae or Kartvelian beds, which some researchers consider as part of the Karaganian (Nevesskaya et al., 2004) or propose to distinguish them as a separate regional stage (Zhgenti, 1976b; Iljina, 2000b; Zhgenti and Maisuradze, 2016). At the same time, there are ideas that the established units of the Konkian Regional Stage are only facies types of sediments without a consistent stratigraphic position (Belokryz, 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. According to the obtained results, the average rate of sedimentation of the studied Konkian deposits is about 3.3 cm/1000 years, which is well consistent with other published data (Palcu et al., 2017). However, it should be noted that these are rather low values of sedimentation regimes, which are generally not typical for sedimentation in 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 formations might differ in a longer formation. Only a small part of the sections of the Eastern Paratethys Konkian has been studied by the paleomagnetic method; therefore, their magnetic polarity pattern requires additional details. All these problems in the stratigraphy of the Konkian sediments suggest that the obtained data on the astronomical cyclicity of these sediments should be so far considered intermediate and require further additional study in other sections of the Middle Miocene.

Lower Maeotian Sediments of the Popov Kamen Section

Research results. In the Popov Kamen section (N 45°16'01.8"; E 36°61'97.6"), Lower Maeotian sediments were studied in three main intervals (86.8–49.6 m; 42.6–19.2 m; and 27.2–12 m) with a thickness of about 37, 13 and 15 m (Rybkina et al., 2015). In total, about 1002 measurements of the magnetic sus-

ceptibility of rocks were made. In the studied deposits, the values of the magnetic susceptibility of rocks vary from 0.02 to 0.18×10^{-3} SI units. Clays are characterized by higher values of magnetic susceptibility (on average, from 0.07 to 0.12×10^{-3} SI units). Carbonate rocks and diatomites are characterized by lower values of magnetic susceptibility (from 0.02 to 0.06×10^{-3} SI units). In the lower part the Lower Maeotian sediments are characterized by higher values of magnetic susceptibility.

A spectral analysis of the data revealed a clear periodicity corresponding to the peak at 6.0 m in the 86.8–49.6 m interval of the studied section (Fig. 26). The peak corresponding to 6 m exceeds the spectral noise interval with 95 and 99% confidence levels, which is clearly seen on the Lomb–Scargle and REDFIT periodograms. Two other, shorter intervals (42.6–19.2 and 27.2–12 m) show a clearly defined peak at 5.2–5.9 m. This peak is correlated with the peak at 6 m, taking into account the decrease in the sedimentation rate in the second half of the Early Maeotian.

The peak at 5.2–5.9 m is weaker in the intervals of 42.6–19.2 and 27.2–12 m, most likely due to their short length (13 and 15 m, respectively). When analyzing the data for all three intervals (86.8–12 m), a peak at 5.8–6 m, which exceeds the spectral noise interval with a 95% confidence level, is clearly visible on the Lomb–Scargle and REDFIT periodograms. The wavelet analysis revealed a periodicity with a peak at 5.2–7.2 m, which is, on average, correlated with a signal at 6 m (Fig. 27). With account of the results of the spectral analysis, the values of the magnetic susceptibility of rocks were processed based on the Gaussian filter using the frequency of the corresponding periodicity of 6 m.

Discussion. According to Vasiliev et al. (2011, Fig. 9), the age of the upper boundary of the Lower Maeotian is presumably estimated to be no younger than about 7.7 Ma according to paleomagnetic data. The age of the lower boundary of the Maeotian may be 8.6–8.2 Ma. In this case, if the sediments accumulated from about 7.7 to 8.2 Ma, the Lower Maeotian should correspond to most of chron C4n.2n (7.701–8.125 Ma, Gradstein et al., 2020) with normal polarity. Nevertheless, a reversed polarity is reported for this sequence of the Lower Maeotian. If sediments accumulated from 7.7 to 8.6 Ma, the Lower Maeotian should correspond to chron C4n.2n and C4r and contain a significant hiatuses with the total duration of not less than 0.4 Ma (i.e., about half of the entire period of the Early Maeotian). The presence of these significant hiatuses in the relatively deep-water deposits of the Lower Maeotian of the Popov Kamen section was not established based on the available paleontological and lithological data (Rostovtseva and Goncharova, 2008; Rostovtseva, 2009a; Trubikhin and Pilipenko, 2011; Radionova et al., 2012).

According to Trubikhin and Pilipenko (2011), and Radionova et al. (2012), boundary of the Lower Mae-

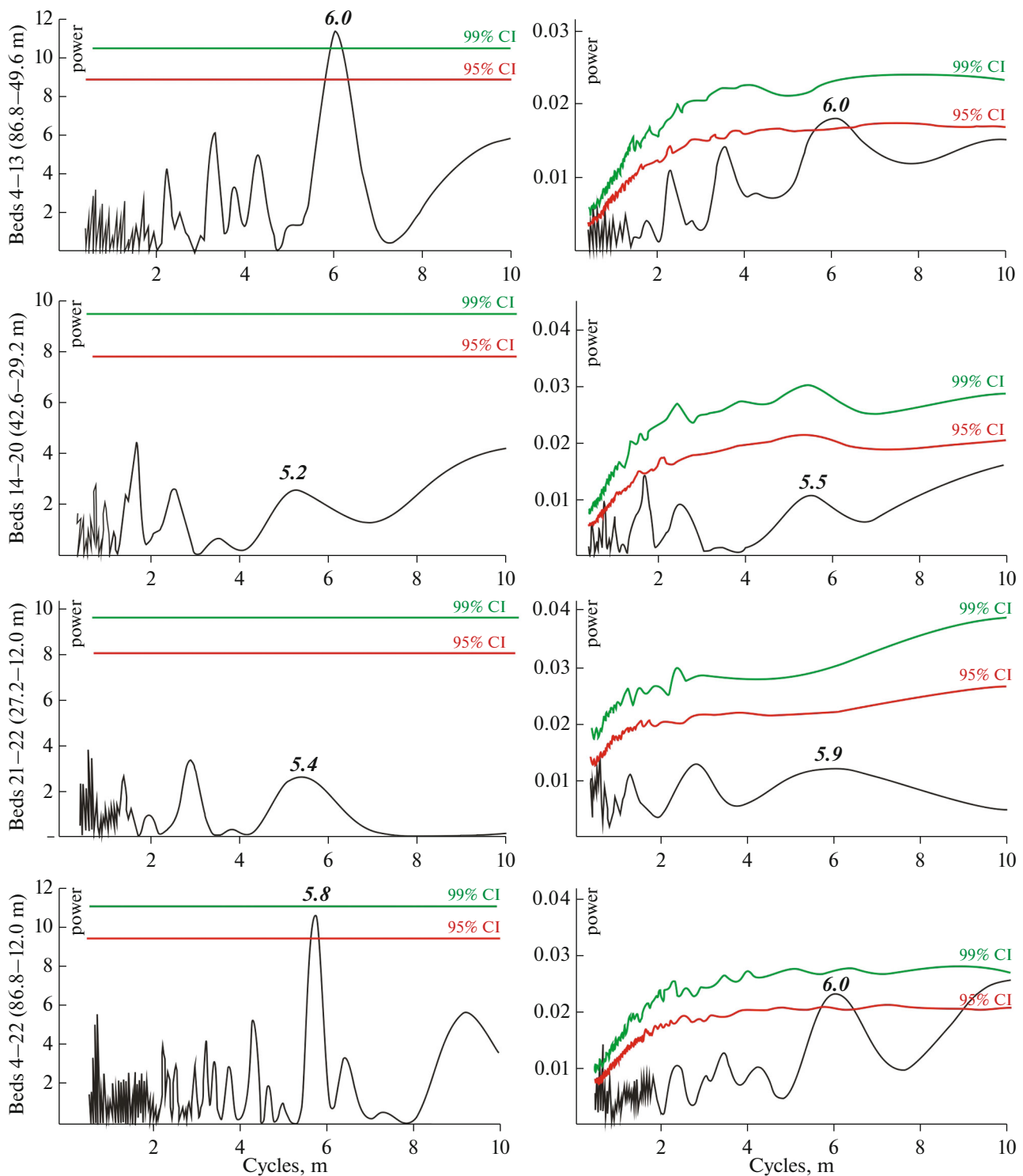


Fig. 26. Lomb–Scargle (left) and REDFIT (right) periodograms of the spectral analysis of data on the magnetic susceptibility of Lower Maetian rocks of the Popov Kamen section (Taman Peninsula).

otian roughly corresponds to the C3Ar/C3An chron transition, which is dated at 6.727 Ma (Gradstein et al., 2020). The paleomagnetic data are confirmed by the results of paleontological studies, namely, by

the presence of diatom index species, *Nitzschia myocenica* (FO 7.1 Ma) and *Thalassiosira convexa* (FO 6.7 Ma), in the upper part of the Lower Maetian (Radionova et al., 2012). This dating of the upper boundary of the

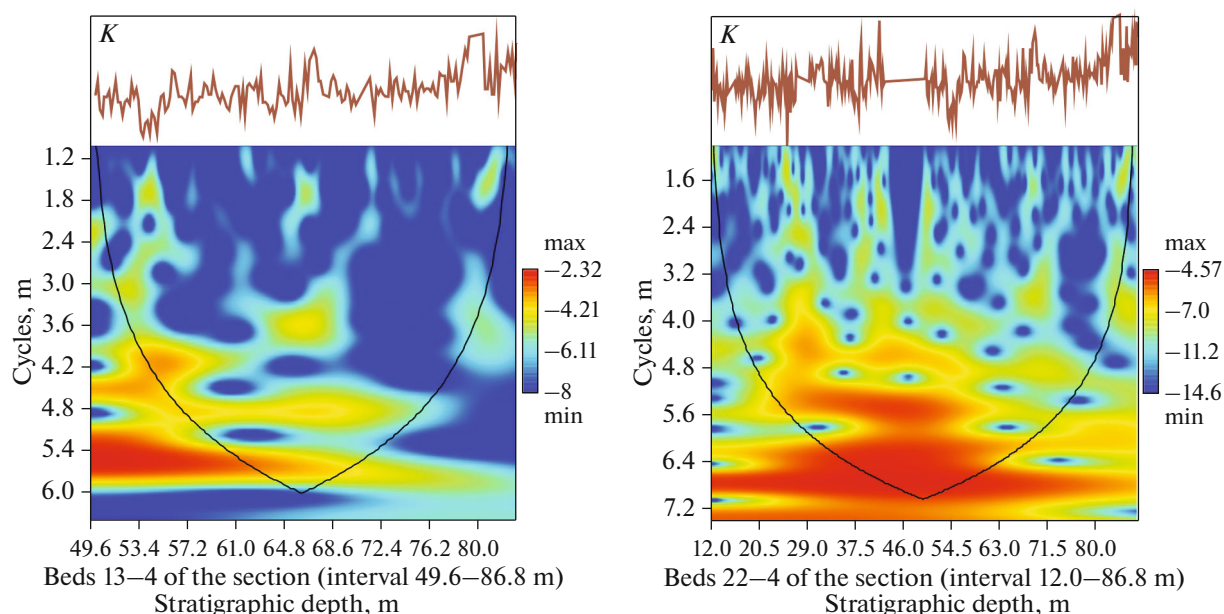


Fig. 27. Wavelet analysis of data on the magnetic susceptibility of Lower Maeotian rocks of the Popov Kamen section (Taman Peninsula). K is the magnetic susceptibility of rocks.

Lower Maeotian, based on paleomagnetic and paleontological data, seems to be more reasonable and will be used in further discussion. According to Trubikhin and Pilipenko (2011), and Radionova et al. (2012), the age of the lower boundary of the Maeotian is dated to about 7.6 Ma.

If we assume that the boundaries of the Lower Maeotian are 6.733 to 8.6–8.2 Ma or about 7.6 Ma, the duration of the Early Maeotian (Bagerovian time) may be no more than 1.9 or 0.9 Ma. The results of the cyclostratigraphic analysis of the studied sediments will be interpreted taking into account these available data.

According to the spectral analysis, a 5.2–6 m signal (min = 5.2 m, mean = 5.6 m, and max = 6.0 m) is determined as statistically important. Taking into account the duration of the Early Maeotian at about 1.9 or 0.9 Ma and thickness of the studied sediments, this signal may be correlated with 100-kyr eccentricity cycle or 41-kyr obliquity cycle. If we consider this signal as a signal corresponding to 24-kyr precession cycle, the Early Maeotian should be too short (no more than 0.4 million years) or include one or more hiatuses with a duration of not less than 0.5–1.5 Ma. No data of significant hiatuses were found in the studied relatively deep-water sediments. The Gaussian filtered data clearly contradict the interpretation of signal at 5.2–6 m as precession cycle.

If the signal at 5.2–6 m corresponds to fluctuations in the eccentricity of the Earth's orbit (100 000 years), the duration of the Early Maeotian may reach 1.9 Ma, taking into account the thickness of the studied sediments (about 105 m). In this case, the average value of the sedimentation rate should be no more than

5 cm/1000 years, which is a rather low value, taking into account the features of the formation of recent sediments in the Black Sea, as well as the intensive development of diatom sedimentation in the Maeotian.

According to Degens et al. (1978), the sedimentation rates in deep water parts of the Black Sea were about 20–50 cm/1000 years in the Pleistocene and Holocene. According to Denisov (1998), recent sediments accumulate within the Kerch–Taman shelf at an average rate of 15 to 30 cm/1000 years. If the sedimentation rate established in the Black Sea is consistent with the duration of the Lower Maeotian (about 1.9 Ma), Bagerovian beds should include the hiatuses of not less than 1.2 Ma, which is hardly possible. Lower Maeotian deposits accumulated under conditions of the development of marine transgression (Nevesskaya et al., 1986).

If the signal at 5.2–6 m corresponds to obliquity variations (41 000 years), the duration of the Early Maeotian may be about 0.9 Ma, taking into account that the thickness of the studied sediments is about 105 m. With this interpretation, the average sedimentation rates were 11–12 cm/1000 years, which is well consistent with the data on the sedimentation in the Black Sea now. There is a significant similarity the obtained Gaussian filtered curve for studied Lower Maeotian sediments with the curve of insolation fluctuations (Laskar et al., 2004) in the period from 7.6 to 6.7 Ma (Fig. 28).

An insignificant gap was found in the record of astronomical cyclicity in the studied sediments, which is revealed at the base of the first detrital limestone interlayer in the upper part of the Lower Maeotian and reflects change in the sedimentation environment

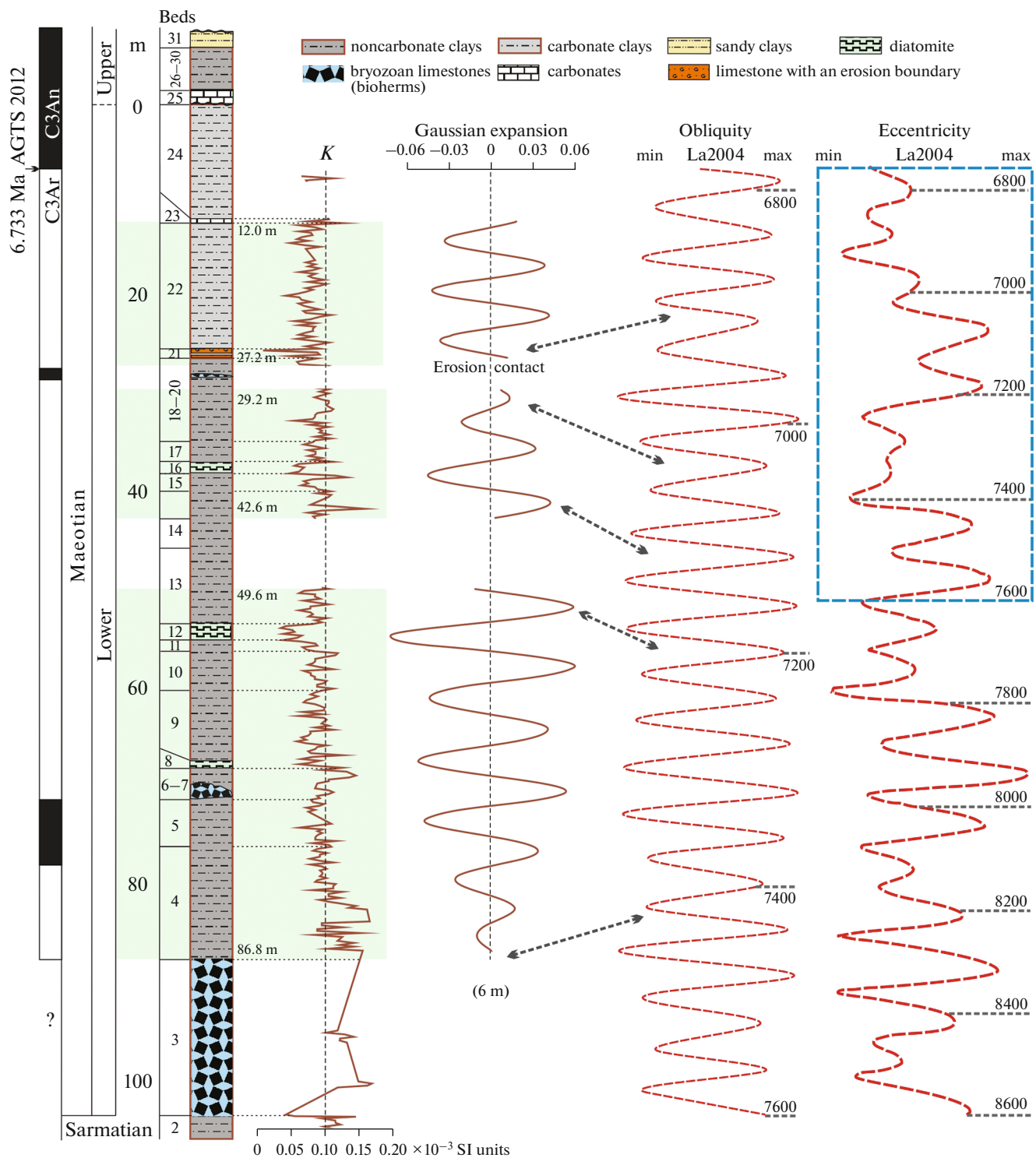


Fig. 28. Analysis of data on the magnetic susceptibility of the Lower Maeotian rocks of the Popov Kamen section (Taman Peninsula) using the AnalySeries software program. Paleomagnetic data according to Trubikhin and Pilipenko (2011). *K* is the magnetic susceptibility of rocks.

(Fig. 28, bed 21). In the second half of the Early Maeotian, the accumulation of noncarbonate sediments was replaced by the deposition of calcareous clays alternating with rare carbonate detrital interlayers

(Rostovtseva, 2009b). The change of the sedimentation regime was determined by the beginning of shallowing of the Kerch part of the paleobasin and by the transport of shallow sediments into the deep-water

zone. This gap may be associated with a partial erosion and redeposition of sediments rather than to the long hiatus.

The study indicates that the Tortonian–Messinian transition can be correlated with clays of the lower part of the Lower Maeotian located below the first diatomite in Maeotian sedimentary successions of the Popov Kamen section. The formation of bryozoan bioherms at the beginning of the Maeotian was determined by the onset of marine transgression, the development of which might be associated with the opening and deepening of the Rifian Strait (Rifian Corridor) in the Mediterranean about 7.6 Ma (Krijgsman et al., 1999).

The results of cyclostratigraphic studies are well consistent with the data on the change in sedimentation conditions in the Mediterranean at the end of the Tortonian and beginning of the Messinian. According to Hüsing et al. (2009), Rosini Interval calcareous sediments accumulated in the Monte dei Corvi section (Northern Apennines, Italy) from 7.616 to 7.168 Ma and their accumulation was associated with a decrease in the isolation of the Mediterranean due to the inflow of Atlantic Ocean waters through the Rifian Strait. The appearance of marine biota and growth of bryozoan bioherms in the Eastern Paratethys at the beginning of the Maeotian may correspond to this stage.

Since 7.168 Ma, intensive formation of diatom and sapropel deposits (Euxinian shale interval) began in the Mediterranean as a result of disruption of the Mediterranean water circulation and weakening of the inflow of ocean waters (Hüsing et al., 2009). This event may be reflected in the appearance of the first diatomite interlayer in the Lower Maeotian of the Popov Kamen section.

Upper Maeotian Sediments of the Zhelezny Rog Section

Research results. In the Zhelezny Rog section (N 45°11'06.1"; E 36°74'48.4"), Upper Maeotian sediments about 80–85 m thick are represented by clays containing diatomite interlayers and a single layer (up to 0.1 m) of detrital limestone. There is a layer of clayey breccia 8 to 10 m thick at the base of the Upper Maeotian. Layers with a monospecies assemblage of diatoms (*Actinocyclus octonarius*) and nannoplankton (*Braarudosphaera bigelowii*) are recognized within of transitional Maeotian/Pontian sediments (Rostovtseva and Kozyrenko, 2006; Radionova and Golovina, 2011). The Upper Maeotian sediments were studied at several intervals of the section with a thickness of 18.6 and 23 m (Rybikina and Rostovtseva, 2014). The study also involved an analysis of the upper part of Lower Maeotian sediments (11 m) and the transitional Maeotian/Pontian beds with *Actinocyclus octonarius* and *Braarudosphaera bigelowii* (30 m). In total, about

1344 measurements of the magnetic susceptibility of rocks were obtained.

The studied Upper Maeotian sediments are characterized by the values of the magnetic susceptibility of rocks from 0.01 to 0.45×10^{-3} SI units. The clays exhibit the values of the magnetic susceptibility ranging from 0.05 to 0.45×10^{-3} SI units (usually from 0.07 to 0.17×10^{-3} SI units). The highest values of magnetic susceptibility occur in clays: $(0.20–0.45) \times 10^{-3}$ SI units; its minimum values occur in diatomite and limestone interbeds: $(0.01–0.05) \times 10^{-3}$ SI units.

The studied sedimentary succession is characterized by different values of magnetic susceptibility.

The highest values of magnetic susceptibility occur in the clays of the upper part of the Lower Maeotian and the lower part of the Upper Maeotian. Lower values of magnetic susceptibility occur in clays of the upper part of the Upper Maeotian. Intermediate values of magnetic susceptibility occur in the clays of transitional Maeotian/Pontian beds.

The spectral analysis of data on the magnetic susceptibility of rocks showed a similar distribution of signals in all studied intervals of the section (Fig. 29). The Lomb–Scargle and REDFIT periodograms show three intervals with sharp signals. In one of these intervals, the peak exceeds the confidence level, which indicates a statistical significance and a high degree of confidence of this signal. In this interval, there is a signal between 7.1 and 8.9 m. The difference in the values of this signal is most likely due to the variability of the sedimentation rate, i.e., with a more intensive accumulation of sediments (e.g., peak at 8.9 m) or with some decrease in the rate of sedimentation (e.g., peak at 7.1 m). Accordingly, the rate of sedimentation was higher at the beginning of the Late Maeotian than at the end of the Maeotian and at the beginning of the Pontian. It is known that the Eastern Paratethys became shallow and significantly desalinated at the beginning of the Late Maeotian. At that time, a large amount of fine suspended matter of river runoff entered the study part of the paleobasin (Rostovtseva, 2009c), which led to an increase in the sedimentation rate. The higher values of magnetic susceptibility of clays in the lower part of Upper Maeotian may also be related to the regressive stage noted at this time. At the end of the Maeotian and beginning of the Pontian, the development of marine transgression led to a decrease in the amount of terrigenous suspended matter entering the studied area of the basin, which determined a decrease in the sedimentation rate. The Lomb–Scargle and REDFIT periodograms also show peaks at 4.3–3.2 and 1.36 m.

Discussion. According to the data of integrated paleontological and biostratigraphic studies (Trubikhin, 1989; Radionova et al., 2012), Upper Maeotian sediments show normal polarity and correlate with most of chron C3An in the magnetostratigraphic scale (Berggren et al., 1995). There is the change from

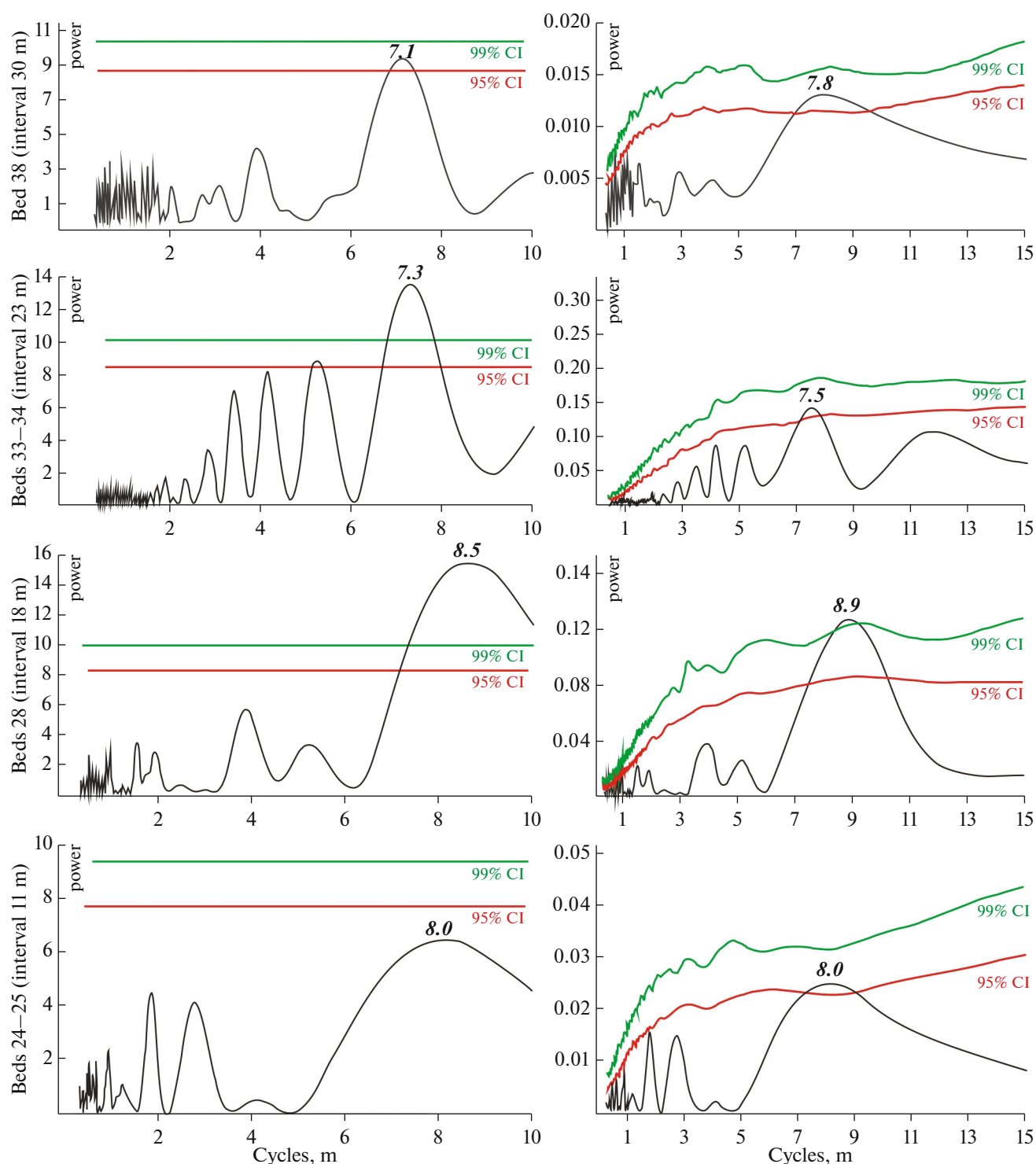


Fig. 29. Lomb–Scargle (left) and REDFIT (right) periodograms of the spectral analysis of data on the magnetic susceptibility of Upper Maeotian rocks of the Zhelezny Rog section (Taman Peninsula).

normal to reversed polarity in the lower part of the Pontian relates to the Chron C3An/C3r boundary; Pontian sediments with reversed polarity are correlated with chron C3r (Trubikhin, 1989; Vasiliev et al., 2011; Radionova et al., 2012).

Based on radiometric, paleontological, and cyclostratigraphic data, the age of the lower and upper boundaries of chron C3An is estimated at 6.733 and 6.033 Ma, respectively (Hilgen et al., 2012). Chron C3An correspond to the time period of about 0.7 Ma.

In the Zhelezny Rog section, the sediments about 130 m thick may correspond to this time period (0.7 Ma). The average sedimentation rate was about 19 cm/1000 years at that time, which is well consistent with rate of sedimentation in the Black Sea now (Degens et al., 1978; Denisov, 1998).

Taking into account the duration of sediment accumulation (about 0.7 Ma) and thickness of sediments (about 130 m) in the studied part of the section, the peak at 7.1–8.9 m (min 7.1 m, average 8 m, max 8.9 m) is generally correlated with the obliquity period (41-kyr obliquity cycle).

There is a significant similarity of the obtained Gaussian filtered curve for studied Upper Maeotian sediments with the curve of insolation fluctuations (Laskar et al., 2004) in the period from 6.7 to 6.3 Ma. (Fig. 30). The correlation was made both at a constant and changing sedimentation rate. The data obtained by taking into account changes in the sedimentation rate seem to be more reasonable. The data obtained by Gaussian filter for the transitional Maeotian/Pontian beds are more correlated with the interval of the curve of the eccentricity of the Earth's orbit, corresponding to the period from 6.350 to 6.150 Ma. In this part of the section, deposits about 17 m thick corresponds to a 100-km eccentricity cycle. This is well consistent with the fact that the overlying Pontian sediments with normal polarity about 20–25 m thick correspond to more than one 100-kyr eccentricity cycle. The transitional Maeotian/Pontian beds can be correlated with the sediments of the uppermost parts of the Tripoli Formation and Miocene pre-evaporitic diatom beds of the Gavdos Island (Metochia A) in the Mediterranean. This is in good agreement with the data on the final stage of the formation of the Tripoli formation, which is recognized from 6.29 Ma and associated with an increase in salinity, the appearance of stress conditions, and an increased isolation of the Mediterranean basin (Blanc-Valleron et al., 2002).

According to the pattern of the curve of the eccentricity of the Earth's orbit, the fluctuations with greater intensity, which are recorded from 6.73 to 6.60 Ma, are also observed at the base of Upper Maeotian sediments. The results of the study of the astronomical cyclicity of the Upper Maeotian sediments confirm the hypothesis that these sediments correspond to most of chron C3An (Trubikhin, 1989; Radionova et al., 2012) and do not contradict the data of insolation variability at the end of the Miocene.

Pontian Sediments of the Zhelezny Rog Section

Research results. In the Zhelezny Rog section, the Pontian sediments are mainly represented by clays about 110 m thick. These sediments consist of the Novorossian beds of the Lower Pontian, as well as the Portaferian and Bosporian beds of the Upper Pon-

tian (Andrusov, 1917b; Popov and Zastrozhnov, 1998; Nevesskaya et al., 2003)². The Portaferian beds are characterized by a peculiar lithology, which is expressed in the development of interbeds of detrital limestones and clayey breccia between the overlying and underlying clays.

All the stratigraphic units of Pontian sediments (112.8 m) were studied by the cyclostratigraphic method (Rostovtseva and Rybkina, 2014, 2017). In total, about 1692 measurements of the magnetic susceptibility of rocks were obtained.

It was established that the magnetic susceptibility of the rocks (K) of Novorossian beds is characterized by values from 0.016 to 0.937×10^{-3} SI units. The highest K values (from 0.52 to 0.937×10^{-3} SI units) are recorded in the upper part of these sediments (in the interval from 65.8–62.0 to 59.2–51.6 m). The Portaferian beds are characterized by K values from 0.03 to 0.19×10^{-3} SI units and Bosporian beds by K values from 0.05 to 0.42×10^{-3} SI units. Limestone interlayers, which occasionally occur in the Zhelezny Rog section, have lower values of magnetic susceptibility of than those of clays.

A spectral analysis of the data series of magnetic susceptibility of rocks of the Portaferian beds showed the absence of a clear record of astronomical cyclicity in these beds. Thus, the Lomb–Scargle and REDFIT periodograms did not reveal peaks exceeding the spectral noise interval with 95 and 99% confidence levels (Fig. 31). The strongest signal observed on the periodograms cannot be used, since it does not reach the spectral noise interval with the 95% confidence level and has a cycle length of 9.4 m, which exceeds the 6-m thickness of the studied Portaferian beds.

The Portaferian Beds are represented mainly by re-sedimentated deposits, which caused a poor preservation of the record of astronomical cyclicity in this succession (Fig. 32).

The spectral analysis of the magnetic susceptibility data from Novorossian beds showed a signal with periodicity at 59.7 m on the Lomb–Scargle periodogram and peaks at 59.7, 3.1, 2.7 and 2.3 m on the REDFIT periodogram, which exceed the spectral noise interval with a 99% confidence level and are significant. The wavelet analysis also revealed cycle between 5.6 and 7.4 m (Fig. 31). The REDFIT periodogram with transformed frequency values also clearly shows a cycle at 6.1 m (Fig. 33, Beds 39–54).

The ratios between the observed periodicities were used to identify Milankovitch cyclicity. The ratio of the 400-kyr eccentricity period to the 41-kyr obliquity period is 9.7 : 1 and the ratio of the 41-kyr obliq-

² The term Portaferian Beds is used in accordance with the latest edition of the Regional Stratigraphic Scale of Neogene Deposits from the Southern Regions in the European Part of Russia, published by the Interdepartmental Stratigraphic Committee of Russia in 2004 (Nevesskaya et al., 2004).

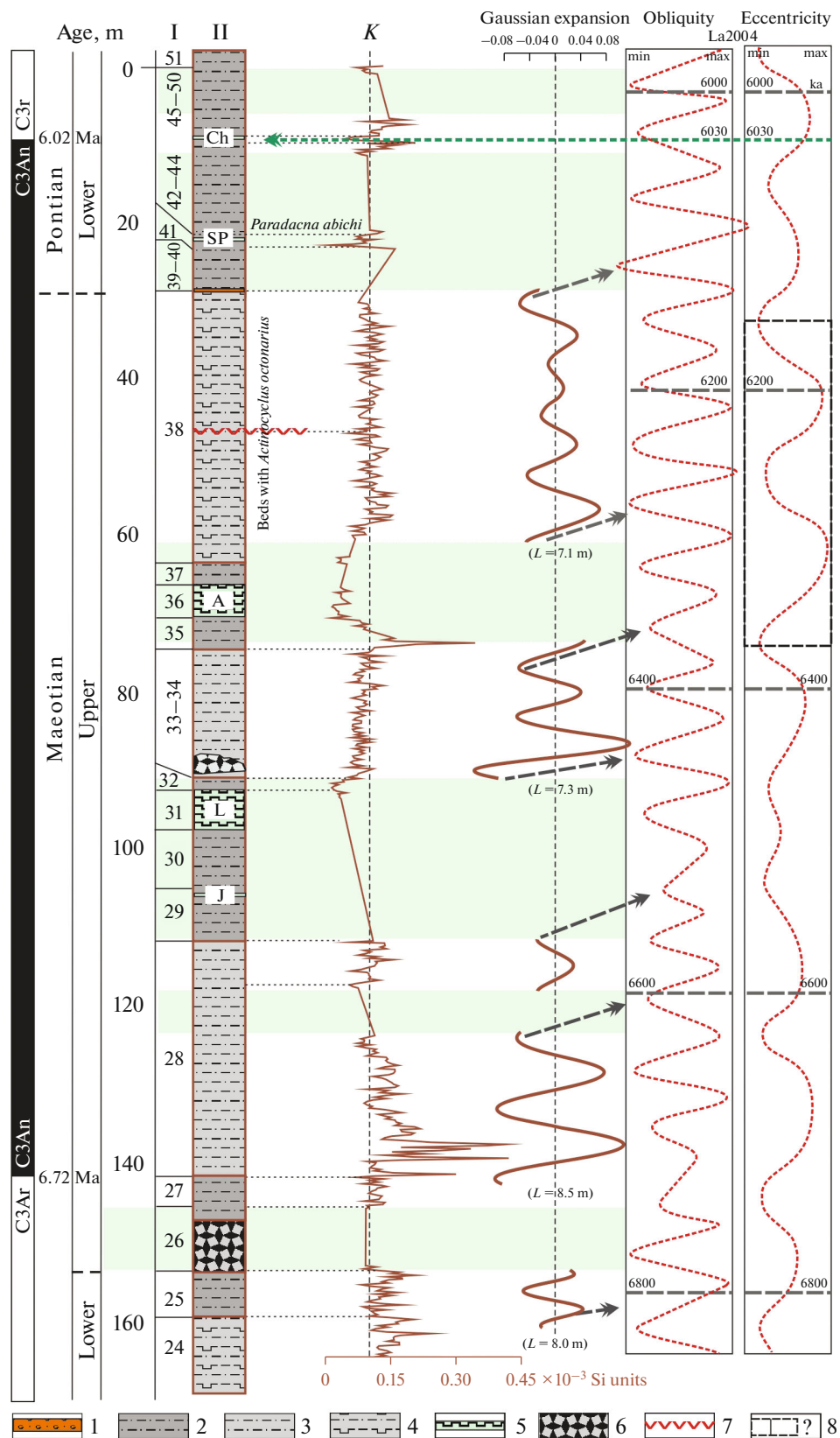


Fig. 30. Analysis of data on the magnetic susceptibility of the Upper Maeotian rocks of the Zhelezny Rog section (Taman Peninsula) using the AnalySeries software program. Lithological types of rocks: (1) detrital limestone; (2)–(4) clays: (2) silty clays, (3) silty and calcareous clays, (4) diatom clays; (5) diatomites (according to Radionova and Golovina, 2011); (6) clayey breccia; (7) volcanic ash; (8) estimated levels of unconformity. Paleomagnetic data according to Trubikhin (in Popov et al., 1996), Vasiliev et al. (2011), and Radionova et al. (2012). *K* is the magnetic susceptibility of rocks.

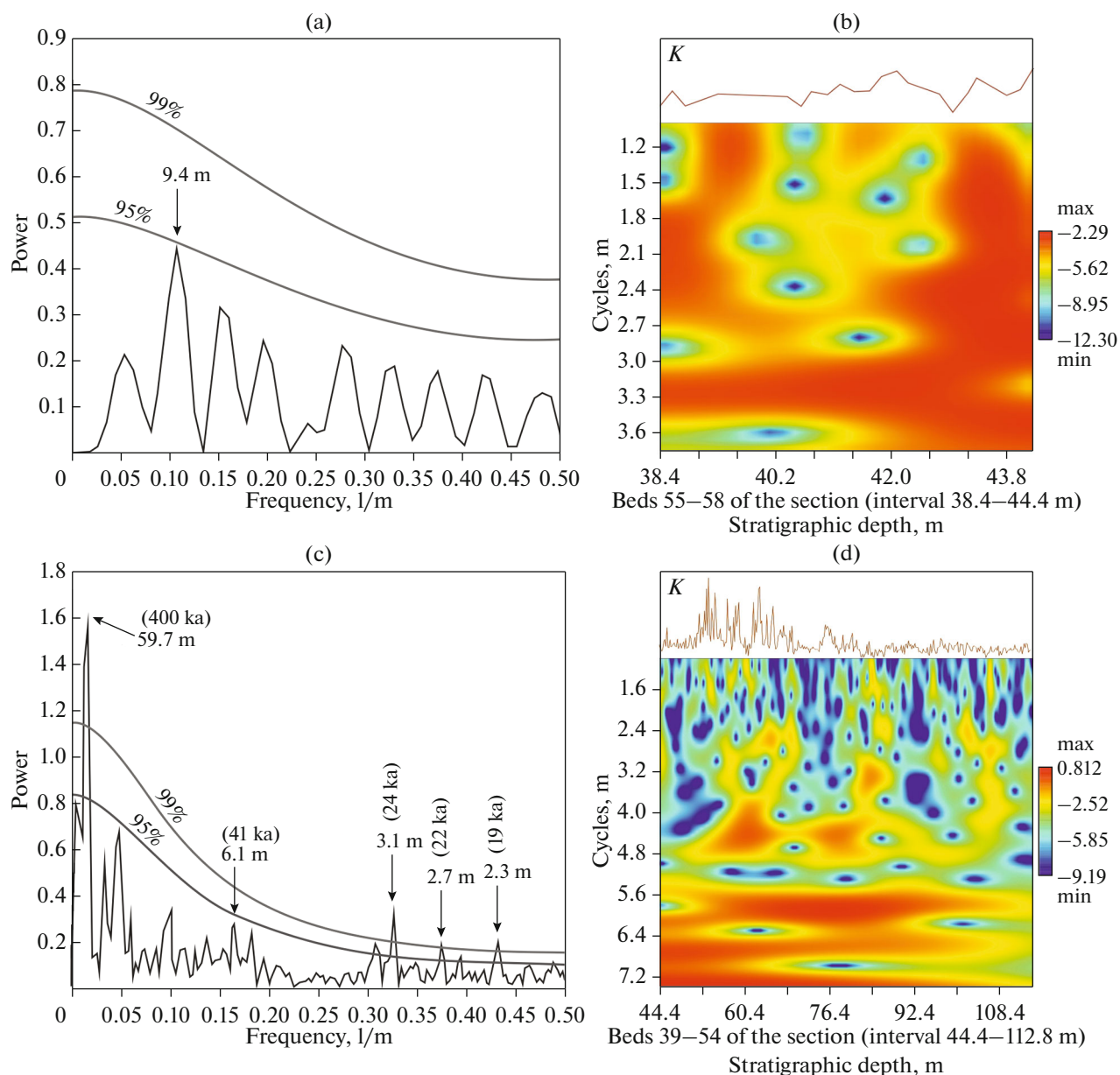


Fig. 31. Results of the REDFIT (a, c) and Wavelet (b, d) analyses of data on the magnetic susceptibility of rocks from the Portafarian (a, b) and Novorossian (c, d) beds exposed in the Zhelezny Rog section (Taman Peninsula). K is the magnetic susceptibility of rocks.

uity period to the 24, 22, and 19-kyr periods of precession is 1.7 : 1, 1.9 : 1, and 2.2 : 1, respectively. The ratio of the established cycles of 59.7 and 6.1 m is 9.7 : 1. The ratios between the observed periodicities were used to identify Milankovitch cyclicity. Based on the analysis of these ratios, it is assumed that there is a record of astronomical cyclicity in sediments of Novorossian that reflects fluctuations in the eccentricity of the Earth's orbit (400 ka, the cycle at 59.7 m), tilt of the Earth's axis (41 ka, the cycle at 6.1 m), and precession (cycles at 3.1, 2.7, and 2.3 m).

Taking into account the change in the sedimentation rate, the cycle at 6.1 m established in the Novo-

rossian sediments may be correlated with the cycles at 7.1–7.8 and 8.0–8.2 m recognized in the transitional Maeotian/Pontian beds, as well as in Bosphorian beds of the studied succession (Fig. 33, beds 38 and 59–66, respectively). Cycles at 3, 3.2, and 4 m, recorded on the Lomb–Scargle and REDFIT periodograms for the studied parts of the section, most likely correspond to the precession periods.

The results of the wavelet analysis are well consistent with the data resulting from analysis of the Lomb–Scargle and REDFIT periodograms, thereby showing the presence of cycles at 5.6–8.1 and 2.4–4.8 m for the whole sequence of Pontian sediments. Analysis

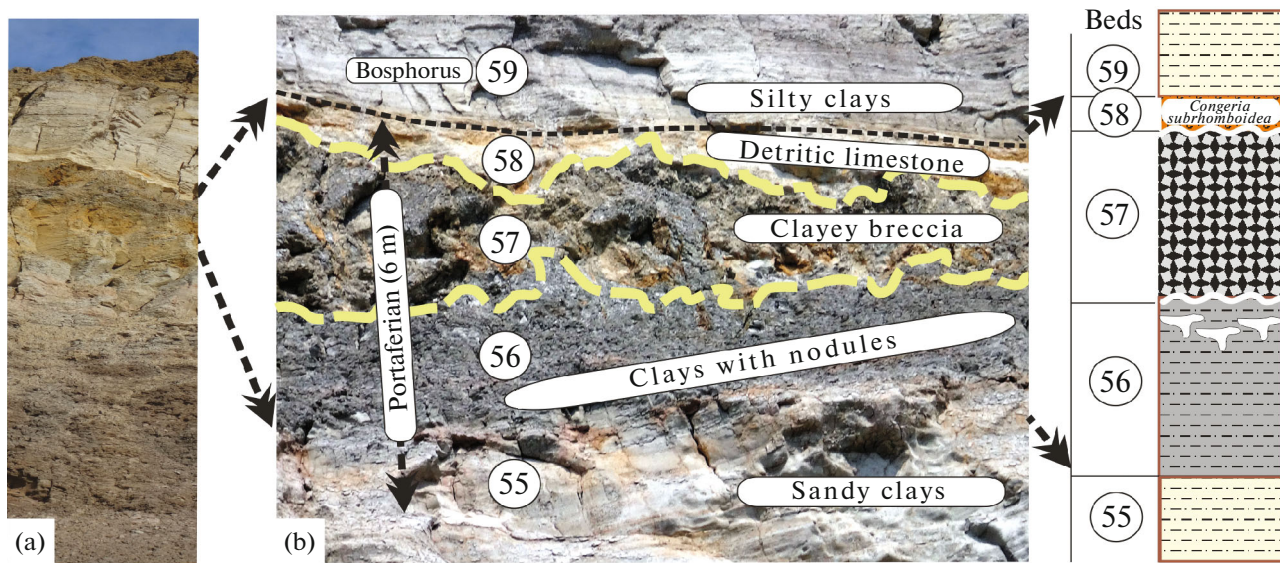


Fig. 32. Lithological structure of Portaferian beds of the Pontian exposed in the Zhelezny Rog section (Taman Peninsula). (a) general view, (b) identified layers in Portaferian sediments.

of the data using the Gaussian filter revealed a record of 21 and 39 cycles with the periodicity at 6.1–8.0 and 3.1–4.0 m in the studied section, including transitional Maeotian/Pontian beds (Fig. 34).

Discussion. The beginning of the Pontian was marked by a transgression (Popov et al., 2004b). In the studied part of the basin, clay sediments accumulated in relatively deep-water conditions. According to the composition of the mollusk fauna, the salinity of the waters was low, but higher than 5–8‰. According to Radionova and Golovina (2011), short episodes of marine-water invasion led to the appearance of nanoplankton and marine diatom species in the Eastern Paratethys during the formation of the transitional Maeotian/Pontian beds, as well as the base of the Pontian. At the end of the Early Pontian, a regressive stage is recognized in the development of the paleobasin.

In the Portaferian, the Eastern Paratethys was restricted, which caused the separation the Caspian Basin from the Euxinian Basin in the northern part (Nevesskaya et al., 1986, 2003; Popov et al., 2004b, 2006). According to Krijgsman et al. (2010), the Portaferian corresponds to the regressive stage recognized in the Dacian Basin, during which there was a sudden change in the ostracod assemblages.

The Bosphorian beds, which were first recognized by Andrusov (1923) in the Kerch–Taman region, were formed during the development of transgression in the Eastern Paratethys. In the Dacian Basin, sections of the Pontian show a lithological change to more basinal sequences (Jipa, 1997).

According to Krijgsman et al. (2010), the age of the boundary is 6.04 ± 0.01 Ma between Maeotian and Pontian beds and 5.8 ± 0.1 Ma between Novorossian

and Portaferian beds based on biostratigraphic and paleomagnetic data. In the Dacian Basin, the boundary between the Portaferian and Bosphorian corresponds to 5.5 ± 0.1 Ma. According to Snel et al. (2006), the boundary between the Maeotian and Pontian corresponds to 6.15 ± 0.11 Ma and the base of the Portaferian and Bosphorian is dated to about 6.0 and 5.6 Ma, respectively. The age of the boundary between the Pontian and Kimmerian is estimated at about 5.3 ± 0.1 Ma. The duration of the Pontian is about 0.85 Myr.

In terms of magnetostratigraphy most of the Pontian are characterized by reversed polarity with an episode of normal polarity near the base (Trubikhin, 1989; Pevzner et al., 2003; Vasiliev et al., 2011). According to the results of integrated biostratigraphic and paleomagnetic studies, normally magnetized Pontian deposits are correlated with chron C3An (Trubikhin (in Popov et al., 1996); Krijgsman et al., 2010; Vasiliev et al., 2011; Radionova and Golovina, 2011; Radionova et al., 2012; Popov et al., 2013). The age of the upper boundary of chron C3An is 6.023 Ma (Gradstein et al., 2020).

According to the Gaussian bandpass-filter data, 14 cycles at 6.1–8.0 m (6.1 m for Novorossian beds and 8.0 m for Upper Pontian beds), correlated with the orbital 41-kyr obliquity period (interval from 95 to 0 m), are recognized in Pontian sediments between the level of paleomagnetic reversal up to the base of the Kimmerian (Fig. 34). Given this, the 95-m interval is estimated to have a duration of ~0.57 Myr. The boundary between the Novorossian and Portaferian beds is dated at about 5.6–5.7 Ma. According to Krijgsman et al. (2010), the age of the Lower Portaferian

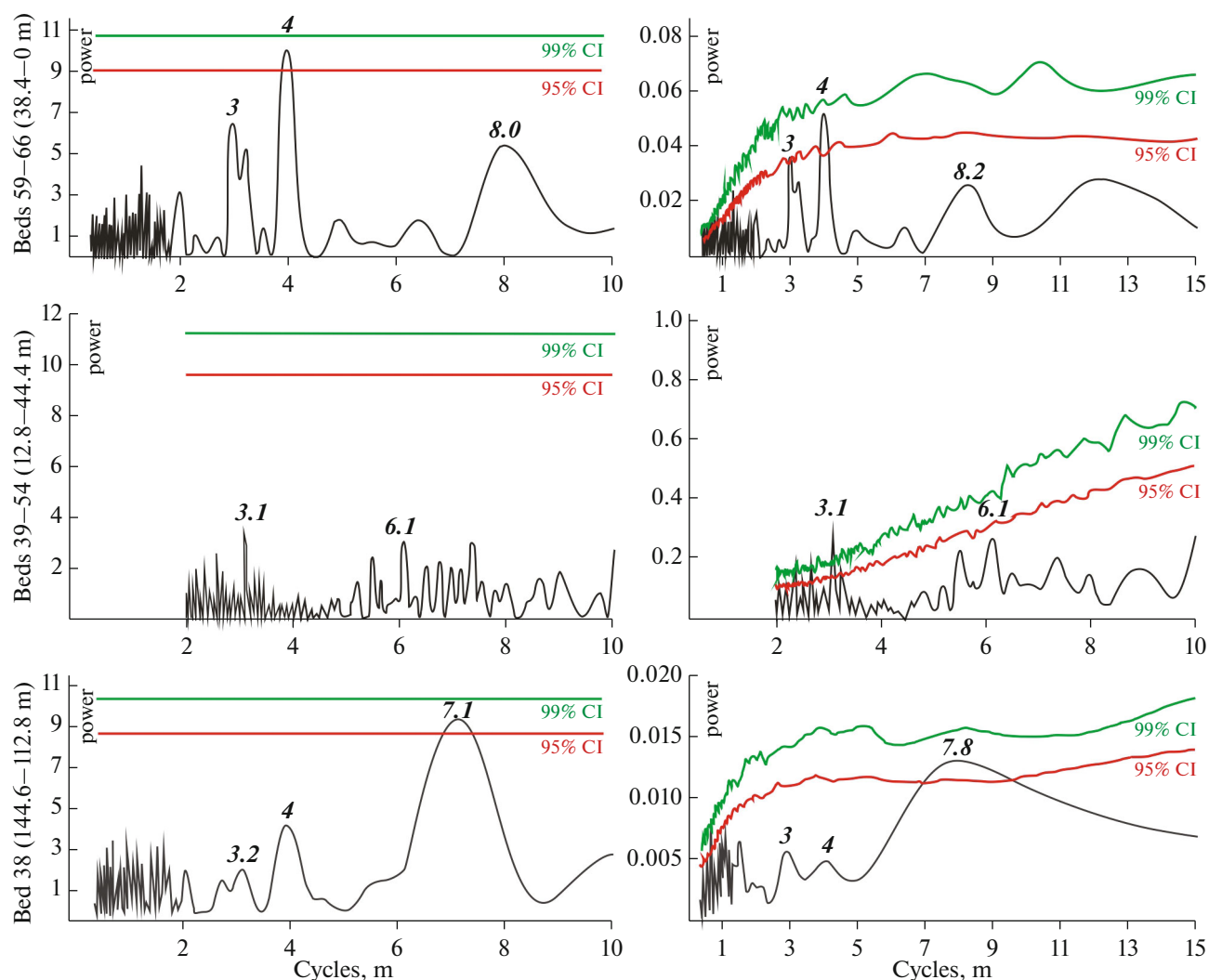


Fig. 33. Lomb–Scargle (left) and REDFIT (right) periodograms of the spectral analysis of data on the magnetic susceptibility of Pontian rocks of the Zhelezny Rog section (Taman Peninsula).

boundary in the Eastern Paratethys is 5.8 ± 0.1 (5.7–5.9) Ma.

The upper part of Novorossian beds (from 65.8 to 59.2 m) has an interval with extremely high values of magnetic susceptibility of rocks, being 0.834 and 0.937×10^{-3} SI units, which can be correlated with the TG22 (5.79 Ma) and TG20 (5.75 Ma) isotope stages, respectively. This is well consistent with the available paleontological and lithological data. In the upper part of Novorossian beds in the Zhelezny Rog section (from the interval of 79 m and above), calcareous nanoplankton and marine diatom species are absent in sediments. At the end of the Novorossian, the connection of the Eastern Paratethys with marine basins was interrupted against the backdrop of increased regression (Radionova and Golovina, 2011). According to the results of the cyclostratigraphic studies, the level of disappearance of marine species of microflora in Novorossian sediments is dated to about 5.88 Ma. The

extremely high values of magnetic susceptibility of rocks in this part of the section can be explained by restricted-basin circulation and increased productivity of diagenetic sulphide minerals during glacial events. The global sea level is expected to significantly decrease (by about 50 m) during the TG22 and TG20 isotope stages associated with episodes of intensive growth of polar ice sheets against the background of general climate cooling (Shackleton et al., 1995; Hodell et al., 2001).

The base of the “stagnation horizon” (the interval from 93.6 to 86.8 m) corresponds to the TG32 isotope stage and onset of the Messinian salinity crisis (MSC), dated as about 5.97 Ma. In sediments of the Lower Pontian, the “stagnation horizon”, which was first described by Andrusov (1903) in the Zhelezny Rog section, is characterized by a darker color of clays with an increased content of manganese compounds. Therefore, the accumulation of most of the sediments

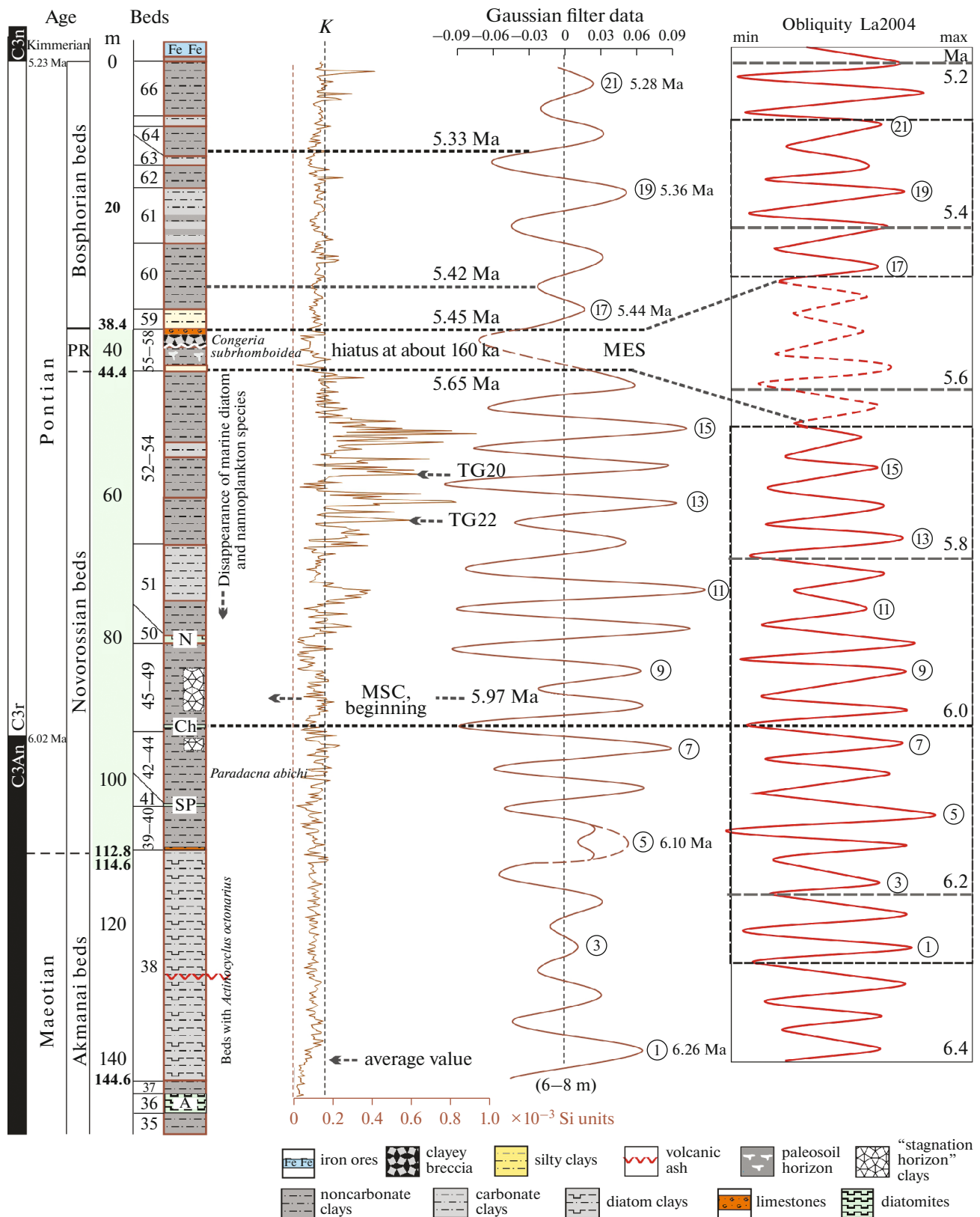


Fig. 34. Analysis of data on the magnetic susceptibility of Pontian rocks from the Zhelezny Rog section (Taman Peninsula) using the AnalySeries software program. A, SP, Ch, and N are diatomite interbeds (according to Radionova and Golovina, 2011). Paleomagnetic data according to Trubikhin (Popov et al., 1996), Vasiliev et al. (2011), and Radionova et al. (2012). Paleontological data according to Radionova and Golovina (2011) and Radionova et al. (2012). Numbers in circles indicate cycle numbers. PR, Portaferian beds, MSC, Messinian salinity crisis, MES, Messinian erosional surface, K, magnetic susceptibility of rocks.

of Novorossian beds (from 93.6 m and upward the section) can be correlated with the time of occurrence of the Messinian salinity crisis and development of the first stage of evaporite formation in the Mediterranean (i.e., Primary Lower Gypsum 5.97–5.6 Ma according to Roveri et al., 2014; Peripheral evaporites 5.97–5.6 Ma according to Bache et al., 2015).

The base of the thin interbed of detrital limestone (Bed 39, level 112.8 m), located at the top of the transitional Maeotian/Pontian beds, is dated to about 6.1 Ma. According to the data of cyclostratigraphic studies, transitional Maeotian / Pontian beds (interval from 144.6 to 114.6 m) accumulated from about 6.3 to 6.1 Ma.

The spectral analysis of the magnetic susceptibility data from Portaferian beds, represented by redeposited sediments, did not reveal a clear record of astronomical cyclicity in these sequence. According to Krijgsman et al. (2010), the fall of water level in the Paratethys corresponds to the beginning of the Portaferian time.

According to the Gaussian bandpass-filter data, four to five cycles (4.8 cycles 8.0 m long) correlated with the 41-kyr obliquity period (interval from 38.4 to 0 m) are recognized in Bosphorian beds.

This gives a duration of ~205 kyr for this sedimentary succession. According to Trubikhin (1989) and Vasiliev et al. (2011), the base of Kimmerian deposits, characterized by the normal polarity, correlates with chron C3n.4n (Thvera). Given that the age of the C3r/C3n boundary is 5.235 Ma (Gradstein et al., 2020), the lower boundary of Bosphorian beds may be dated to about 5.4–5.5 Ma. Given these determination, the Bosphorian correlates to the Upper Gypsum and the Lago Mare biofacies characterized by Paratethyan fossil assemblages. According to biostratigraphic and paleomagnetic data, the age of the lower boundary of the Bosphorian in the Dacian basin is differently estimated: 5.5 ± 0.1 Ma (Krijgsman et al., 2010), 5.6 Ma (Snel et al., 2006), or 5.45 Ma (Popescu et al., 2006; Bache et al., 2012). According to Krijgsman et al. (2010), the global climate warming and increased humidity after the TG12 isotope stage, dated to about 5.5 Ma, led to an increase in water masses in the Paratethys, which determined a widespread development of transgression at the end of the Pontian.

According to data on the astronomical cyclicity of Novorossian and Bosphorian beds, the age of the lower and upper boundaries of the Portaferian is about 5.65 and 5.45 Ma, respectively. Taking into account the 6 m thickness of sediments and the presence of resedimented deposits in the record of Portaferian as well as obtained astronomical cycles in metres, we propose a ~150–160 ky hiatus between the Lower and Upper Pontian. The obtained data are confirmed by the concept of presence of an intra-Pontian unconformity in the Eastern Paratethys (Gillet et al., 2007; Suc

et al., 2015), which corresponds to the time of a significant sea-level fall in the Mediterranean basin and is an equivalent of the Messinian erosional surface (MES) (Tari et al., 2015, 2016; Krezsek et al., 2016). In the Messinian, a major sea-level drop in the Mediterranean occurred from 5.6 to 5.46 Ma (Clauzon et al., 1996; Bache et al., 2012).

If we accept that there was no hiatus in the Portaferian, the upper boundary of the Pontian should correspond to about 5.4 (5.5) Ma, taking into account the preserved record of the astronomical cyclicity of the studied sediments. This interpretation of the data is not supported by a number of facts:

(1) the presence of a 38-m sequence of Bosphorian beds in the Zhelezny Rog section; the base of these beds in the Dacian Basin is dated to about 5.6–5.5 Ma (Snel et al., 2006; Krijgsman et al., 2010);

(2) the transgressive sequence of the uppermost Zheleznyi Rog Pontian (i.e. Bosphorian), which must have accumulated during the period of a major sea-level drop in the Mediterranean (from 5.6 to 5.46 Ma according to Clauzon et al., 1996; Bache et al., 2012) in the case under consideration;

(3) the presence of Portaferian beds in the section, which are characterized by resedimented deposits and erosional surfaces;

If we correlate the recognized 14 cycles in the studied sediments (the interval from 95 to 0 m) with the precession periods, the top of the Pontian would correspond to about 5.69 Ma. In that case, the Pontian/Kimmerian boundary would be marked by hiatus of at least ~460 kyr that disagrees with biostratigraphic and lithological data, as well as with the presence of Bosphorian transgressive succession in the section. Therefore, the results of cyclostratigraphic studies make it possible to correlate the boundary between the Novorossian and Portaferian with the beginning of the formation of the Messinian erosional surface (MES) within the Mediterranean.

The results of cyclostratigraphic studies make it possible to estimate the rates of sedimentation. Thus, sedimentation rate of transitional Maeotian/Pontian beds was about 16.3 cm/kyr. For the Novorossian, the sedimentation rate was estimated at 13.5 cm/kyr, and for the Bosphorian it was estimated at 19.5 cm/kyr. These values do not contradict other estimates of sedimentation regimes. According to Popescu et al. (2010), the sedimentation rate in the Black Sea (deep-hole well 380) was about 13 cm/1000 years at the Late Miocene–Early Pliocene.

The cyclostratigraphic data obtained by Gaussian filtering at 6.1–8.0 m (obliquity cyclicity) and at 3.1–4.0 m (precession cyclicity) are well consistent with each other.

Findings

(1) The study showed that the astronomical cyclicity was reflected in relatively deep-water clayey Konkian, Maeotian, and Pontian sediments of the Eastern Paratethys (key sections of the Taman Peninsula).

(2) In the studied Maeotian and Pontian sediments, cycles at 6–8 m may correspond to the 41-kyr obliquity period and cycles at 3 and 4 m may correspond to periods of 19, 22, and 24 kyr precession. The determination of the astronomical tuning of the Konkian using the revealed cycle at 3.3 m is still debatable due to a sharp change in sedimentation regimes during the accumulation of these deposits, as well as due to the existing discussions about their stratigraphy.

(3) The average sedimentation rates were estimated at 11–12 cm/kyr for the Early Maeotian, 19 cm/kyr for the Late Maeotian, about 16.3 cm/kyr for the transitional Maeotian/Pontian beds, 13.5 cm/kyr for the Early Pontian (Novorossian), and 19.5 cm/kyr for the Late Pontian (Bosphorian).

(4) According to the cyclostratigraphic data, the Sarmatian/Maeotian boundary has an age of 7.6 Ma, the Lower/Upper Maeotian boundary is dated at ~6.7 Ma, the Maeotian/Pontian boundary is dated at ~6.1–6.03 Ma, and the Pontian/Kimmerian boundary is dated at ~5.2 Ma. The lower and upper boundaries of Portaferian beds are dated 5.65 and 5.45 Ma, respectively.

(5) The Novorossian/Portaferian boundary is marked by a hiatus of ~150–160 kyr, which is correlated with stage of the development of the Messinian Erosional Surface (MES) in the Mediterranean. These data are well consistent with the presence of re-sedimented deposits and erosional boundaries in Portaferian sedimentary sequence as well as the concept of intra-Pontian unconformity established in deposits from the western part of the Black Sea (Gillet et al., 2007). The total duration of the Pontian is not more than 1 Ma (about 0.8–0.9 Ma).

CONCLUSIONS

Major Results of the Revision of the Neogene Stratigraphic Scheme of the Eastern Paratethys

The available new data on phytoplankton groups (nannofossils, dinocysts, and diatoms), magnetostratigraphic characteristics of the sections, and cyclostratigraphic studies enable the revision of range and boundaries of Neogene regional stages of the Eastern Paratethys and their correlation with the Neogene stratotype stages of the Mediterranean and Central Paratethys. These studies were carried out with constant monitoring of the parallel study of fauna groups traditional for the Paratethys, i.e., mollusks and foraminifers. The main results are summarized in the revised scheme of the Neogene of the Eastern

Paratethys (Fig. 35), where the confidently dated boundaries of the regional stages and substages are marked with solid lines and the numbers show their absolute age.


The most significant results are as follows:

Caucasian regional stage. The base of the Caucasian Stage (weakly carbonate deposits of the Alkunian Horizon) are fairly widespread not only in Ciscaucasia (Dmitrieva et al., 1959; Beluzhenko et al., 2018) but also in Transcaucasia and in the Kartli depression of Georgia [the base of the Upper Uplistsikhe Subformation (Minashvili and Ananiashvili, 2017)]. According to nannofossils, this level is recognized as the *Cycli-cargolithus floridanus* beds, which were traced in many sections of Ciscaucasia and were correlated with the upper part of the NN1 *Triquetrorhabdulus carinatus* Zone according to the Martini scale. The occurrence of the zonal species together with *T. milowii* and the absence of *Sphenolithus ciperoensis* in this assemblage serve as a basis for correlation of the Alkunian Horizon with the base of the Miocene.

The dinocyst assemblage of this level was recognized as *Deflandrea spinulosa* beds of the transitional Oligocene–Miocene age. In the Kuban section the disappearance of *Chiropteridium* and the last common frequent occurrence (LCO) of *Apteodinium australiense* and *Apteodinium maculatum* were recorded within the beds, and the LCO of *Deflandrea spinulosa* (which is also a species passing from the Oligocene) was marked at the top. Finds of *Tuberculodinium van-campoae* (a characteristic Early Miocene species) (Filippova et al., 2010, 2015) and the absence of *Chiropteridium* at this level indicate a transitional Paleogene–Neogene nature of the assemblage.

Similar associations of nannoflora and dinocysts were recorded in the stratotype section of the Alkunian Horizon on Alkunka Creek, in the stratotype of the Caucasian Regional Stage on the Kuban River near the city of Cherkessk (data from L.A. Golovina and G.N. Aleksandrova), and down the river near the village of Karamurzinsky (Filippova et al., 2015), in the Alkun sediments on the Belaya River section (data from J. Krhovski (Krhovski et al., 1995), Golovina and Zaporozhets), and in the sections of North Ossetia (i.e. Fiagdon, Mairamadag—Filippova, et al., 2010, Beluzhenko et al., 2018). The sediments from the lower part of the Septarian Formation (or Septarian beds of the Zelenchuk Formation) in the Kuban section are characterized by the same dinocyst assemblage the *Deflandrea spinulosa* Beds.

Stratigraphically above *Sumatradinium* spp. beds were recognized based on dinocysts in the Zelenchuk and lower part of the Karadzhalka formations, which correspond to the upper substage of the Caucasian Regional Stage; their base is correlated with the lower boundary of the dinocyst zone of *Sumatradinium soucouyantiae* Zone (DN2) according to the de Verteuil and Norris scale (1996). Zone DN2 is correlated with

Time, Ma	Chronos	Polarity	Epochs	Mediterranean stages	Nannoplankton	Dinocysts	Regional Stage of the Central Paratethys	Regional Stage of the Eastern Paratethys												
				GTS2020				Dacian	Euxinic	Caspian										
0	C1n		Q	0.77 Ionian	NN21		Paludine beds	Pleistocene												
	C1r	1.8 Calabrian		—				Gurian	Apsheronian _{1.8}											
C2	2.58 Gelasian	NN17		DPL1				Kuyalnikian	Akchagylian _{2.9}											
C2An	Pliocene	3.6 Piacenzian	NN16	DP4	Romanian	Kimmerian		Balakhanian												
C2Ar		Zanclean	NN13	DP3					Dacian	Bosporian	Babajanian									
C3n			NN13	DP2								Pontian	Novorossian beds							
C3r			NN12	DP1										Macotian	Upper					
C3An		Late Miocene	Messinian	NN11					DM9	Pannonian (s.l.)	Sarmatian s.l.					Upper (Khersonian)				
C3Ar	Tortonian				NN10	DM8		Sarmatian s.s.				Middle (Bessarabian)								
C3Br													NN9	DM7	Badenian		Upper			
C4n							NN8											DM6	Lower	Konkian
C4r																				
C4An		NN6	DM4	Ottangian					Sakaraulian											
C4Ar	NN5				DM3	Eggenburgian		Caucasian												
C5n										Middle Miocene	Serravallian	NN4	DM2	Egerian	Kalmykian Regiostage					
C5r							Langhian									NN3	DM1	Kalmukian		
C5An																			NN2	DM1
C5Ar		NN1	DM1	Kalmukian																
C5ACn	NN1				DM1	Kalmukian														
C5ADn								NN1	DM1	Kalmukian										
C5Bn							NN1				DM1	Kalmukian								
C5Br													NN1	DM1	Kalmukian					
C5Cn		NN1	DM1	Kalmukian																
C5Cr	NN1				DM1	Kalmukian														
C5Dn								NN1	DM1	Kalmukian										
C5Dr							NN1				DM1	Kalmukian								
C5Fn													NN1	DM1	Kalmukian					
C6n		NN1	DM1	Kalmukian																
C6r	NN1				DM1	Kalmukian														
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C6Ar							NN1				DM1	Kalmukian								
C6AAn													NN1	DM1	Kalmukian					
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C6Cn	NN1				DM1	Kalmukian														
C6Cr								NN1	DM1	Kalmukian										
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its appearance was recorded at the base of the dinocysts *Cousteaudinium aubryae* zone (DN3) and is correlated with the base of the nannofossil zone NN3 of the Burdigalian (de Verteuil and Norris, 1996; de Verteuil, 1997). Therefore, the Caucasian Regional Stage covers the chronostratigraphic interval from the boundary Chattian/Aquitania interval to the lower strata of the Burdigalian stage according to ISC-2020 (Gradstein et al., 2020). It should be noted here that points of the global Burdigalian and Langhian stratotypes have not yet been established in the ISC.

Sakaraulian regional stage. The mollusk composition of the Kartli depression of Georgia, stratotypical for the Sakaraulian, is closest to the Eggenburgian assemblage (about 1/3 of common species) and includes the characteristic Lower Miocene species, such as *Glycymeris fichteli*, *Fragum semirugosum*, *Acanthocardia grandis*, *A. kuebeckii*, *Glossus maior*, and *Venus (Dosina) burdigalensis*.

Based on the occurrence of dinocysts *Cousteaudinium aubryae*, *Trinovantedinium harpagonium*, and *Lincolodinium multivirgatum*, the sediments of the upper part of the Sakaraulian hypostratotype section (Nadarbazevi) are correlated with the interval of the *Sumatradinium soucouyantiae* (DN2) and *Cousteaudinium aubryae* (DN3) zones of Verteuil and Norris (1996), which are correlated with the upper strata of zone NN2—lower strata of zone NN4 according to the nannoplankton Martini scale (Martini, 1971) and are of Burdigalian age. It is not yet possible to make clearer correlations, since Sakaraulian dinocyst associations in the studied sections are represented by taxa of a wide stratigraphic range not only in Georgia but also along the Kuban River.

The Upper Maikopian sediments with typical Sakaraulian mollusks were found in the Babol section in northern Iran. The sediments contain nannofossils *Triquetrorhabdulus challengerii* and *Sphenolithus conicus*. The first species has a narrow stratigraphic distribution within zones NN1–NN2 of the Lower Miocene.

According to the magnetostratigraphic characteristics, the upper half of the Voskovogorsk Formation and the Olginskaya Formation on the Belaya River are correlated with the main part of the Burdigalian (except its uppermost part).

Kozakhurian regional stage. In the stratotype sections of the Kozakhurian Regional Stage in Georgia, dinocysts were found in the lower and middle parts of the regional stage, where they are mainly represented by taxa of a wide stratigraphic range; however, by exceptionally marine assemblages.

In the sections of the Kartli Depression in Georgia, the transition from the Kozakhurian to Tarkhanian is represented by an unconformity and conglomerate layer, whereas in Ciscaucasia there is a smooth transition from the Maikopian Group to the Tarkhanian without any evidence of a break. Therefore, it is quite

possible that the Kozakhurian of Georgia does not fully correspond to the uppermost Maikopian of Ciscaucasia.

Based on the occurrence of common Paratethian endemic brackish-water genera and species of mollusks, the Kozakhurian of Georgia can be correlated with the Upper Ottnangian of the Central Paratethys, although the stratigraphic level of their boundaries may differ significantly.

In the middle and upper parts of the Ritsa Formation in Central and Western Ciscaucasia, dinocyst assemblages are dominated by *Batiacasphaera* species (*B. micropapillata*, *B. sphaerica*, and *B. baculata*); a constant occurrence of prasinophytes and freshwater algae (*Pediastrum*, *Ovoidites*, *Leiosphaeridia*, *Tasmanites*, and *Botryococcus*) is typical here. A similar assemblage was recorded the uppermost Maikopian Group in northern Azerbaijan. The dominance of *Batiacasphaera* species indicates limited communications between the paleobasin and open ocean species, colder formation conditions in the middle of the Kozakhurian time than at the beginning and end of the Kozakhurian. A significant diversity of prasinophytes and green algae and a large number of redeposited taxa indicate intensive drift from the adjacent land and a probable water stratification. Based on dinocysts, *Batiacasphaera* Beds are dated to the Burdigalian age.

The mass occurrence of *Spiniferites* with a noticeable proportion of *Achomosphaera*, *Sumatradinium*, *Operculodinium*, *Hystrichosphaeropsis*, and *Systematophora* (in the section of the Bulganak anticline), the presence of planktonic foraminifers (in the SG-12000 section), recorded at the end of the Ritsa time, indicate a recovery of marine neritic environments and warming during the continued accumulation of typical noncalcareous Maikopian facies with pyritization and jarosite in the basin during weathering.

The **Tarkhanian regional stage** differs from the Maikopian in the accumulation in oxygenated waters, and in the development of a rich benthic life in the basin and appearance of deep-sea fishes. Based on the presence of dinocysts *Labyrithodinium truncatum*, the lower part of the Tarkhanian Regional Stage (up to the Tarkhanian marl) in the section on the Kuban River is correlated with the *Distatodinium paradoxum* Zone (DN4) on the Atlantic coast of the United States (de Verteuil and Norris, 1996; Köthe, 2012), subzone D17b of Western Europe (Powell and Brinkhuis, 2004), *Labyrithodinium truncatum* Zone of the Danish sector of the North Sea (Dybkjær and Pia-secki, 2010), and zone DM4 of North-Western Europe (King, 2016), which are dated as the terminal Burdigalian—lower part of Langhian according to the International Stratigraphic Chart.

At the same time, the mass occurrence of the zonal nannoplankton species *Sphenolithus heteromorphus* in the Tarkhanian and the presence of *Helicosphaera waltrans*, important for the Paratethys stratigraphy, with

the absence of *Helicosphaera ampliaperta* make it possible to correlate the Tarkhanian association with the ***Sphenolithus heteromorphus* Zone** (NN5) according to the Martini scale (1971). The finds of planktonic foraminifers *Orbulina suturalis*, *Globorotalia* (*Globorotalia*) *scitula*, and *G. (Fohsella) peripheroronda* in the section of the Pshekha River indicate their attribution to the ***Orbulina suturalis* Zone** (M6) according to the scale of Wade et al. (2011) and suggest the correlation of Tarkhanian with the mid Langhian, aged from 15.1 to about 14 Ma.

The interpretation of magnetostratigraphic data based on this correlation (Palcu et al., 2017) infers the dating of the base of Tarkhanian to 14.85–14.9 Ma, whereas the base of the Middle Miocene is dated at 15.97 Ma according to the international scale (see Fig. 19). In the absence of break at the Tarkhanian–Kozakhurian boundary (which is observed in most relatively deep-water sections), a significant part of the Upper Maikopian should belong to the lowermost Middle Miocene and be correlated with the Lower Langhian. Undoubtedly, this Middle Miocene part of the Maikopian Group is included in the local subdivisions of the uppermost Maikopian (the Ritsa and Zoramakent formations), which underlie the Tarkhanian without unconformity.

According to paleomagnetic data (Palcu et al., 2017), the top of Tarkhanian is correlated with chron C5Bn.1n and has an age of about 14.8 Ma. According to these data, the Tarkhanian is very short (not more than 100 ka) and is correlated with the upper part of the Lower Badenian and the second half of the Langhian according to the ISC.

Chokrakian regional stage. The studied Chokrakian phytoplankton assemblages are poor and do not contain stratigraphically important species. A significant parameter for assessing the age is the presence of the Belomechet mammal assemblage on the Kuban River in the uppermost Lower Chokrakian, which is believed to belong to the uppermost zone MN5–lowermost zone MN6 of the Mein mammal scale. This fact also makes it possible to date this assemblage as a part of the Upper Langhian according to the ISC.

According to paleomagnetic data, the age of the base of the Chokrakian Regional Stage in the reference sections of Western Ciscaucasia (the Belaya and Pshekha rivers) is 14.77–14.8 Ma. The boundary between the upper and lower substages of the Chokrakian in the Belaya River section, where it is faunistically well dated, lies in the upper part of chron C5ADn and has an age of about 14.2 Ma; and the age of the top of the regional stage is 13.8–13.9 Ma (see Fig. 19). According to these data, the Chokrakian Regional Stage also still belongs to the upper strata of the Langhian according to the ISC; the age of its top is estimated at 13.82 Ma.

The **Karaganian regional stage** with an impoverished endemic fauna cannot be biostratigraphically

correlated with open basins; therefore, its correlation with the ISC is fully based on paleomagnetic data. The base of the Karaganian lies in the upper or middle part of normal polarity chron C5ACn and its age is estimated at 13.8–13.9 Ma. The boundary between the upper and lower substages of the Karaganian in the Belaya River section, where it is characterized by mollusk fauna, lies in the middle part of chron C5ABn and is therefore dated to about 13.5 Ma. The age of the top is estimated at 13.4 Ma (Palcu et al., 2017). According to these data, the Karaganian is correlated with the upper strata of the Lower Badenian of the Central Paratethys in the case of its two-term division and with the lower strata of the Serravallian according to the Mediterranean scale and ISC.

The **Konkian regional stage** is accepted in this study as three-membered and includes Kartvelian beds as the lower subdivision, since the assemblage of mollusks and benthic foraminifers contains characteristic Konkian species (including specific endemics) at the base of these beds. Based on the nannoplankton assemblage, *Reticulofenestra pseudumbilicus* Beds were recognized in Konkian deposits; these beds are traced in a number of Ciscaucasian sections (Belaya, Chumnaya gully, Pshekha, Fars, and Bolshoy Zelenchuk rivers) and in Western Kazakhstan (Krashennikov et al., 2003; Vernigorova et al., 2006; Golovina, 2019; Bratishko et al., 2015). Their richest assemblage is correlated with the undivided assemblage of NN6 *Discoaster exilis*–NN7 with *Discoaster kugleri* zones (Golovina and Vernigorova, 2011). The presence of *Rhabdosphaera poculii* and *Rhabdosphaera pannonica* is an important additional biomarker for correlation, since it was previously believed that these species were present only in the Central Paratethys (Chira, 1999). According to these data, the Konkian Regional Stage is correlated with the Upper Badenian (Kosovian) of the Central Paratethys and with the upper half of the Serravallian according to the ISC (Golovina in Krashennikov et al., 2003; Vernigorova et al., 2017).

The base of the Konkian Regional Stage, which corresponds to the base of Kartvelian Beds, is at the top of chron C5ABn and has an age of 13.4 Ma (Palcu et al., 2017). The boundary between the Sartaganian + Veselyanka and Kartvelian beds, which is well dated by foraminifers and nannoplankton in the section of Zelensky Hill on the Taman Peninsula, almost completely coincides with the boundary between subchrons C5Ar.2n/C5Ar.3r and is therefore dated to 12.9 Ma. According to these data, the Konkian Regional Stage is correlated with the middle part of the Serravallian. The age of the boundary between the Konkian Regional Stage and Lower Sarmatian (Volhynian) is 12.65 Ma (Palcu et al., 2017).

Sarmatian regional stage. Diatoms showed a high stratigraphic potential for the stratigraphy of the Upper Sarmatian and Maeotian, where the presence of oceanic marker species of the Mediterranean and

oceanic zonal scales with a narrow stratigraphic distribution interval was established (Radionova et al., 2012). Thus, the presence of *Thalassiosira burckliana* (FO 8.9 Ma, LO 7.9 Ma) and *Nitzschia fossilis* (FO 8.9 Ma) in the upper strata of the Sarmatian makes it possible to estimate the age of this part of the section at no more than 8.9 Ma (Popov et al., 2016), which is much younger than the previously proposed datings. The cooccurrence of the oceanic species *Thalassiosira burckliana* (LO 7.9 Ma), *Th. groudowii* (LO 7.9 Ma), *Th. antiqua* (FO 7.7 Ma), and *Nitzschia fossilis* near the Sarmatian/Maeotian boundary makes it possible to date the top of the Sarmatian at 7.7–7.9 Ma.

According to paleomagnetic data, the base of the Sarmatian lies within subchron C5Ar.1r with an estimated age of 12.65 Ma (Palcu et al., 2015, 2017). The boundary between the lower and middle Sarmatian (Volhynian/Bessarabian) has not yet been accurately dated by paleomagnetic or isotopic methods. The data of previous studies (Trubikhin in *Unifitsirovannaya...*, 2004) and results of studying the Panagia section (see Fig. 20) show that most of the Middle Sarmatian s.l. belongs to the normal polarity zone correlated with long chron C5n. It is difficult to date the boundary between the middle and upper parts of the Sarmatian s.l. (Bessarabian/Khersonian) due to a sedimentation break and few continuous sections. On the Taman Peninsula, where this interval is most fully represented, it is located in the reverse polarity zone correlated with chron C4Ar and is dated to 9.6 Ma BP (Palcu et al., 2021). According to these data, the Sarmatian of the Eastern Paratethys corresponds to the Upper Serravallian and most of the Tortonian in the ISC.

Maeotian regional stage. The sharp sea level fall at the Sarmatian/Maeotian boundary resulted in the cessation of marine sedimentation in most areas of the Eastern Paratethys. Therefore, the Maeotian transgression represents a gradual diachronous filling of the regressed reservoir. The base of the Maeotian is characterized by both direct and reverse polarity within chron C4n.1r and C3Br.3r. The earliest dates of about 7.65 Ma (C4n.1r) were determined for the deepest part of the depression of the Dacian Basin and for the Panagia section of the Taman Peninsula (Palcu et al., 2021).

The base of the Upper Maeotian is stratigraphically slightly below the C3Ar/C3An paleomagnetic inversion, which is dated to 6.73 Ma but often disturbed by slope and landslide processes. In the most complete sections (Zhelezny Rog), it lies at the top of chron C3Ar and has an age of about 6.75 Ma. According to the paleomagnetic characteristics, the top of the Maeotian is in the upper part of chron C3An and has an age of about 6.1 Ma. Therefore, according to these data, the Maeotian is correlated with the upper strata of the Tortonian and lower half of the Messinian in the ISC.

Pontian regional stage. The boundary between the Maeotian and Pontian in the Euxinic Basin is marked by the appearance of typical brackish-water cardids (Andrusov, 1903) and ostracods, as well as of *Caspidinium rugosum* (“*Impagidinium globosum/spongium*” group) and *Galeacysta etrusca* among dinocysts. It is located slightly below the C3An/C3r paleomagnetic inversion (6.0 Ma) and is dated to about 6.1 Ma (Filippova and Trubikhin, 2009; Popov et al., 2016). In the Dacian Basin, it is placed at the base of Beds with marine fauna of ostracods and foraminifers (Krijgsman et al., 2010; Stoica et al., 2013), which infers to its lower position, but does not significantly influence the estimate of the age of the boundary.

The paleogeographical changes associated with the Messinian salinity crisis occurred at the level of reverse polarity magnetochron C3r. The use of cyclostratigraphic methods made it possible to correlate them with the main stages of the Messinian salinity crisis in the Mediterranean. Sediments of the Novorossian Substage correspond to the first stage of the crisis with the disturbance of normal circulation in the Mediterranean. The regression and sedimentation break, which led to a complete disintegration of the Eastern Paratethys Basin and further accumulation of *Congerina subrhomboidea* Beds, are correlated with the peak of the crisis, fall of water level, development of the Messinian erosional surface in the Mediterranean, and accumulation of evaporites. The Bosphorian transgression corresponds to the third stage characterized by accumulation of desalinated Lago Mare facies with brackish-water fauna of Pontian origin. The depositional hiatus is estimated at 160 ka based on the data of astronomically driven cyclicity (Rostovtseva and Rybkina, 2014, 2017). According to these data, the top of the Pontian has an age of 5.2 Ma and the Pontian Regional Stage is therefore correlated with the Upper Messinian—base of the Zanclean in the ISC.

Paleomagnetic data show a sharp discrepancy between the volume and boundaries of the Pontian that are accepted in the Euxinic and Dacian basins. In the stratotypical Kerch–Taman region, the entire Pontian Regional Stage except the base itself is characterized by reverse magnetization (Pevzner and Chikovani, 1978; Trubichin, 1989; Krijgsman et al., 2010; Vasilev et al., 2011), which is correlated with chron C3r, while the “Upper Pontian” (“Bosphorian”) of the Dacian basin includes two episodes of normal polarity, C3n.4n (Thvera) and C3n.3n (Sidufjall), which are included in the Kimmerian in the Kerch–Taman sections. In this sense, the top of the Pontian of the Dacian Basin is dated to 4.7–4.9 Ma (Vasilev et al., 2004; Krijgsman et al., 2010), rather than 5.2, as in the Euxinic Basin.

Kimmerian regional stage. In the Euxinic Basin the boundary between the Pontian and Azov Kimmerian Beds in the stratotype Kerch–Taman region lies at the end of the reversely magnetized C3r interval (see

Fig. 21). Almost at the base of Azov beds, there is a normal polarity subchron correlated with subchron C3n.4n (Thvera). These data give grounds to estimate the age of the Kimmerian base as close to 5.2–5.3 Ma, since the base of subchron C3n.4n in GPTS 2020 is dated to 5.235 Ma (Gradstein et al., 2020).

The Kimmerian is characterized mainly by a reverse magnetic polarity interrupted by four intervals of normal polarity (Khramov, 1958; Semenenko and Pevzner, 1979; Zubakov and Kochegura, 1984, etc.). On the whole, it is correlated with the uppermost strata of chron C3r and lower strata of chron C2Ar and includes the entire C3n chron. The Lower Kimmerian (Azov beds) includes normal polarity subchron C3n.4n (Thvera). The normal polarity interval at the base of the Kamysh–Burun Beds of the Middle Kimmerian is correlated with subchron C3n.3n (Sidufjall) and makes it possible to roughly date the boundary between the lower and middle Kimmerian substages at 4.9 Ma BP. The next interval of normal polarity, correlated with subchron C3n.2n (Nunivak), is also confined to the Middle Kimmerian, while the uppermost normally magnetized interval is correlated with subchron C3n.1n (Cochiti) and ends with reverse polarity chron C2Ar. According to these data, the Kimmerian is correlated with the Zanclean without the base itself in the Mediterranean scale.

In the Caspian part of the basin, an extensive Balakhanian regression corresponds to the Kimmerian; it was accompanied by deep incisions and the accumulation of coarse terrigenous continental and deltaic strata in the alluvial fans of the Productive Series.

Akchagylian regional stage. The base of the Akchagylian Stage in the Caspian Basin is characterized by a normal polarity interval, which continues from the continental Torongly Formation (Trubikhin, 1977) and Productive Series of the Kura Basin (Van Baak et al., 2019), followed by a reverse magnetized interval (see Fig. 21). This pattern was observed in many sections of the Caspian region (which are most complete in Dagestan, Azerbaijan, and Turkmenistan); however, its correlation with GPTS differs. Two different ages were proposed for the base of the Akchagylian Stage: the viewpoint officially accepted in Russia dates the base of the Akchagylian Stage to the base of the Gauss Zone (Gauss, C2An) with an age of 3.6 Ma, while the top is marked in the upper strata of the normally magnetized Olduvai subchron (C2n) (Trubikhin, 1977; Semenenko and Pevzner, 1979; Moloskovskii and Khramov, 1997; Nevesskaya et al., 2005).

According to the other age model, the lower boundary of the Akchagylian Stage is placed in the lower strata of the uppermost normally magnetized part of the Gauss zone (Upper Gauss, C2An.1n) and has an age of about 2.95 Ma, and the upper boundary is marked within the normally magnetized Reunion subchron (C2r.1n) with an age of 2.13 Ma (Lazarev et al., 2019, 2021). This is based on new magneto-

stratigraphic data, $^{40}\text{Ar}/^{39}\text{Ar}$ dating of sections of the Kura basin, and revision of data on magnetostratigraphy of Turkmenistan sections.

Based on this knowledge, the Akchagylian is in any case correlated with the Piacenzian and Gelasian; however, the “long Akchagylian” is almost completely correlated with these MSC stages, while the “short Akchagylian” is correlated with the upper part of the Piacenzian and lower half of the Gelasian (see Fig. 12).

It is assumed that the stratigraphic range of the Kuyalnikian beds of the Euxinic basin corresponds to the Akchagylian, based on finds of Akchagylian fauna in these beds (in the base and upper strata of the sections of the Kerch–Taman region), as well as on a similar paleomagnetic characteristics (Fig. 9) (Semenenko, 1975; Semenenko and Pevzner, 1979; Nosovskii and Semenenko in *Neogenovaya sistema*, 1986).

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

- Abdul Aziz, H., Di Stefano, A., Foresi, L.M., Hilgen, F.J., Iaccarino, S.M., Kuiper, K.F., Lirer, F., Salvatorini, G., and Turco, E., Integrated stratigraphy and $^{40}\text{Ar}/^{39}\text{Ar}$ chronology of early Middle Miocene sediments from DSDP Leg 42A, Site 372 (Western Mediterranean), *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2008, vol. 257, nos. 1–2, pp. 123–138.
- Abdul Aziz, H., Hilgen, F.J., Krijgsman, W., and Calvo, J.P., An astronomical polarity time scale for the late middle Miocene based on cyclic continental sequences, *J. Geophys. Res.*, 2003, vol. 108, no. B3, p. 2159.
- Abels, H.A., Hilgen, F.J., Krijgsman, W., Kruk, R.W., Raffi, I., Turco, E., and Zachariasse, W.J., Long-period orbital control on middle Miocene global cooling: Integrated stratigraphy and astronomical tuning of the Blue Clay Formation on Malta, *Paleoceanography*, 2005, vol. 20, no. 4.
- Aeoriae, S., Harzhauser, M., Hohenegger, J., Mandic, O., Pervesler, P., Roetzel, R., Rögl, F., Scholger, R., Spezzaferrri, S., Stingl, K., Vábenická, L., Zorn, I., and Zuschin, M., Stratigraphy and correlation of the Grund formation in the Molasse basin, northeastern Austria (middle Miocene, lower Badenian), *Geol. Carpathica, Bratislava*, vol. 55, no. 2, 2004, pp. 207–215.
- Agalarova, D.A., *Mikrofauna ponticheskikh otlozhenii Azerbaidzhana i sopredel'nykh raionov* (Microfauna of Pontian Deposits of Azerbaijan and Adjacent Regions), Leningrad: Nedra, 1967.
- Agnini, C., Fornaciari, E., Raffi, I., Catanzariti, R., Pălike, H., Backman, J., and Rio, D., Biozonation and biochronology of Paleogene calcareous nannofossils from low and middle latitudes, *Newsl. Stratigr.*, 2014, vol. 47, pp. 131–181.
- Agnini, C., Monechi, S., and Raffi, I., Calcareous nannofossil biostratigraphy: Historical background and application in Cenozoic chronostratigraphy, *Lethaia*, 2017, vol. 50, pp. 447–463.
- Akhmetiev, M.A., Phytostratigraphy of Paleogene and Miocene continental deposits of extratropical Asia, in *Tr. Geol. Inst. Ross. Akad. Nauk* (Trans. Geol. Inst. Russ. Acad. Sci.), 1993, vol. 475, pp. 1–43.
- Akhmetiev, M.A. and Zaporozhets, N.I., Succession of dinocysts in sections of the Paleogene and Lower Miocene of the Russian Platform in the Crimean–Caucasian region and Turanian platform as a reflection of ecosystem transformations, in *Tr. Geol. Inst. Ross. Akad. Nauk* (Trans. Geol. Inst. Russ. Acad. Sci.), 1996, vol. 501, pp. 55–69.
- Akhmetiev, M.A., Lopatin, A.V., Sytchevskaya, E.K., and Popov, S.V., Northern Peri-Tethys biogeography during Late Eocene–Early Miocene. Pt. 4. Late Oligocene–Early Miocene. Terrestrial surroundings. Conclusions, *J. Paleontol.*, 2005, vol. 39, Suppl. 1, pp. S1–S54.
- Akhmetiev, M.A., Popov, S.V., Krhovsky, J., et al., *Paleontology and Stratigraphy of the Eocene–Miocene Sections of the Western Pre-Caucasia, Excursion Guidebook (Field Symp., August 1–9, 1995)*, Moscow: Paleontol. Inst. Ross. Acad. Nauk, 1995.
- Aleksandrova, G.N., Golovina, L.A., and Popov, S.V., Biostratigraphy of the Early Miocene of Eastern Ciscaucasia based on dinocysts and calcareous nannofossils: Results of the study of the reference section along the Kuban River, *Stratigr. Geol. Correl.*, 2022 (in press).
- Alizade, A.A., *Akchagyl Turkmenistana* (Turkmenistan Akchagylia), Moscow: Gosgeoltekhizdat, 1961, vol. 1.
- Amitrov, O.V., History of gastropods of Paleogene seas in Western Eurasia, in *Tr. Paleontol. Inst. Ross. Akad. Nauk* (Trans. Paleontol. Inst. Russ. Acad. Sci.), 1993, vol. 254, pp. 1–208.
- Ananova, E.N., *Pyl'tsa v neogenovyykh otlozheniyakh yuga Russkoi ravniny* (Pollen of Neogene deposits in the South of the Russian Plain), Leningrad: Izd. Leningr. Univ., 1974.
- Ananiashvili, G.D., The territory of Georgia and adjacent regions in the Tarkhanian, in *Tr. Geol. Inst. Gruz. SSR, Nov. Ser.* (Trans. Geol. Inst. Georgian SSR Acad. Sci., New Ser.), 1985, vol. 90, pp. 1–217.
- Ananiashvili, G.D. and Minashvili, Ts.D., Biostratigraphy of the upper part of the Maikopian series of Georgia, in *Tr. Geol. Inst. Gruz. SSR, Nov. Ser.* (Trans. Geol. Inst. Georgian SSR Acad. Sci., New Ser.), 2000, vol. 15, pp. 116–125.
- Andreansky, G., *Die Flora der Sarmatischen Stufe in Ungarn*, Budapest, 1959.
- Andreescu, I., Limitele si subdiviziunile Pontianului, *Acad. Repub. Soc. Rom., Stud. Cercet. Geol., Geofiz., Geogr., Ser. Geol.*, 1975, vol. 20, no. 2, pp. 235–245.
- Andreeva-Grigorovich, A.S., Zonal division of the Neogene deposits of the Central and Eastern Paratethys based on calcareous nannofossils, in *Mater. 11 Kongr. Karpato-Balk. Assots.* (Proc. 11th Congr. Carpathian–Balkan Assoc.), Kiev: Naukova Dumka, 1977, pp. 6–7.
- Andreeva-Grigorovich, A.S., Distribution of dinoflagellate cysts in the Maikopian Series of the Northern Stavropol region, *Paleontol. Zh.*, 1980, no. 17, pp. 74–79.
- Andreeva-Grigorovich, A.S., The lower boundary of the Middle Miocene of the Paratethys: Current position based on planktonic microorganisms and correlation, *Geol. Zh.*, 2005, no. 2, pp. 23–34.
- Andreeva-Grigorovich, A.S. and Nosovskii, M.F., On stratigraphic analogs of the Konkian Stage in the Central Paratethys, in *Stratigrafiya kainozoya Severnogo Prichernomor'ya i Kryma* (Stratigraphy of the Cenozoic of the Northern Black Sea and Crimea), Dnepropetrovsk: Izd. Dnepropetr. Gos. Univ., 1976a, pp. 72–77.
- Andreeva-Grigorovich, A.S. and Stupnitskii, V.M., Calcareous nannofossils of Lower Miocene deposits in southeastern Ciscaucasia, *Geol. Zh.*, 1976b, vol. 36, no. 1, pp. 139–142.
- Andreeva-Grigorovich, A.S. and Gruzman, A.D., On the assemblages of foraminifers and calcareous nannofossils in the stratotype of the Menilithic Formation along the Chechve River (Ukrainian SSR), *Paleontol. Sb.*, 1978, no. 15, pp. 83–89.
- Andreeva-Grigorovich, A.S. and Turchinova, S.M., Calcareous nannofossils subdivision of Upper Miocene deposits in the northwestern part of the Cis-Carpathian trough (Podluby area), *Paleontol. Sb.*, 1983, no. 20, pp. 66–70.
- Andreeva-Grigorovich, A.S. and Gruzman, A.D., Biostratigraphic evidence of the Paleogene and Neogene boundary in the Central and Eastern Paratethys, *Paleontol. Zh.*, 1989, no. 6, pp. 91–95.
- Andreeva-Grigorovich, A.S., Zaporozhets, N.I., Shevchenko, T.V., Aleksandrova, G.N., Vasil'eva, O.N., Yakovleva, A.I., Stotland, A.B., and Savitskaya, N.A., *Atlas dinotist paleogena Ukrainy, Rossii i sopredel'nykh stran* (At-

- las of Dinocysts of the Paleogene of Ukraine, Russia, and neighboring countries), Kiev: Naukova Dumka, 2011.
- Andreeva-Grigorovich, A.S., Kovač, M.M., Halássová, E.Yu., Hudačkova, N.Yu., and Zlinska, A.Yu., Nannoplankton and foraminifers of Miocene (Badenian–Pannonian) deposits of IntraCarpathian Neogene basins of Slovakia and Ukraine (biostratigraphy and paleoecology), *Geol. Zh.*, 2007, no. 1, pp. 77–91.
- Andreyeva-Grigorovich, A.S. and Halássová, E., Calcareous nannofossils biostratigraphy of the Early Miocene sediments of the Vienna basin NE part (Slovakia), *Slovak Geol. Mag.*, 2000a, vol. 6, nos. 2, 3, pp. 101–105.
- Andreyeva-Grigorovich, A.S. and Savitskaya, N.A., Nannoplankton of the Tarkhanian deposits of the Kerch Peninsula (Crimea), *Geol. Carpathica*, 2000b, vol. 51, no. 6, pp. 399–406.
- Andreyeva-Grigorovich A., Oszczyk N., Savitskaya N., Ślaczka, A., and Trofimovic, N., Correlation of Late Badenian salts of the Weliczka, Bochnia and Kalush areas (Polish and Ukrainian Carpathian Foredeep), *Ann. Soc. Geol. Pol.*, 2003, vol. 73, pp. 67–89.
- Andreyeva-Grigorovich, A., Oszczyk, N., Ślaczka, A., Oszczyk-Clowes, M., Savitskaya, N., and Trofimovic, N., New data on the stratigraphy of the folded Miocene zone at the front of the Ukrainian outer Carpathians, *Acta Geol. Pol.*, 2008, vol. 58, no. 3, pp. 325–353.
- Andrusov, N.I., Geological studies on the Kerch Peninsula in 1882 and 1883, *Zap. Novoross. O-va Estestvoispyt.*, 1884, vol. 9, no. 2, pp. 1–198.
- Andrusov, N.I., Kerch limestone and its fauna, *Zap. Sankt-Peterburg. Mineral. O-va*, 1890, Pt. 26, pp. 193–344.
- Andrusov, N.I., On geological studies in the Baku province and on the eastern coast of the Caspian Sea in the summer of 1895, *Tr. Sankt-Peterburg. O-va Estestvoispyt. Otd. Geol. Mineral.*, 1896, vol. 24, pp. 141–160.
- Andrusov, N.I., Materials for studying the cis-Caspian Neogene. Akchagylia beds, *Tr. Geol. Kom.*, 1902, vol. 15, no. 4, pp. 1–153.
- Andrusov, N.I., Geological studies on the Taman Peninsula, *Mater. Geol. Ross.*, 1903, vol. 21, no. 2, pp. 257–383.
- Andrusov, N.I., On the genus *Arcicardium* Fischer, *Ezheg. Geol. Mineral. Ross.*, 1907–1908, vol. 9, nos. 4–5, pp. 105–114.
- Andrusov, N.I., Konkian Stage (Pholadidae beds), in *Trudy Geol. Mineral. Muz. Akad. Nauk, T. 2, Vyp. 6* (Proc. Geol. Mineral. Mus. Acad. Sci., vol. 2, no. 6), 1917a, pp. 167–261.
- Andrusov, N.I., Pontian Stage, *Izv. Geol. Kom.*, 1917b, vol. 4, Part 2, no. 2, pp. 1–41.
- Andrusov, N.I., Relationships between Euxinic and Caspian basins in the Neogene period, *Izv. Ross. Akad. Nauk, Ser. 6*, 1918, vol. 12, no. 8, pp. 749–760.
- Andrusov, N.I., Apsheonian Stage, *Trudy Geol. Kom., Nov. Ser.*, 1923, vol. 110, pp. 1–294.
- Andrusov, N.I., On the age and stratigraphic position of Akchagylia beds, *Zap. Mineral. Obshch.* 1912, vol. 48, no. 1, pp. 271–291, in *Izbr. Trudy, T. 2* (Selected Papers, vol. 2), 1963, pp. 141–150.
- Andrussow, N., Die Schichten von Kamyschburun und der Kalkstein von Kertsch in der Krim, *Jahrb. Geol. Reichsanst.*, 1886, vol. 36, no. 1, pp. 127–140.
- Andrussow, N., Die Südrussischen Neogenablagerungen. Th. 2. Sarmatische Stufe, *Zap. Leningr. Mineral. Obshch.*, 1899, vol. 36, no. 1, pp. 101–170 (*Izbr. Trudy*), 1961, vol. 1, pp. 173–206.
- Arevadze, F.M., About ostracods from Maetian deposits developed along the Atap River (Western Georgia), *Soobshch. Akad. Nauk Gruz. SSR*, 1987, vol. 126, no. 1, pp. 193–196.
- Asadullaev, E.M. and Pevzner, M.A., Paleomagnetism and stratigraphy of Late Cenozoic deposits of the near-Kura lowland, in *Paleomagnitnyi analiz pri izuchenii chetvertichnykh otlozhenii i vulkanitov* (Paleomagnetic Analysis in the Study of Quaternary Deposits and Volcanic Rocks), Moscow: Nauka, 1973, pp. 6–11.
- Astakhova, T.V., Gorak, S.V., Kraeva, E.Ya., et al., *Geologiya shel'fa USSR* (Geology of the shelf of the Ukrainian SSR), Kiev: Naukova Dumka, 1984.
- Auer, G., Piller, W.E., and Harzhauser, M., High-resolution calcareous nannoplankton palaeoecology as a proxy for small-scale environmental changes in the Early Miocene, *Mar. Micropaleontol.*, 2014, vol. 111, pp. 53–65.
- Avakov, G.S., Flora of the Karaganian and Konkian stages of Georgia, *Extended Abstract of Cand. Sci (Geol.–Mineral.) Dissertation*, Tbilisi: Izd. Tbil. Gos. Univ., 1970.
- Bache, F., Popescu, S.-P., Rabineau, M., Gorini, C., Suc, J.-P., Clauzon, G., Olivet, J.-L., Rubino, J.-L., Melinte-Dobrinescu, M.C., Estrada, F., Londeix, L., Armijo, R., Meyer, B., Jolivet, L., Jouannic, G., Leroux, E., Aslanian, D., Dos Reis, A.T., Mocochain, L., Dumurdžanov, N., Zagorchev, I., Lesić, V., Tomić, D., Çagatay, M.N., Brun, J.-P., Sokoutis, D., Csato, I., Ucakus, G., and Çakır, Z., A two step process for the reflooding of the Mediterranean after the Messinian Salinity Crisis, *Basin Res.*, 2012, vol. 24, pp. 125–153.
- Bache, F., Gargani, J., Suc, J.-P., Gorini, C., Rabineau, M., Popescu, S.-P., Leroux, E., Do Couto, D., Jouannic, G., Rubino, J.-L., Olivet, J.-L., Clauzon, G., Dos Reis, A.T., and Aslanian, D., Messinian evaporite deposition during sea level rise in the Gulf of Lions (Western Mediterranean), *Mar. Pet. Geol.*, 2015, vol. 66, pp. 262–277.
- Baciu, D.-S., Bannikov, A.F., and Tyler, J.C., Revision of the fossil fishes of the family Caproidae (Acanthomorpha), *Studi Ric. Giacim. Terz. Bolca. Verona.*, 2005, vol. 11, pp. 7–74.
- Backman J., Raffi I. Calibration of Miocene nannofossil events to orbitally tuned cyclostratigraphies from Ceara Rise, in *Proc. Ocean Drill. Program: Sci. Results*, Shackleton N.J., Curry W.B., Richter C., and Bralower T.J., Eds., 1997, vol. 154, pp. 83–99.
- Backman, J., Raffi, I., Rio, D., Fornaciari, E., and Pälike, H., Biozonation and biochronology of Miocene through Pleistocene calcareous nannofossils from low and middle latitudes, *Newsl. Stratigr.*, 2012, vol. 45, pp. 221–244.
- Bagdasaryan, K.G., *Razvitie mollyuskovoi fauny chokraka Gruzii* (Development of the Mollusk Fauna of the Chokranian of Georgia), Tbilisi: Metsniereba, 1965.
- Bagdasaryan, K.G., *Fauna mollyuskov tarkhanskogo gorizonta i usloviya ee sushchestvovaniya* (Fauna of Mollusks of the Tarkhanian Stage and Conditions of Its Existence), Tbilisi: Metsniereba, 1970.
- Bagdasaryan, K.G., *Kardiidy miotsena Yuga SSSR* (Cardiids of the Miocene in the South of the USSR), Tbilisi: Metsniereba, 1978.

- Baikovskaya, T.N., On the Neogene flora of the Transcarpathian region of the Ukrainian SSR, *Tr. L'vov. Geol. Obshch., Ser. Paleontol.*, 1953, vol. 2, pp. 211–215.
- Bakrač, K., Koch, G., and Sremac, J., Middle and Late Miocene palynological biozonation of the south-western part of Central Paratethys (Croatia), *Geol. Croat.*, 2012, vol. 65, no. 2, pp. 207–222.
- Bannikov, A.F., Genus *Scomberoides* (Teleostei) in the Miocene of the Caucasus, *Paleontol. Zh.*, 1984, no. 1, pp. 108–110.
- Bannikov, A.F., Fossil mackerels of the USSR, in *Tr. Paleontol. Inst. Akad. Nauk SSSR* (Trans. Paleontol. Inst. USSR Acad. Sci.), 1985, vol. 210, pp. 1–111.
- Bannikov, A.F., Fossil carangids and black pomfret of the USSR, in *Tr. Paleontol. Inst. Akad. Nauk SSSR* (Trans. Paleontol. Inst. USSR Acad. Sci.), 1990, vol. 244, pp. 1–108.
- Bannikov, A.F., On early Sarmatian fishes from the Eastern Paratethys, *J. Paleontol.*, 2009, no. 5, pp. 87–89.
- Bannikov, A.F., *Iskopaemye pozvonochnye Rossii i sprovedel'nykh stran. Iskopaemye kolyucheperye ryby (Teleostei, Acanthopterygii)* (Fossil Vertebrates from Russia and Adjacent Countries. Fossil Spiny-finned Fishes (Teleostei, Acanthopterygii)), Moscow: GEOS, 2010.
- Bannikov, A.F., A new Late Neogene genus of croakers (Perciformes, Sciaenidae) from the Eastern Black Sea Region, *J. Paleontol.*, 2013, vol. 47, no. 2, pp. 190–198.
- Bannikov, A.F., Early Sarmatian (Volhynian) bony fishes of the Eastern Paratethys, in *Morfologicheskaya evolyutsiya i stratigraficheskie problemy. Mater. 65 Sess. Paleontol. Ob-va Ross. Akad. Nauk* (Morphological Evolution and Stratigraphic Problems. Proc. 65th Sess. Paleontol. Soc. Russ. Acad. Sci.), St. Petersburg: Vseross. Nauchno-Issled. Geol. Inst., 2019, pp. 207–209.
- Bannikov, A.F., New locality of Tarkhanian (Lower–Middle Miocene) bony fishes in the northwestern Caucasus, in *Biogeografiya i evolyutsionnye protsessy. Mater. LXVI Sess. Paleontol. Obshch. Ross. Akad. Nauk* (Biogeography and Evolutionary Processes. Proc. 66th Sess. Paleontol. Soc. Russ. Acad. Sci.), St. Petersburg: Vseross. Nauchno-Issled. Geol. Inst., 2020, pp. 214–216.
- Bannikov, A.F. and Parin, N.N., The list of marine fishes from Cenozoic (Upper Paleocene–Middle Miocene) localities in southern European Russia and adjacent countries, *J. Ichthyol.*, 1997, vol. 37, no. 2, pp. 133–146.
- Barbot de Marny, N., Über die jüngeren Ablagerungen des Südlichen Rusland, *Sitzungsber. Akad. Wiss. Wien, Abt. A1*, 1866, vol. 53, no. 4, pp. 339–342.
- Barbot de Marny, N.P., *Geologicheskii ocherk Khersonskoi gubernii* (Geological Outline of the Kherson Province), St. Petersburg, 1869.
- Barg, I.M., *Biostratigrafiya verkhnego kainozoya Yuzhnoi Ukrainy* (Biostratigraphy of the Upper Cenozoic of Southern Ukraine), Dnepropetrovsk: Izd. Dnepropetr. Gos. Univ., 1993.
- Barg, I.M., On the significance of the Tarkhanian Regional Stage (Neogene) in establishing the boundary of the Lower and Middle Miocene in the Paratethys, in *Geobiosfernye sobytiya i istoriya organicheskogo mira. Tez. Dokl. LIV Sess. Paleontol. O-va* (Geobiospheric Events and History of the Organic World. Abstr. 54 Sess. Paleontol. Soc.), St. Petersburg, 2008, pp. 15–16.
- Barg, I.M., Grigorovich, A.S., and Nosovskii, M.F., On the stratigraphic position of Crimean spiralis clays, *Tekton. Stratigr.*, 1975, no. 7, pp. 62–65.
- Barg, I.M. and Ivanova, T.A., Stratigraphy and geological development of Plain Crimea in the Miocene, *Stratigr. Geol. Korrel.*, 2000, vol. 8, no. 3, pp. 83–93.
- Barg, I.M., Ivanova, T.A., Bondar', O.V., et al., Stratotype of Veselyanka beds of the Konkian Regional Stage (Middle Miocene, Southern Ukraine), *Paleontol. Sb.*, 2005, no. 37, pp. 105–111.
- Barg, I.M., Ivanova, T.A., Bondar', O.V., Starin, D.A., and Saponova, D.A., On the biostratigraphy of Neogene deposits of the Borisfensky Gulf of the Eastern Paratethys, *Geol. Zh.*, 2012, no. 3, pp. 127–137.
- Bartol, M., *Middle Miocene Calcareous Nannoplankton of NE Slovenia (Western Central Paratethys)*, Založba ZRC. Ljubljana, 2009.
- Beldean, C., Filipescu, S., and Bălc, R., Paleoenvironmental and biostratigraphic data for the Early Miocene of the northwestern Transylvanian Basin based on planktonic foraminifera, *Carpathian J. Earth Environ. Sci.*, 2012, vol. 7, no. 1, pp. 171–184.
- Beldean, C., Bercea, R., and Filipescu, S., Sedimentology and biostratigraphy of the Early–Middle Miocene transition in NW Transylvanian Basin (Pâglișa and Dej sections), *Stud. Univ. Babeș-Bolyai: Geol.*, 2013, vol. 58, no. 1, pp. 57–70.
- Belokrys, L.S., On the main criterion for the regional stratigraphic division of Miocene deposits from the Black Sea–Caspian basin, in *Stratigrafiya kainozoya Severnogo Prichernomor'ya i Kryma: Sb. Nauchn. Trudov* (Coll. Sci. Works “Stratigraphy of the Cenozoic of the Northern Black Sea and Crimea”), Dnepropetrovsk: Dnepropetr. Gos. Univ., 1987, pp. 7–20.
- Beluzhenko, E.V., Stratigraphy of the Middle–Upper Miocene and Pliocene deposits of the Psekups–Belaya interfluvium (Northwestern Caucasus). Article 1. Middle Miocene, *Byull. Mosk. O-va Ispyt. Priro., Otd. Geol.*, 2002, vol. 77, no. 1, pp. 47–59.
- Beluzhenko, E.V., Filippova, N.Yu., and Golovina, L.A., Alkuniyan Formation and Paleogene–Neogene Boundary in the Northern Caucasus and Ciscaucasia, in *Tr. Nauchno-Issled. Inst. Geol. Mineral. Syr'ya Voronezh. Gos. Univ.*, 2018, vol. 102, pp. 1–102.
- Berger, W., Flora und Klima im Jungtertiär des Wiener Beckens, *Z. Dtsch. Geol. Ges.*, 1954, vol. 195, pp. 228–333.
- Berggren, W.A., Kent D.V., Swisher III, C.C., and Aubry, M.-P., A revised Cenozoic geochronology and chronostratigraphy, *Spec. Publ.–SEPM (Soc. Sediment. Geol.)*, 1995, vol. 54, pp. 129–212.
- Bidzinashvili, L.Sh., On the upper stages of the Middle Miocene of Georgia, in *Mater. Geol. Neftegazonosn. Gruz.* (Materials on Geology and Oil-and-Gas Content in Georgia), Tbilisi: Metsniereba, 1974, pp. 70–96.
- Blanc-Valleron, M.M., Pierre, C., Caulet, J.P., Caruso, A., Rouchy, J.M., Cespuglio, G., et al., Sedimentary, stable isotope and micropaleontological records of paleoceanographic change in the Messinian Tripoli Formation (Sicily, Italy), *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2002, vol. 185, pp. 255–286.
- Bobrinskaya, O.G., Gruzman, A.D., Krashennnikov, V.A., Serova, M.Y., and Venglinskyi, I.V., Stratigraphy of the Oli-

- gocene and Miocene deposits of the western Ukraine and Moldavia, in *Oligocene–Miocene Foraminifera of the Central Paratethys*, Cicha, I., Rogl, F., Rupp, Ch., and Ctyroka, J., Eds., *Abh. Senckenb. Naturforsch. Ges.*, 1998, vol. 549, pp. 34–43.
- Bogachev, V.V., New species of mollusks from Miocene deposits of Novochoerkassk, *Izv. Geol. Kom.*, 1905, vol. 24, no. 3, pp. 159–188.
- Bogachev, V.V., Materials on the ichthyofauna of the Maeotian Sea, *Dokl. Akad. Nauk SSSR*, 1942, vol. 37, no. 2, pp. 89–92.
- Bogachev, V.V., Amvrosian Lower Sarmatian fishes, *Dokl. Akad. Nauk SSSR*, 1955, vol. 105, no. 3, pp. 570–572.
- Bogdanowicz, A.K., Chokrakian foraminifers of Western Ciscaucasia, in *Tr. Vseross. Neft. Nauchno-Issled. Geol. Inst., Nov. Ser.* (Trans. All-Russ. Petrol. Res. Explor. Inst. New Ser.), 1950, vol. 51, pp. 129–205.
- Bogdanowicz, A.K., Tarkhanian deposits of the Kuban in the light of the study of microfauna, in *Mikrofauna, Sb. 4* (Microfauna, Vol. 4), 1951, pp. 113–128.
- Bogdanowicz, A.K., Miliolids and peneroplids, in *Tr. Vseross. Neft. Nauchno-Issled. Geol. Inst., Nov. Ser.* (Trans. All-Russ. Petrol. Res. Explor. Inst. New Ser.), 1952, vol. 64,ossil foraminifers of the USSR), pp. 1–338.
- Bogdanowicz, A.K., On the Saccaminae Zone from the Upper Maikopian deposits of the Northern Caucasus and its main types, *Dokl. Akad. Nauk SSSR*, 1954, vol. 98, no. 1, pp. 119–122.
- Bogdanowicz, A.K., New data on the stratigraphic and spatial distribution of the Maikopian microfauna in the Northern Caucasus, in *Paleogenovye otlozheniya yuga Evropeiskoi chasti SSSR* (Paleogene Deposits in the South of the European Part of the USSR), Moscow: Izd. Akad. Nauk SSSR, 1960a, pp. 245–276.
- Bogdanowicz, A.K., On new and little-known foraminifers from the Miocene of Western Ciscaucasia, in *Tr. Kazan. Fil. Vseross. Nauchno-Issled. Inst. Geol.*, Moscow, 1960b, vol. 3, pp. 241–263.
- Bogdanowicz, A.K., On the zonal subdivision of the Maikopian Group of the Kuban Lowland in the Stavropol Region and Zatrechnaya Plain based on the Foraminiferal Fauna, in *Geologiya tretichnykh i mezozoiskikh otlozhenii Severnogo Kavkaza. Tr. Grozn. Nauchno-Issled. Inst.* (Geology of Tertiary and Mesozoic Deposits of the Northern Caucasus. Trans. Grozny Geol. Res. Inst.), 1961, vol. 8, pp. 90–99.
- Bogdanowicz, A.K., Stratigraphic and facial distribution of foraminifers in the Miocene of Western Ciscaucasia and issues of their genesis, *Tr. Kazan. Fil. Vseross. Nauchno-Issled. Inst.*, 1965, no. 16, pp. 300–350.
- Bogdanowicz, A.K., Maeotian Miliolida from Western Ciscaucasia, *Tr. Kazan. Fil. Vseross. Nauchno-Issled. Inst.*, 1969, vol. 19, pp. 64–113.
- Bogdanowicz, A., Entwicklungsetappen der Foraminiferen des Miozans von Nord-kaukasus und Fragen deren Genese, *Mem. BRGM*, 1971, vol. 2, no. 78, pp. 739–744.
- Bogdanowicz, A.K., On some morphological anomalies of miliolid shells, in *Novoe v sistematike mikrofauny. Tr. Vseross. Neft. Nauchno-Issled. Geol. Inst., Nov. Ser.* (New in the Systematics of Microfauna. Trans. All-Russ. Petrol. Res. Explor. Inst. New Ser.), 1971, vol. 291, pp. 7–17.
- Bogdanowicz, A.K., Foraminifers of the Eastern Paratethys, in *Neogenovaya sistema. T. 2* (Neogene System. Vol. 2), Moscow: Nedra, 1986, pp. 244–250.
- Bogdanowicz, A.K. and Buryak, V.N., The foredeep of Western Ciscaucasia, in *Neogenovaya sistema. T. 1* (Neogene System. Vol. 1), Moscow: Nedra, 1986, pp. 151–172.
- Bogdanowicz, A.K. and Goncharova, I.A., Living conditions and changes in the composition of foraminifers and bivalves in the Late Tarkhanian on the Kerch Peninsula, *Byull. Mosk. Obshch. Ispyt. Prir., Otd. Geol.*, 1976, vol. 51, no. 2, pp. 155–156.
- Bogdanowicz, E.M. and Ivanova, T.A., On a new find of planktonic microorganisms in Maeotian deposits of Crimea, *Dokl. Nats. Akad. Nauk Ukr.*, 1997, no. 6, pp. 127–129.
- Borgh ter, M., Vasiliev, I., Stoica, M., Knežević, S., Matenco, L., Krijgsman, W., Rundić, L., and Cloetingh, S., The isolation of the Pannonian basin (Central Paratethys): New constraints from magnetostratigraphy and biostratigraphy, *Global Planet. Change*, 2013, vol. 103, pp. 99–118.
- Bramlette, M.N. and Riedel, W.R., Stratigraphic value of discoasters and some other microfossils related to recent Coccolithophore, *J. Paleontol.*, 1954, vol. 28, pp. 385–403.
- Bratishko, A., Schwarzhans, W., Reichenbacher, B., Vernyhorova, Y., and Čorić, S., Fish otoliths from the Konkian (Miocene, early Serravallian) of Mangyshlak (Kazakhstan): testimony to an early endemic evolution in the Eastern Paratethys, *Paläontol. Z.*, 2015, vol. 89, no. 4, pp. 839–889.
- Bugrova, E.M., Central part of the Northern Caucasus. Biostratigraphy of Cenozoic deposits of Russia and adjacent areas based on foraminifers, in *Prakticheskoe rukovodstvo po mikrofaune SSSR. Foraminifery kainozoya* (Practical Guide to the Microfauna of the USSR. Cenozoic Foraminifers), St. Petersburg: Nedra, 2006a, pp. 78–86.
- Bugrova, E.M., Eastern Ciscaucasia. Biostratigraphy of Cenozoic deposits of Russia and adjacent areas based on foraminifers, in *Prakticheskoe rukovodstvo po mikrofaune SSSR. Foraminifery kainozoya* (Practical Guide to the Microfauna of the USSR. Cenozoic Foraminifers), St. Petersburg: Nedra, 2006b, pp. 97–100.
- Bukry, D., Biostratigraphy of Cenozoic marine sediments by calcareous nannofossils, *Micropaleontology*, 1978, vol. 24, pp. 44–60.
- Buleishvili, D.A., *Geologiya i neftegazonosnost' mezhgornoi vpadiny Vostochnoi Gruzii* (Geology and Oil-and-Gas Content of the Intermountain Basin in Eastern Georgia), Leningrad: Gostoptekhizdat, 1960.
- Carnevale, G., Bannikov, A.F., Landini, W., and Sorbini, C., Volhynian (early Sarmatian sensu lato) fishes from Tsurevsky, Northern Caucasus, Russia, *J. Paleontol.*, 2006, vol. 80, no. 4, pp. 684–699.
- Chang, L., Vasiliev, I., Van Baak, C.G.C., Krijgsman, W., Dekkers, M.J., and Roberts, A.P., Identification and environmental interpretation of diagenetic and biogenic greigite in sediments: A lesson from the Messinian Black Sea, *Geochem., Geophys., Geosys.*, 2014, vol. 15, pp. 3612–3627.
- Chelidze, L.T., Fossil flora of the Vale locality, *Soobshch. Akad. Nauk Gruz. SSR*, 1965, vol. 337, no. 2, pp. 17–32.
- Chepalyga, A.L., East Paratethys–Tethys marine connections along Euphrat Passage during Neogene, *Rom. J. Stratigr.*, 1995, vol. 76, Suppl. 7, pp. 149–150.

- Chira, C., Middle Miocene calcareous nannoplankton from the western Transylvanian Basin, *Rom. Biostratigr., Taxon. Palaeoecol., Stud. Univ. Babes-Bolyai: Geol.*, 1999, vol. 44, no. 2, pp. 3–75.
- Chira, C., Early Miocene calcareous nannofossils assemblages from Transylvania, *Acta Palaeontol. Rom.*, 2004, vol. 4, pp. 81–88.
- Chira, C. and Malacu, A., Biodiversity and paleoecology of the Miocene calcareous nannoplankton from the Sibiu Area (Transylvania, Romania), *Acta Palaeontol. Rom.*, 2008, vol. 6, pp. 17–28.
- Chira, C. and Marunteanu, M., Calcareous nannofossils and dinoflagellates from the Middle Miocene of the Transylvanian Basin, Romania, in *Abstr. 10 INA (Int. Nannoplankton Assoc.) Conf.*, Bremen, *J. Nannoplankton Res.*, 2000, vol. 22, no. 2, pp. 89–90.
- Chira, C. and Vulc, A.-M., The Miocene calcareous nannofossils from Bistrita area (Transylvania, Romania), *Geology*, 2003, vol. 48, pp. 67–80.
- Cicha, I., Rögl, F., Rupp, Ch., and Ctyroka, J., Oligocene–Miocene foraminifera of the Central Paratethys, *Abh. Senckenb. Naturforsch. Ges.*, 1998, vol. 549.
- The Messinian Salinity Crisis from Mega-Deposits to Microbiology—A Consensus Report no. 33, in *CIESM Workshop Monographs*, Brand, F., Ed., Monaco, 2008.
- Ciobanu, M., *Fauna Fossilă din Oligocenul de la Piatra Neamț*, București: Acad. R.S.R., 1977.
- Cita, M.B. and Gartner, S., The stratotype Zanclean foraminiferal and nannofossil biostratigraphy, *Riv. Ital. Paleontol. Milano*, 1973, vol. 79, no. 4, pp. 503–558.
- Clauzon, G., Suc, J.-P., Gauter, F., Berger, A., and Loutre, M.-F., Alternate interpretation of the Messinian salinity crisis: Controversy resolved? *Geology*, 1996, vol. 24, no. 4, pp. 363–366.
- Čorič, S., Occurrences of endemical Pannonian calcareous nannoplankton genus *Isolithus* Luljeva, 1989, in the Central Paratethys, *Scr., Fac. Sci. Nat.*, Masaryk Univ., Brno, 2001–2002, vols. 31–32, pp. 19–22.
- Čorič, S., Calcareous nannofossil biostratigraphy of the Muhlbach beds (Gaiendorf Formation, Lower Badenian), *Ann. Naturhist. Mus. Wien.*, 2003, vol. 104A, p. 15–21.
- Čorič, S., Endemic Sarmatian and Pannonian calcareous nannoplankton from the Central Paratethys, in *Abstr. 12th Congr. Reg. Com. Mediter. Neogene Stratigr.*, Harzhauser, M. and Zuschin, M., Eds., 2005, pp. 53–54.
- Čorič, S. and Hohenegger, J., Quantitative analyses of calcareous nannoplankton assemblages from the Baden–Sooss section (Middle Miocene of Vienna Basin, Austria), *Geol. Carpathica*, 2008, vol. 59, pp. 447–460.
- Čorič, S., Rögl, and F. Roggendore-1, Borehole, a key-section for Lower Badenian transgressions and the stratigraphic position of the Grund Formation (Molasse Basin, Lower Austria), *Geol. Carpathica*, 2004, vol. 55, no. 2, pp. 165–178.
- Čorič, S.S. and Švabenska, L., Calcareous nannofossil biostratigraphy of the Grund Formation (Molasse Basin, Lower Austria), *Geol. Carpathica*, 2004, vol. 55, pp. 147–153.
- Čorič, S.S., Švabenska, L., Rögl, F., and Petrova, P., Stratigraphical position of *Helicosphaera waltrans* nannoplankton horizon (NN5 Lower Badenian), *Joannea Geol. Paläontol.*, 2007, vol. 9, pp. 17–19.
- Cox, A., Geomagnetic reversals, *Science (New York)*, 1969, vol. 163, pp. 237–245.
- Cziczter, I., Magyar, I., Pipik, R., Böhme, M., Coric, S., Bakrač, R., Suto-Szentai, M., Lantos, M., Babinszki, E., and Müller, P., Life in the sublittoral zone of long-lived Lake Pannon: Paleontological analysis of the Upper Miocene Szák Formation, Hungary, *Int. J. Earth Sci. (Geol. Rundsch.)*, 2008, vol. 98, no. 7, pp. 17–41.
- Danil'chenko, P.G., Main assemblages of the ichthyofauna of the Cenozoic seas of the Tethys, in *Tr. Paleontol. Inst. Akad. Nauk SSSR. Iskopaemye kostistye ryby SSSR* (Trans. Paleontol. Inst. USSR Acad. Sci. "Fossil Bony Fishes of the USSR"), 1980, vol. 178, pp. 175–183.
- Danil'chenko, P.G., Marine and brackish-water fishes of the Paratethys, *Stratigrafiya SSSR. Neogenovaya sistema* (Stratigraphy of the USSR. Neogene System), Muratov, M.V. and Nevesskaya, L.A., Eds., Moscow: Nedra, 1986, vol. 2, pp. 302–305.
- Danukalova, G.A., Bivalves and Akchagylian stratigraphy, in *Tr. Paleontol. Inst. Ross. Akad. Nauk* (Trans. Paleontol. Inst. Russ. Acad. Sci.), 1996, vol. 265, pp. 1–131.
- Davitashvili, L.Sh., On the Konkian Stage of Georgia, *Azerb. Neft. Khoz.*, 1930, no. 10, pp. 55–57.
- Davitashvili, L.Sh., *Obzor mollyuskov tretichnykh i posletretichnykh otlozhenii Krymsko-Kavkazskoi neftenosnoi provintsi* (Review of Mollusks of Tertiary and Post-Tertiary Deposits of the Crimean–Caucasian Oil-bearing Province), Leningrad–Moscow: Otd. Nauchno-Tekhn. Inf., 1933.
- Davitashvili, L.Sh., On the fauna of the Kotsakhurian Stage, *Byull. Mosk. Obshch. Ispyt. Priro.*, Otd. Geol., 1934, vol. 12, no. 3, pp. 392–408.
- Davitashvili, L.Sh., About some representatives of the *Dreissensia angusta* Rouss. group from Kimmerian deposits, *Probl. Paleontol.*, 1937, vol. 2/3, pp. 598–599.
- Degens, E.T., Stoffers P., Golubic, S., and Dickman, M.D., *Varve Chronology: Estimated Rates of Sedimentation in the Black Sea Deep Basin*, Washington: US Gov. Print. Off., 1978, pp. 499–508.
- Denisov, V.I., Patterns of the formation of suspended matter on the Black Sea shelf, *Extended Abstract of Cand. Sci. (Geogr.) Dissertation*, Rostov-on-Don: Rostov Gos. Univ., 1998.
- Didkovskii, V.Ya., On the phylogenetic development of some representatives of the family Peneroplidae, *Dopov. Akad. Nauk. Ukr. SSR*, 1958a, no. 3, pp. 324–328.
- Didkovskii, V.Ya., On the phylogenetic development of the genus *Articulina*, *Geol. Zh.*, 1958b, vol. 18, no. 1, pp. 46–60.
- Didkovskii, V.Ya., On the microfauna of the Middle Sarmatian Black Sea Basin in the Ukrainian SSR, *Geol. Zh.*, 1962, vol. 22, no. 1, p. 20.
- Didkovskii, V.Ya., Biostratigraphy of Neogene deposits in the south of the Russian Platform based on foraminiferal fauna, *Extended Abstract of Doctoral (Geol.–Mineral.) Dissertation*, Kiev, 1964.
- Didkovskii, V.Ya., Stages of development of foraminifers in the Pontian–Caspian region and Galicia–Podolsk Bay from the Miocene to present, in *Tr. VIII Ses. Vses. Paleontol. Obshch.* (Proc. 8th Sess. All-Union Paleontol. Soc.), Moscow: Nedra, 1966, pp. 183–189.
- Didkovskii, V.Ya. and Satanovskaya, Z.N., *Paleontologicheskii spravochnik. T. 4. Foraminifery miotsena Ukrainy* (Pa-

- leontological Handbook. Vol. 4: Foraminifers of the Miocene of Ukraine), Kiev: Naukova Dumka, 1970.
- Didkovskii, V.Ya., Lyul'eva, S.A., and Lyul'ev, Yu.B., Microfauna and coccolithophorids from the clay strata of the Lower Sarmatian of the southeast of the Ukrainian SSR, *Geol. Zh.*, 1968, vol. 28, no. 6, pp. 76–89.
- Didkovskii, V.Ya., Prisyazhnyuk, V.A., Lyul'eva, S.A., and Lyul'ev, Yu.B., Sarmatian deposits of Mogilev Transnistria, *Geol. Zh.*, 1981, vol. 41, no. 4, pp. 107–113.
- Dmitrieva, R.G., Somov, V.D., and Bogdanowicz, A.K., Alkunian Horizon and its stratigraphic significance, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1959, no. 8, pp. 87–99.
- D'Orbigny, A., *Foraminifères Fossiles du Bassin Tertiaire de Vienne*, Paris, 1846.
- Dorofeev, P.I., Sarmatian plants from the Tiligula and Yuzhny Bug rivers, in *Tr. Bot. Inst. Akad. Nauk SSSR, Ser. 1.* (Trans. Bot. Inst. USSR Acad. Sci. Ser. 1), 1955, vol. 11, pp. 144–160.
- Dorofeev, P.I., Maeotic plants from the outskirts of Odessa, *Bot. Zh. Akad. Nauk Ukr. SSR*, 1951, no. 3, pp. 31–40.
- Dorofeev, P.I., Sarmatian flora of Apsheron, *Dokl. Akad. Nauk SSSR*, 1964, vol. 156, no. 1, pp. 82–84.
- Dorofeev, P.I., On the Pliocene flora of Nagavskaya clays on the Don River, *Dokl. Akad. Nauk SSSR*, 1957, vol. 117, no. 1, pp. 124–126.
- Dybkaer, K. and Piasecki, S., Neogene dinocyst zonation for the eastern North Sea Basin, Denmark, *Rev. Palaeobot. Palynol.*, 2010, vol. 161, pp. 1–29.
- Dzhanelidze, O.I., On the study of foraminifers from Konian and Sarmatian deposits of Georgia, *Soobshch. Akad. Nauk Gruz. SSR*, 1953, vol. 14, no. 3, pp. 153–158.
- Dzhanelidze, O.I., *Foraminifery nizhnego i srednego miotsena Gruzii* (Foraminifers of the Lower and Middle Miocene of Georgia), Tbilisi: Metsniereba, 1970.
- Dzhaparidze, I.N., Early Miocene Flora of Eastern Georgia, in *Tr. Geol. Inst. Gruz. SSR, Nov. Ser.* (Trans. Geol. Inst. Georgian SSR, New Ser.), 1982, vol. 77, pp. 1–119.
- Eberzin, A.G., Elements of Akchagylia fauna in the Eastern Crimea and western part of the Kerch Peninsula, *Izv. Akad. Nauk SSSR, Otd. Matem. Estestv. Nauk, Ser. 7*, 1931, no. 3, pp. 387–392.
- Eberzin, A.G., Genus *Limnocardium Stoliczka* in the Pliocene of the Pontian–Caspian basin, in *Tr. Paleontol. Inst. Akad. Nauk SSSR* (Trans. Paleontol. Inst. USSR Acad. Sci.), 1947, vol. 13, no. 4, pp. 1–156.
- Eberzin, A.G., Neogene of northern Turkmenistan, *Trudy Kompleksn. Yuzhn. Geol. Eksped. Akad. Nauk SSSR*, 1960, no. 5, pp. 155–259.
- Eberzin, A.G., Brackish-water Cardiiids of the Pliocene of the USSR. Part 5, in *Tr. Paleontol. Inst. Akad. Nauk SSSR* (Trans. Paleontol. Inst. USSR Acad. Sci.), 1967, vol. 112, pp. 1–168.
- Ehrenberg, G.G., Ober neue Charaktere der erdigen und derben Mineralien, *Ann. Phys. Chem. (Poggendorff's Ann.)*, 1836, vol. 39, pp. 101–106.
- Erünel-Erentöz, L., Mollusques du Néogène des bassins de Karaman, Adana et Hatay (Turquie), Ankara, *Publ. Inst. Etud. Rech. Miner. Turquie, Ser. C*, 1958, no. 4, pp. 1–232.
- Filippova, N.Yu., Spores, pollen, and organic-walled phytoplankton from the Neogene deposits of the Zhelezny Rog reference section (Taman' Peninsula), *Stratigr. Geol. Correl.*, 2002, vol. 10, no. 2, pp. 176–188.
- Filippova, N.Yu. and Trubikhin, V.M., On the correlation of the Upper Miocene deposits of the Black Sea and Mediterranean basins, *Aktual'nye problemy neogenovoi i chetvertichnoi stratigrafii i ikh obsuzhdenie na 33 Mezhdunarod. Geol. Kongr.* (Topical Problems of Neogene and Quaternary Stratigraphy and Their Discussion at 33 Int. Geol. Congr.), Gladenkov, Yu.B., Ed., Moscow, 2009, pp. 142–152.
- Filippova, N.Yu., Beluzhenko, E.V., and Golovina, L.A., Micropaleontological Data (Dinocysts, Calcareous nannofossils, Spores and Pollen) and Biostratigraphy of the Alkun Formation, North Ossetia, *Stratigr. Geol. Correl.*, 2010, vol. 18, no. 3, pp. 307–330.
- Filippova, N.Yu., Beluzhenko, E.V., and Golovina, L.A., On the Paleogene–Neogene Boundary and Age of the Alkunian Formation in the North Caucasus and Ciscaucasia, *Stratigr. Geol. Correl.*, 2015, vol. 23, no. 6, pp. 620–644.
- Fischer, A.G., Boer de, P.L., and Premoli Silva, I., Cyclostratigraphy, in *Global Sedimentary Geology Program: Cretaceous Resources, Events and Rhythms*, Beaudoin, B. and Ginsburg, R.N., Eds., Dordrecht: Kluwer, NATO ASI Ser., 1988, pp. 139–172.
- Fornaciari, E. and Rio, D., Latest Oligocene to early Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region, *Micropaleontology*, 1996, vol. 42, no. 1, pp. 1–36.
- Fornaciari, E., Di Stefano, A., Rio, D., and Negri, A., Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region, *Micropaleontology*, 1996, vol. 42, no. 1, pp. 37–63.
- Gabelaya, Ts.D., *Ryby pliocenovykh otlozhenii Gruzii* (Fishes of Pliocene Deposits of Georgia), Tbilisi: Metsniereba, 1976.
- Gabuniya, L.K., *K istorii gipparionov (po materialam iz neogena SSSR)* (On the History of Hipparions (Based on Materials from the Neogene of the USSR)), Moscow, Akad. Nauk SSSR, 1959.
- Galović, I., How tectonic, sea level changes and (dis)connections with others marine areas influenced on calcareous nannoplankton assemblage during the Sarmatian, in *Pannonian Transition, 4th Croatian Geol. Congr. Abstr. Book.*, 2010, pp. 58–59.
- Galović, I., Sarmatian calcareous nannofossil assemblages in the SW Paratethyan marginal marine environments: Implications for palaeoceanography and the palaeoclimate, *Progr. Oceanogr.*, 2017, vol. 156, pp. 209–220.
- Garecka, M., Record of changes in the Oligocene–Miocene sediments of the Menilite–Krosno series of the Skole unit based on calcareous nannoplankton studies: biostratigraphy and palaeogeographical implications (Polish Outer Carpathians), *Biul. Pansw. Inst. Geol.*, 2012, vol. 453, pp. 1–22.
- Gazdzicka, E., Nannoplankton stratigraphy of the Miocene deposits in Tarnobrzeg area (northeastern part of the Carpathian Foredeep, *Geol. Quart.*, 1994, vol. 38, pp. 553–570.
- Geological Time Scale*. Vol. 2, Gradstein, F., Ogg, J., Schmitz, M., and Ogg, G., Eds., 2020, Amsterdam: Elsevier, 2020.
- Gerke, A.A., Variability of *Miliolina akneriana* (Orb.) and *Sigmilina tschokrakensis* Gerke in the Chokrakian–Spiralis Beds of Eastern Ciscaucasia, in *Probl. Paleontol.* (Prob-

- lems of Paleontology), Moscow: Mosk. Gos. Univ., 1938, vol. 4, pp. 293–324.
- Gillet, H., Lericolais, G., and Rehault, J.-P., Messinian event in the Black Sea: Evidence of a Messinian erosional surface, *Mar. Geol.*, 2007, vol. 244, pp. 142–165.
- Gladenkov, Yu.B., Biosphere stratigraphy (problems of stratigraphy of the 21st century), in *Tr. Geol. Inst. Vseross. Akad. Nauk* (Trans. Geol. Inst. Russ. Acad. Sci.), 2004, vol. 551, pp. 1–120.
- Glibert, M. and Poel van de, L., Les Bivalvia fossiles du Cénozoïque étranger des collections de l'Institut royal des Sciences naturelles de Belgique. 4. Heteroconchia. 2. Corbiculidae à Petricolidae, *Mém. Inst. R. Sci. Natur. Belg.*, 1966, vol. 82, no. 2, pp. 1–82.
- Golovina, L.A., Specific nannofossils of the Neogene of the Eastern Mediterranean and Eastern Paratethys, in *Sb. Nauchn. Tr. 12 Vseross. Palinol. Konf.* (Coll. Sci. Works 12th All-Russ. Palynol. Conf.), St. Petersburg: Vseross. Neft. Nauchno-Issled. Geol. Inst., 2008, pp. 16–20.
- Golovina, L., Calcareous nannofossils-based biostratigraphic subdivisions in the reference sections of the Taman trough and Ciscaucasia, *Paleontol. J.*, 2019, vol. 53, no. 9, pp. 899–907.
- Golovina, L.A. and Bylinskaya, M.E., Tarkhanian associations of calcareous nannofossils and planktonic foraminifers from Ciscaucasia and their significance for detailing the regional stratigraphic scheme of the south of Russia, in *Sovrem. Probl. Geol., Geofiz. Geoekol. Sev. Kavk., t. 10, ch. 1* (Current Problems of Geology, Geophysics, and Geoecology. Ser. Caucasian. Vol. 10, Pt. 1), Grozny: Inst. Istor. Estestvozn. Tekh. Ross. Akad. Nauk, 2020, pp. 98–103.
- Golovina, L.A. and Vernigorova, Y.V., Middle Miocene (Konkian) calcareous nannoplankton and foraminiferal assemblages (Taman Peninsula and Cis-Caucasia, Russia), in *Proc. 4th Int. Workshop "Neogene of Central and South-Eastern Europe"*, Slovakia, 2011, pp. 11–12.
- Golovina, L.A., Muzylev, N.G., and Roshka, V.Kh., New data on the stratigraphy of Badenian deposits of Moldavia, in *Paleontol.-Stratigr. Issled. Mezozoya i kainozoya mezhdurech'ya Dnestr-Prut* (Paleontological and Stratigraphic Studies of the Mesozoic and Cenozoic in the Dniester-Prut Interfluvium), Kishinev: Shtinitsa, 1986, pp. 24–34.
- Golovina, L.A., Muzylev, N.G., and Ushakova, M.G., Calcareous nannofossils and variants of stratigraphic interpretation of the section of well 380/380-A in the Black Sea, in *Byull. Kom. Izuch. Chetvertichn. Perioda* (Tertiary Period Bull.), Moscow: Nauka, 1987, pp. 36–44.
- Golovina, L.A., Muzylev, N.G., and Trubikhin, V.M., Calcareous nannofossils and paleomagnetic stratigraphy of the Neogene deposits of Turkmenistan and Azerbaijan, *Vopr. Mikropaleontol.*, 1989, no. 30, pp. 79–89.
- Golovina, L.A., Goncharova, I.A., and Rostovtseva, Yu.V., New data on the Middle Miocene biostratigraphy (nannofossils, mollusks) and lithology of the Tamanskii Peninsula and Western Ciscaucasia, *Stratigr. Geol. Correl.*, 2004, vol. 12, no. 6, pp. 637–646.
- Golovina, L.A., Radionova, E.P., Van Baak, C.G.C., Krijgsman, W., and Palcu, D., A late Maeotian age (6.7–6.3 Ma) for the enigmatic "Pebbly Breccia" unit in DSDP Hole 380A of the Black Sea, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2019, vol. 533, 109269.
- Goncharova, I.A., *Dvustvorchatye mollyuski tarkhanskogo i chokrakskogo basseinov* (Bivalves of the Tarkhanian and Chokrakian Basins), Moscow: Nauka, 1989.
- Goncharova, I.A., On taxonomical position of *Davidschvilia* Merklin and *Zhgentiana* Janssen et al. (Bivalvia, Lutetiidae) from the Middle Miocene of Eastern Paratethys, in *Proc. 8th Int. Workshop "Neogene of Central and South-Eastern Europe"*, Poland, 2019, pp. 40–41.
- Goncharova, I.A. and Golovina, L.A., On the problem of stratigraphy of Konkian deposits, in *Paleontol. doslidzhennya v Ukraini: istoriya, suchasni stanta perspektivi Zb. nauk IGN NAN Ukraini* (Paleontological Studies in Ukraine: History, Present-day State and Prospects. Coll. Sci. Works Inst. Geol. Sci. Natl. Acad. Sci. Ukr.), Kiev: NoraCprint, 2007, pp. 289–297.
- Goncharova, I.A. and Popov, S.V., Mollusks of the Sivash beds of the Dnieper–Donetsk depression, *Paleontol. Zh.*, 1995, no. 4, pp. 54–66.
- Goncharova, I.A., Khondkarian, S.O., and Shcherba, I.G., The Tarkhanian–Karaganian Stage in development of the Euxinian–Caspian Basin (Eastern Paratethys). Part 1: Tarkhanian, *Stratigr. Geol. Correl.*, 2001, vol. 9, no. 5, pp. 508–522.
- Goncharova, I.A., Khondkarian, S.O., and Shcherba, I.G., The Tarkhanian–Karaganian Stage in development of the Euxinian–Caspian Basin (Eastern Paratethys). Part 2, *Stratigr. Geol. Correl.*, 2002, vol. 10, no. 2, pp. 196–208.
- Gozhyk, P., Semenenko, V., Andreeva-Grigorovich, A., and Maslun, N., The correlation of the Neogene of Central and Eastern Paratethys segments of Ukraine with the International Stratigraphic Chart based on planktonic microfossils, *Geol. Carpathica*, 2015, vol. 66, no. 3, pp. 235–244.
- Grigorovich, A.S., Vertical distribution of peridinians in Upper Oligocene and Lower Miocene sediments of the Black Sea Basin, in *Tekton. Stratigr., Vyp. 7* (Tectonics and Stratigraphy. Vol. 7), Kiev: Naukova Dumka, 1975, pp. 48–51.
- Grigorovich, A.S. and Veselov, A.A., *Peridinea* from the boundary beds of the Paleogene and Neogene of the Black Sea depression, *Dokl. Akad. Nauk Ukr. SSR, Ser. B.*, 1971, no. 7, pp. 581–583.
- Grossgeim, V.A., *Paleogen Severo-Zapadnogo Kavkaza* (Paleogene of the Northwestern Caucasus), Moscow: Gostoptekhizdat (*Trudy Krasnodar. Fil. Vses. Neftgaz. Nauchno-Issled. Inst.*), 1960, vol. 4.
- Grothe, A., Sangiorgi, F., Mulders, Y.R., Vasiliev, I., Reichart, G.-J., Brinkhuis, H., Stoica, M., and Krijgsman, W., Black Sea desiccation during the Messinian Salinity Crisis: Fact or fiction? *Geology*, 2014, vol. 42, no. 7, pp. 1–4.
- Grothe, A., Sangiorgi, F., Brinkhuis, H., Stoica, M., and Krijgsman, W., Migration of the dinoflagellate *Galeacysta etrusca* and its implications for the Messinian salinity crisis, *Newsl. Stratigr.*, 2018, vol. 51, pp. 73–91.
- Gradstein, F., Ogg, J., Schmitz, M., Ogg, G. (Eds.) *A Geological Time Scale*, 2012. vol. 2. Cambridge Univ. Press.
- Gruzinskaya, K.F., Grishanov, A.N., Goinov, V.V., Eremin, V.N., and Molostovskii, E.A., Stratigraphy and paleomagnetism of the Sarmatian of the Caucasus, in *Stratigrafiya i korrelyatsiya sarmatskikh i meoticheskikh otlozhenii Yuga SSSR* (Stratigraphy and correlation of Sarmatian and Maeotian deposits in the south of the USSR), Saratov: Izd. Saratov Gos. Univ., 1986, pp. 130–139.

- Gruzinskaya, K.F., Sarmatian mollusk fauna of Eastern Georgia, *Cand. Sci. (Geol–Mineral.) Dissertation*, Tbilisi, 1966.
- Gunderson, K.L., Kodama, K.P., Anastasio, D.J., and Pazzaglia, F.G., Rock-magnetic cyclostratigraphy for the Late Pliocene–Early Pleistocene Stirone section, Northern Apennine mountain front, Italy, *Spec. Publ.—Geol. Soc. London*, 2012, vol. 373.
- Gurarii, G.Z., Some data on the characteristics of the geomagnetic field at the boundary of the Gauss and Matuyama chrons (Pyrnuar section, western Turkmenistan), *Izv., Phys. Solid Earth*, 2015, vol. 51, no. 5, pp. 651–673.
- Gur'ev, N.V., Late Miocene flora of the environs of the city of Krymsk (Northern Caucasus), *Extended Abstract of Cand. Sci. (Biol.) Dissertation*, Inst. Akad. Nauk SSSR, 1987.
- Hammer, Ø., Harper, D.A.T., and Ryan, P.D., PAST: Paleontological statistics software package for education and data analysis, *Palaeontol. Electronica*, 2001, vol. 4, pp. 1–9.
- Harzhauser, M. and Piller, W.E., The Early Sarmatian: Hidden seesaw changes, *CFS, Cour. Forschungsinst. Senckenberg*, 2004, vol. 246, pp. 89–112.
- Harzhauser, M., Kranner, M., Mandic, O., Strauss, Ph., Siedl, W., and Piller, W.E., Miocene lithostratigraphy of the northern and central Vienna Basin (Austria), *Aust. J. Earth Sci.*, 2020, vol. 113, no. 2, pp. 169–200.
- Harzhauser, M., Mandic, O., and Zuschin, V., Changes in Paratethyan marine mollusks at the Early/Middle Miocene transition: diversity, palaeogeography and palaeoclimate, *Acta Geol. Pol.*, 2003, vol. 53, no. 4, pp. 323–339.
- Hilgen, F.J., Extension of the astronomically calibrated (polarity) time scale to the Miocene–Pliocene boundary, *Earth Planet. Sci. Lett.*, 1991, vol. 107, pp. 349–368.
- Hilgen, F.J., Abdul Aziz, H., Krijgsman, W., Raffi I., and Turco, E., Integrated stratigraphy and astronomical tuning of the Serravallian and lower Tortonian at Monte dei Corvi (Middle–Upper Miocene, northern Italy), *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2003, vol. 199, pp. 229–264.
- Hilgen, F.J., Lourens, L.J., and Van Dam, J.A., *The Neogene Period, A Geological Time Scale*, Gradstein, F., Ogg, J., Schmitz, M., and Ogg, G., Eds., 2012, vol. 2, Cambridge: Cambridge Univ. Press., pp. 923–979.
- Hilgen, F.J., Schwarzbacher, W., and Strasser, A., Concepts and definitions in cyclostratigraphy (second report of the cyclostratigraphy working group), *SEPM. Spec. Publ.*, Tulsa, 2004, vol. 81, pp. 303–305.
- Hinnov, L.A. and Ogg, J.G., Cyclostratigraphy and the astronomical time scale, *Stratigraphy*, 2007, vol. 4, nos. 2/3, pp. 239–251.
- Hodell, D.A., Curtis, J.H., Sierro, F.J., and Raymo, M.E., Correlation of late Miocene to early Pliocene sequences between the Mediterranean and North Atlantic, *Paleoceanography*, 2001, vol. 16, pp. 164–178.
- Hohenegger, J., Ćorić, S., Khatun, M., Pervesler, P., Rögl, F., Rupp, C., Selge, A., Uchmann, A., and Wagerich, M., Cyclostratigraphic dating in the Lower Badenian (Middle Miocene) of the Vienna Basin (Austria): the Baden–Soos core, *Int. J. Earth Sci.*, 2009a, vol. 98, pp. 915–930.
- Hohenegger, J., Rögl, F., Ćorić, S., Pervesler, P., Lirer, F., Roetzel, R., Scholger, R., and Stingl, K., The Styrian Basin: a key to the Middle Miocene (Badenian/Langhian) Central Paratethys transgressions, *Aust. J. Earth Sci.*, 2009b, vol. 102, pp. 102–132.
- Hohenegger, J., Ćorić, S., Wagerich, V., et al., Timing of the Middle Miocene Badenian stage of the Central Paratethys, *Geol. Carpathica*, 2014, vol. 65, no. 1, pp. 55–66.
- Holcová, K., New methods in foraminiferal and calcareous nannoplankton analysis and evolution of Oligocene and Miocene basins of the Southern Slovakia, *Slovak Geol. Mag.*, 2001, vol. 7, pp. 19–41.
- Holcová, K., Quantitative calcareous nannoplankton biostratigraphy of the Oligocene/Miocene boundary interval in the northern part of the Buda Basin (Central Paratethys), *Geol. Quart.*, 2005, vol. 49, pp. 263–274.
- Holcová, K., Calcareous nannoplankton and foraminiferal response to global Oligocene and Miocene climatic oscillations: a case study from the Western Carpathian segment of the Central Paratethys, *Geol. Carpathica*, 2017, vol. 68, no. 3, pp. 207–228.
- Hoyle, T.M., Leroy, S.A., López-Merino, L., Miggins, D.P., and Koppers, A.A., Vegetation succession and climate change across the Plio–Pleistocene transition in eastern Azerbaijan, central Eurasia (2.77–2.45 Ma), *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2020, vol. 538.
- Hüsing, S.K., Hilgen, F.J., Abdul Aziz, H., and Krijgsman, W., Completing the Neogene geological time scale between 8.5 and 12.5 Ma, *Earth Planet. Sci. Lett.*, 2007, vol. 253, pp. 340–358.
- Hüsing, S.K., Kuiper, K.F., Link, W., Hilgen, F.J., and Krijgsman, W., The upper Tortonian–lower Messinian at Monte dei Corvi (Northern Apennines, Italy): Completing a Mediterranean reference section for the Tortonian Stage, *Earth Planet. Sci. Lett.*, 2009, vol. 282, pp. 140–157.
- Iljina, L.B., On the communications of the Maeotian Sea with the Eastern Tethys, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1980, no. 7, pp. 138–142.
- Iljina, L.B., Key to marine Middle Miocene gastropods from Southwestern Eurasia, in *Tr. Paleontol. Inst. Ros. Akad. Nauk* (Trans. Paleontol. Inst. Russ. Acad. Sci.), 1993, vol. 255, pp. 1–151.
- Iljina, L.B., Zoogeography of Sarmatian gastropods, *Paleontol. J.*, 1998, vol. 32, no. 4, pp. 344–352.
- Iljina, L.B., On connections between basins of the Eastern Paratethys and adjacent Seas in the Middle and Late Miocene, *Stratigr. Geol. Korrel.*, 2000a, vol. 8, no. 3, pp. 300–306.
- Iljina, L.B., On the regional Konkian Stage (Middle Miocene) in the Eastern Paratethys, *Stratigr. Geol. Korrel.*, 2000b, vol. 8, no. 4, pp. 372–378.
- Iljina, L.B., On the origin and composition of Early Chokrakian (Middle Miocene) gastropods of the Eastern Paratethys, *Paleontol. J.*, 2004, vol. 38, no. 6, pp. 618–626.
- Iljina, L.B., Nevesskaya, L.A., and Paramonova, N.P., *Zakonovernosti razvitiya mollyuskov v opresnennykh basseinaх neogena Evrazii* (Patterns of Development of Mollusks in Desalinated Basins of the Neogene of Eurasia), Moscow: Nauka, 1976.
- Il'inskaya, I.A., Neogene floras of the Transcarpathian region of the Ukrainian SSR, in *Flora i fauna Karpat* (Flora and Fauna of the Carpathians), Leningrad: Izd. Akad. Nauk SSSR, 1960, pp. 75–86.
- International Chronostratigraphic Chart*, 2021.

- Ivanov, D.A., Palynological study of Miocene sediments from Northwestern Bulgaria, *Extended Abstract of Cand. Sci. (Geol.) Dissertation*, Sofia, 1995.
- Ivanova, T.A. and Bogdanowicz, E.M., Features of the stratigraphy of Sarmatian deposits of Plain Crimea based on foraminifers and calcareous nannofossils, *Visn. Dnipropetr. Univ. Ser. Geol.—Gegogr.*, 2004, vol. 6, no. 8, pp. 6–11.
- Ivanova, T.A., Barg, I.M., and Bogdanowicz, E.M., Tarkhanian Regional Stage of Plain Crimea, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1998, no. 2, pp. 44–50.
- Janssen, A.W., Janssen, R., Voort van der, J., *Spaniodontella* Andrussow in Goloubiatnikow, 1902: a critical survey of use and validity of the genus and its relationship to the genus *Alveinus* Conrad, 1865 (Mollusca, Bivalvia: Glossoidea, Kelliellidae), *Cainozoic Res.*, 2015, vol. 15, pp. 127–146.
- Jerkovič, L. and Čorič, S., Middle Miocene (Badenian/Sarmatian) calcareous nannoplankton from the southern margin of the Central Paratethys (Northern Bosnia), *J. Nannoplankton Res., Abs. INA 11 Conf.*, Lincoln, Nebraska, 2006, pp. 31–33.
- Jimenez-Moreno, G., Head, M.J., and Harzhauser, M., Early and Middle Miocene dinoflagellate cyst stratigraphy of the central Paratethys, central Europe, *J. Micropalaeontol.*, 2006, vol. 25, pp. 113–139.
- Jipa, D., Late Neogene–Quaternary evolution of Dacian basin (Romanian). An analysis of sediment thickness pattern, *Geo-Eco-Marina*, 1997, vol. 2, pp. 127–134.
- Jorissen, E.L., Leeuw de, A., Van Baak, C.G.C., Mandic, O., Stoica, M., Abels, H.A., and Krijgsman, W., Sedimentary architecture and depositional controls of a Pliocene river-dominated delta in the semi-isolated Dacian Basin, Black Sea, *Sediment. Geol.*, 2018, vol. 368, pp. 1–23.
- Kalinichenko, G.P. and Pronin, K.K., Finds of calcareous nannofossils in Pontian deposits of Odessa, in *Aktual'nye voprosy geologii Ukrainy. Mater. Konf. Molodykh Uch. Inst. Geol. Nauk Akad. Nauk Ukr. SSR* (Proc. Conf. Young Scientists Inst. Geol. Sci. Ukrainian SSR “Topical Issues of Geology of the Ukraine”), 1985, pp. 53–54.
- Karlov, N.N., On the age of formation conditions of membrane-porous reefs of Kerch Peninsula, *Izv. Akad. Nauk Ser. Geol.*, 1937, no. 6, pp. 1003–1035.
- Karpatian. A Lower Miocene Stage of the Central Paratethys*, Bzrobahaty, R., Cicha, I., Kováč, M., and Rögl, F., Eds., Brno: Masaryk Univ., 2003.
- Kazanskii, A.Yu., Paleomagnetism of Paleogene and Neogene deposits of Kazakhstan and Siberia, *Extended Abstract of Cand. Sci. (Geol.—Mineral.)*, Novosibirsk, 1988.
- Khalilov, D.M. and Kuznetsova, Z.V., Microfauna and stratigraphy of the Maikopian Group of Azerbaijan, in *Maikopskie otlozheniya i ikh vozrastnye analogi na Ukraine i v Srednei Azii* (Maikopian Deposits and Their Age Analogs in Ukraine and Central Asia), Kiev: Naukova Dumka, 1964, pp. 123–130.
- Kharatishvili, T.D., *Fauna sakaraul'skogo gorizonta i ee vozrast* (Fauna of the Sakaraulian Stage and Its Age), Tbilisi: Izd. Akad. Nauk Gruz. SSR, 1952.
- Khramov, A.N., *Paleomagnetism and Stratigraphic Correlation*, Canberra: Dep. Geophys. Aust. Natl. Univ., 1960.
- Khramov, A.N., Paleomagnetic correlation of sedimentary strata, in *Tr. Vseross. Neft. Nauchno-Issled. Geol. Inst.* (Trans. All-Russ. Petrol. Res. Explor. Inst.), Leningrad: Gostoptekhizdat, 1958, vol. 116, pp. 1–218.
- King, C., Biostratigraphy, in *A Revised Correlation of Tertiary Rocks in the British Isles and Adjacent Areas of NW Europe*, King, C., Gale, A.S., and Barry, T.L., Eds., Spec. Pap.—*Geol. Soc. London*, 2016, vol. 27, pp. 19–57.
- Koiava, K.I., Biostratigraphy of Sarmatian deposits of Eastern Georgia based on foraminifers, *Extended Abstract of Cand. Sci. (Geol.—Mineral.) Dissertation*, Tbilisi, 2006.
- Kojumdgieva, E.I., On some features of the stratigraphy of Karagana in Varna region, *Izv. Nauchn. Geol. Inst.*, 1965, vol. 2, pp. 19–60.
- Kojumdgieva, E.I., Hemi Stenohaline marine forms from the Lower Sarmatian of northwestern Bulgaria, *Izv. Geol. Inst., Ser. Paleontol.*, 1969, vol. 18, pp. 5–12.
- Kolakovskii, A.A., *Pliotsenovaya Flora Kodora* (Pliocene Flora of Kodor), Sukhumi: Izd. Akad. Nauk Gruz. SSR, 1964, vol. 1.
- Kolesnikov, V.P., Middle and Upper Pliocene of the Caspian region, in *Stratigrafiya SSSR. T. 12. Neogen SSSR* (Stratigraphy of the USSR, Vol. 12: Neogene of the USSR), Moscow: Izd. Akad. Nauk SSSR, 1940, pp. 407–447.
- Kolesnikov, V.P., On the study of the Akchagylian Stage, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1936, no. 6, pp. 799–822.
- Kolesnikov, V.P., *Sarmatskie molluski* (Sarmatian Molluscs), Leningrad: Izd. Akad. Nauk SSSR, 1935.
- Konenkova, I.D., On some foraminifer species from Chokrakian and Karaganian deposits of the Eastern Black Sea region (southern slope of the Ukrainian shield), in *Paleontol. Sb.* (Coll. Sci. Works in Paleontology), Lviv: Lviv Gos. Univ., 1989, no. 26, pp. 11–18.
- Konenkova, I.D., Stratigraphic division of Cenozoic deposits of the Eastern Cis-Azov region based on foraminifers, in *Stratigrafiya kainozoya Severnogo Prichernomor'ya i Kryma: Sb. Nauchn. Trudov* (Coll. Sci. Works “Stratigraphy of the Cenozoic of the Northern Cis-Azov Region and Crimea”), Dnepropetrovsk: Dnepropetr. Gos. Univ., 1984, pp. 21–30.
- Konenkova, I.D. and Bogdanowicz, E.M., Foraminifers and calcareous nannofossils of Miocene deposits from the southern slope of the Ukrainian shield (eastern Black Sea region), in *Biosfery geol. minulogo Ukraini* (Biosphere of the Geological Past of Ukraine), Kiev: Inst. Geol. Nauk Nats. Akad. Nauk Ukr., 1994a, pp. 88–90.
- Konenkova, I.D. and Bogdanowicz, E.M., Distribution of foraminifers and calcareous nannofossils in Tarkhanian–Chokrakian deposits of the Malyy Kamyshtak area (Kerch Peninsula), in *Biosfery geol. minulogo Ukraini* (Biosphere of the Geological Past of Ukraine), Kiev: Inst. Geol. Nauk Nats. Akad. Nauk Ukr., 1994b, pp. 95–96.
- Kornilova, V.S., Essay on the history of flora and vegetation of Kazakhstan, in *Rastitel'nyi pokrov Kazakhstana* (Vegetation Cover of Kazakhstan), Alma-Ata, 1966, vol. 1, pp. 37–190.
- Kováč, M., Andreyeva-Grigorovich, A., Bajraktarević, Z., Brzobohatý, R., Filipescu, S., Fodor, L., Harzhauser, M., Oszczypko, N., Pavelic, D., Rögl, F., Saftić, B., Sliva, L., and Studencka, B., Badenian evolution of the Central Paratethys sea: paleogeography, climate and eustatic sea level changes, *Geol. Carpathica*, 2007, vol. 58, pp. 579–606.
- Koval', Ya.M., On a new locality of the Tertiary flora of the Northern Cis-Azov region, *Zap. Geol. Fak. Khar'k. Univ.*, 1955, vol. 12, pp. 93–96.

- Kovalenko, E.I., Mel'nikov, Yu.V., Kokarev, A.D., et al., *Geologicheskaya Karta Kavkaza masshtaba 1 : 50000. Ingushetiya. List K-38-42-B i dr.* (The 1 : 50000 Geological Map of the Caucasus. Ingushetia. Sheet K-38-42-B, etc.), Essentuki: Tsentr. Geol.-S'emochnykh Eksped., 1977.
- Krasheninnikov, V.A., Elphidiids of Miocene deposits of Podolia, in *Tr. Geol. Inst. Akad. Nauk SSSR* (Trans. Geol. Inst. USSR Acad. Sci.), 1960, vol. 21, pp. 1–142.
- Krasheninnikov, V.A., On the structure of the mouth of some representatives of nonionids and elphidiids, *Vopr. Mikropaleontol.*, 1958a, no. 2, pp. 105–122.
- Krasheninnikov, V.A., Rotaliids and anomalinids of Miocene deposits of Podolia, in *Trudy Vseross. Nauchno-Issled. Geol. Neft. Inst. Paleontol. Sb.* (Trans. All-Russ. Petrol. Res. Explor. Inst. Coll. Sci. Works in Paleontology), vol. 9, 1958b, pp. 212–259.
- Krasheninnikov, V.A., Foraminifers, in *Atlas srednemiotse-novoi fauny Severnogo Kavkaza i Kryma. Trudy Vses. Nauchno-Issled. Inst. Priro. Gazov* (Atlas of the Middle Miocene Fauna of the Northern Caucasus and Crimea. Proc. All-Union Res. Inst. Natl. Gases), Moscow: Gostoptekhizdat, 1959, pp. 15–109.
- Krasheninnikov, V.A., Basov, I.A., and Golovina, L.A., *Vostochnyi Paratetis: tarkhanskii i konkskii regionaryusy* (Eastern Paratethys: Tarkhanian and Konkian Regional Stage-Regional stages), Moscow: Nauchn. Mir, 2003.
- Krezsek, C., Schleder, Z., Bega, Z., Ionescu, G., and Tari, G., The Messinian sea-level fall in the western Black Sea: small or large? Insights from offshore Romania, *Pet. Geosci.*, 2016, vol. 22, pp. 392–399.
- Krhovsky, J., Zaporozhets, N.I., Radionova, E.P., et al., Microphytoplankton, pollen, spores and plant's megafossils from Majkopian deposits of Belaja valley, North West Pre-Caucasus: preliminary results of studying, in *Proc. Symp. "Paleontology and Stratigraphy of the Eocene–Miocene Sections of the Western Pre-Caucasia"*, Paleontol. Inst. Russ. Acad. Sci., 1995, pp. 1–3.
- Krijgsman, W., Langereis, C.G., Zachariasse, W.J., Boccacetti, M., Moratti, G., Gelati, R., Iaccarino, S., Papani, G., and Villa, G., Late Neogene evolution of the Tera–Guercif Basin (Rifian Corridor, Morocco) and implications for the Messinian salinity crisis, *Mar. Geol.*, 1999, vol. 153, pp. 147–160.
- Krijgsman, W., Stoica M., Vasiliev, I., and Popov, V.V., Rise and fall of the Paratethys Sea during the Messinian Salinity Crisis, *Earth Planet. Sci. Lett.*, 2010, vol. 290, nos. 1–2, pp. 183–191.
- Krijgsman, W., Tesakov, A., Yanina, T., Lazarev, S., Danukalova, G., Van Baak, C., Agustí, J., Alçiçek, M.C., Aliyeva, E., Bista, D., Bruch, A., BüyükmERIC, Y., Bukhsianidze, M., Flecker, R., Frolov, P., Hoyle, T.M., Jorissen, E.L., Kirscher, U., Koriche, S.A., Kroonenberg, S.B., Lordkipanidze, D., Oms, O., Rausch, L., Singarayer, J., Stoica, M., Velde van de, S., Titov, V.V., and Wesselingh, F.P., Quaternary time scales for the Pontocaspian domain: Interbasinal connectivity and faunal evolution, *Earth-Sci. Rev.*, 2019, vol. 188, pp. 1–40.
- Krijgsman, W., Palcu, D.V., Andreetto, F., Stoica, M., and Mandic, O., Changing seas in the late Miocene Northern Aegean: A Paratethyan approach to Mediterranean basin evolution, *Earth-Sci. Rev.*, 2020, vol. 210, 103386.
- Krishtofovich, A.N. and Baikovskaya, T.N., *Sarmatskaya flora Krynki* (Sarmatian Flora of Krynka), Moscow: Nauka, 1965.
- Kulichenko, V.G., Lyul'eva, S.A., and Lyul'ev, Yu.B., Invertebrates and calcareous nannofossils from Konkian deposits of the southern slope of the Azov massif, *Geol. Zh.*, 1976a, vol. 36, no. 2, pp. 87–99.
- Kulichenko, V.G., Lyul'ev, Yu.B., and Lyul'eva, S.A., Miocene deposits of the northwestern shelf of the Black Sea, *Geol. Zh.*, 1976b, vol. 36, no. 5, pp. 121–134.
- Kurtskhaliya, T.A., On analogs of the Hattian and Aquitanian stages in Eastern Georgia, *Izv. Geol. Obshch. Gruz.*, 1982, vol. 9, no. 1/2, pp. 50–55.
- Kurtskhaliya, T.A., Buleishvili, D.A., and Papava, D.Yu., On the occurrence of the Aquitanian Stage in Georgia, *Soobshch. Akad. Nauk Gruz. SSR*, 1972, vol. 86, no. 2, pp. 369–372.
- Kutuzkina, E.F., Materials on the Tertiary flora of Kyrgyzstan, in *Sb. pamyati A.N. Krishtofovicha* (Collection of Science Works in Memory of A.N. Krishtofovich), Moscow: Izd. Akad. Nauk SSSR, 1957, pp. 259–276.
- Kutuzkina, E.F., Sarmatian flora of Armavir, in *Paleobotanika. Vyp. 5* (Paleobotany. Vol. 5), Moscow–Leningrad: Izd. Akad. Nauk SSSR, 1964, pp. 145–230 (*Trudy Bot. Inst. Akad. Nauk SSSR. Ser. 8*).
- Kutuzkina, E.F., Some representatives of the Mediterranean flora in the Upper Sarmatian of Krasnodar krai, *Bot. Zh.*, 1974, vol. 59, no. 2, pp. 251–260.
- Kvaliashvili, G.A., On the relationship between the Sakaraulian and Kotsakhurian stages of Georgia, in *Fauna mezozoya i kainozoya Gruzii i ee geoistorich. znachenie* (Fauna of the Mesozoic and Cenozoic of Georgia and Its Geohistorical Significance), Tbilisi: Metsniereba, 1970, pp. 6–69.
- Kvaliashvili, G.A., *Onkoforovi (rzhakievii) gorizont Evrazii* (Oncophoric (Rzehakian) Stage of Eurasia), Tbilisi: Izd. Akad. Nauk Gruz. SSR, 1962.
- Lancis, C., Tent-Manclús, J.E., Flores, J.A., and Soria, J.M., The Pliocene Mediterranean infilling of the Messinian erosional surface: new biostratigraphic data based on calcareous nannofossils (Bajo Segura Basin, SE Spain), *Geol. Acta.*, 2015, vol. 13, no. 3, pp. 211–228.
- Laskar, J., Robutel, P., Joutel, F., Gastineau, M., Correia, A.C.M., and Levrard, B., A long-term numerical solution for the insolation quantities of the Earth, *Astron. Astrophys.*, 2004, vol. 428, pp. 261–285.
- Lazarev, S., Jorissen, E.L., Velde van de, S., Rausch, L., Stoica, M., Wesselingh, F.P., Van Baak, C.G., Yanina, T.A., Aliyeva, E., and Krijgsman, W., Magneto-biostratigraphic age constraints on the palaeoenvironmental evolution of the South Caspian basin during the Early-Middle Pleistocene (Kura basin, Azerbaijan), *Quat. Sci. Rev.*, 2019, vol. 222, 105895.
- Lazarev, S., Leeuw de, A., Stoica, M., Mandic, O., Van Baak, C.G.C., Vasiliev, I., and Krijgsman, W., From Khersonian drying to Pontian “flooding”: late Miocene stratigraphy and palaeoenvironmental evolution of the Dacian Basin (Eastern Paratethys), *Global Planet. Change*, 2020, vol. 192, 103224.
- Lazarev, S., Kuiper, K.F., Oms, O., Bukhsianidze, M., Vasilyan, D., Jorissen, E.L., Bouwmeester, M.J., Aghayeva, V., van Amerongen, A.J., Agustí, J., Lordkipanidze, D., and Krijgsman, W., Five-fold expansion of the Caspian Sea in the

- late Pliocene: New and revised magnetostratigraphic and $^{40}\text{Ar}/^{39}\text{Ar}$ age constraints on the Akchagyl Stage, *Global Planet. Change*, 2021, vol. 206, 103624.
- Lehotayova, R., *Helicosphaera porosa*—new species of calcareous nannoflora from Oligocene/Miocene boundary, *Zapad. Karp. Ser. Paleontol.*, 1985, pp. 103–104.
- Leie, Ya.B., Floristic substantiation of the division of Paleogene and Neogene deposits of Armenia (according to a spore–pollen analysis), in *Palinologicheskii metod v stratigrafii. Mat. 2 Mezhd. Palinol. Konf. (Palynological Method in Stratigraphy. Proc. 2nd Int. Palynol. Conf.)*, Leningrad: Nauka, 1968, pp. 86–89.
- Lirer, F. and Iaccarino, S.M., Integrated stratigraphy (cyclostratigraphy and biochronology) of late Middle Miocene deposits in the Mediterranean area and comparison with the North and Equatorial Atlantic Oceans: synthesis of the major results, *Terra Nova*, 2005, vol. 17, pp. 338–349.
- Lirer, F., Harzhauser, M., Pelosi, N., Piller, W.E., Schmid, H.P., and Sprovieri, M., Astronomically forced teleconnection between Paratethyan and Mediterranean sediments during the Middle and Late Miocene, *Palaeogeogr., Palaeoecol.*, 2009, vol. 275, pp. 1–13.
- Liverovskaya, E.V., Mollusk fauna of the Upper Maikopian of the Northern Caucasus, in *Issledovanie maikopskoi svity na Severnom Kavkaze. Tr. Neft. Geol. Razved. Inst., Ser. A, vol. 104 (A Study of the Maikopian Formation in the Northern Caucasus. Trans. Petrol. Res. Explor. Inst. Ser. A. Vol. 104)*, Leningrad–Moscow, 1938, pp. 23–42.
- Loeblich, A.J.R. and Tappan, H., Sarcodina chiefly “Thecamoebians” and Foraminifera, in *Treatise Invertebr. Paleontol. Protista 2*, Vol. 1, New York, 1987.
- Louwye, S., Foubert, A., Mertens, K., and Van Rooij, D., IODP Expedition 307, Scientific Part. Integrated stratigraphy and palaeoecology of the Lower and Middle Miocene of the Porcupine Basin, *Geol. Mag.*, 2007, vol. 145, pp. 1–24.
- Louwye, S., Marquet, R., Bosselaers, M., and Lambert, O., Stratigraphy of an Early–Middle Miocene sequence near Antwerp in northern Belgium (southern North Sea Basin), *Geol. Belg.*, 2010, no. 13(3), pp. 269–284.
- Lyul'eva, S.A., New Miocene and Pliocene calcareous nannofossils in the south of Ukraine, *Dokl. Akad. Nauk Ukr. SSR, Ser. B*, 1989a, no. 1, pp. 10–14.
- Lyul'eva, S.A., *Ceratolites* (calcareous nannofossils) of Miocene and Pliocene deposits in the southwestern USSR, *Dokl. Akad. Nauk Ukr. SSR, Ser. B*, 1989b, no. 11, pp. 14–17.
- Lyul'eva, S.A., *Ceratolites* of the Upper Miocene–Lower Pliocene of Ukraine and Western Transcaucasia, in *Paleontol. Sb. (Coll. Sci. Works in Paleontology)*, Kiev, 1990a, no. 27, pp. 96–103.
- Lyul'eva, S.A., New representatives of calcareous nannofossils in the Sarmatian of the southern regions of Ukraine, *Dokl. Akad. Nauk Ukr. SSR, Ser. B*, 1990b, no. 3, pp. 5–8.
- Lyul'eva, S.A., Calcareous nannofossils of Dacian deposits in the southwest of Ukraine, *Dokl. Akad. Nauk Ukr. SSR, Ser. A*, 1991, no. 1, pp. 73–78.
- Lyul'eva, S.A., Evolution of *Ceratolites* (calcareous nannofossils) and problems of biostratigraphy and biochronology of the Miocene–Pliocene, in *Sb. Filogeneticheskie aspekty paleontol. (Phylogentetic Aspects of Paleontology. Coll. Sci. Works)*, St. Petersburg: Nauka, 1993, pp. 41–49.
- Lyul'eva, S.A., Calcareous nannofossils of Sarmatian deposits of Ukraine, in *Sb. Nauchn. Tr. Inst. Geol. Nauk Nats. Akad. Nauk Ukr. (Collect. Sci. Pap. Inst. Geol. Sci. Natl. Acad. Sci. Ukr.)*, Kiev, 2009, pp. 322–330.
- Lyul'eva, S.A. and Prisyazhnyuk, V.A., New biostratigraphic data on Beds with *Lentipecten denudatum* (Miocene) in Ciscarpathia, *Geol. Zh.*, 1992, no. 3, pp. 117–121.
- Maisuradze, L.S., *Foraminifery sarmata Zapadnoi Gruzii (Foraminifers of the Sarmatian of Western Georgia)*, Tbilisi: Metsniereba, 1971.
- Maisuradze, L.S., *K paleobiologicheskoi istorii foraminifer pozdnego miotsena Chernomorsko-Kaspiiskogo basseina (On the Paleobiological History of Late Miocene Foraminifers in the Black Sea–Caspian Basin)*, Tbilisi: Metsniereba, 1980.
- Maisuradze, L.S., Minashvili, Ts.D., and Koiava, K.P., Biostratigraphy of Sarmatian deposits of the Zhinvali–Gombori Subzone based on foraminifers and calcareous nannofossils, in *Tr. Geol. Inst. Akad. Nauk Gruz., Nov. Ser. (Trans. Geol. Inst. Georgian Acad. Sci. New. Ser.)*, vol. 119, 2004, pp. 295–309.
- Mandič, O., Pectinid bivalves from the Grund Formation (Lower Badenian, Middle Miocene, Alpine–Carpathian Foredeep): Taxonomic revision and stratigraphic significance, *Geol. Carpathica*, 2004, vol. 55, no. 2, pp. 129–146.
- Mandič, O. and Harzhauser, M., Mollusks from the Badenian (Middle Miocene) of the Gaiendorf Formation (Alpine Molasse Basin, NE Austria): Taxonomy, paleoecology and biostratigraphy, *Ann. Naturhist. Mus. Wien*, 2003, vol. 104A, pp. 85–127.
- Martini, E., Standard Tertiary and Quaternary calcareous nannoplankton zonation, in *Proc. 2nd Plankton. Conf.*, Roma, 1970–1971, pp. 739–785.
- MăruŃeanu, M., Distribution of the Miocene calcareous nannofossils in the Intra- and Extra-Carpathian areas of Romania, *Knihovnička Zemniho Plynu Nafty*, 1992, vol. 14b, no. 2, pp. 247–261.
- MăruŃeanu, M., The Meotian nannoplankton study, *Ann. Inst. Geol. Rom.*, 1998, vol. 70, pp. 87–90.
- MăruŃeanu, M., Litho- and biostratigraphy (calcareous nannoplankton) of the Miocene deposits from the Outer Moldavides, *Geol. Carpathica*, 1999, vol. 50, no. 4, pp. 313–324.
- MăruŃeanu, M. and Chira, C., Marine middle Miocene calcareous nannoplankton: a comparative study of the Subcarpathians and Transylvanian Basin, in *Abstr. 16th Carpathian–Balkan Congr.*, Vienna, 1998.
- MăruŃeanu, M., Papaianopol, I., Popescu, Gh., Olteanu, R., Macalet, R., Pestrea, S., and Petcu, I., Biostratigraphic studies for the standart scale of the Neogene–Moesian and Moldavian platforms, *Rom. J. Stratigr.*, 1998a, vol. 78, pp. 63–68.
- MăruŃeanu, M., Papaianopol, I., Popescu, Gh., Olteanu, R., Pestrea, S., and Macalet, R., The Meotian nannoplankton study, *Ann. Inst. Geol. Rom.*, 1998b, vol. 70, pp. 108–112.
- MăruŃeanu, M., Crihan, M., and Chira, C., Badenian nannofossil zonation—the Carpathian area, Romania, *Acta Palaeontol. Rom.*, 2000, vol. 2, pp. 261–267.
- Mdzinarishvili, R.Z., *Otchet o geologicheskikh issledovaniyakh v raione Gori (Report on Geological Studies in the Gori area)*, Tbilisi: Gruzneft', 1954.
- Melinte-Dobrinescu, M. and Brustur, T., Oligocene–Lower Miocene events in Romania, *Acta Palaeontol. Rom.*, 2008, vol. 6, pp. 203–215.

- Merklin, R.L., Lamellibranchs of spiralis clays, their habitat and life, in *Tr. Paleontol. Inst. Akad. Nauk SSSR* (Trans. Paleontol. Inst. USSR Acad. Sci.), Moscow: Izd. Akad. Nauk SSSR, 1950, vol. 28.
- Merklin, R.L., Stages of development of the Konkian basin in the Miocene of the south of the USSR, *Byull. Mosk. Obshch. Ispyt. Prir., Otd. Geol.*, 1953, vol. 28, no. 3, pp. 89–91.
- Merklin, R.L., Bogdanowicz, A.K., and Buryak, V.N., On the fauna from the upper part of Ritsa deposits of the Kuban and Bolshoi Zelenchuk rivers (Northern Caucasus), *Byull. Mosk. Obshch. Ispyt. Prir., Otd. Geol.*, 1964, vol. 39, no. 4, pp. 52–56.
- Mikhailovskii, G.P., Estuaries of the Danube Delta in the Izmail district of the Bessarabian province, *Uch. Zap. Yur'ev. Univ.*, 1909a, vol. 17, no. 8, pp. 1–64.
- Mikhailovskii, G.P., Geological studies in the southwest of Bessarabia, *Izv. Geol. Kom.*, 1909b, vol. 28, no. 6, pp. 477–508.
- Miller, K.G. and Wright, J.D., Success and failure in Cenozoic global correlations using golden spikes: a geochemical and magnetostratigraphic perspective, *Episodes*, 2017, vol. 40, no. 1, pp. 8–21.
- Minashvili, T., Calcareous nannofossil biostratigraphy and correlation of Oligocene and Miocene deposits of Georgia, *Mem. Sci. Geol.*, 1992, vol. 43, pp. 277–282.
- Minashvili, Ts.D., Biostratigraphy of Miocene deposits of Western Georgia based on calcareous nannoplankton, *Cand. Sci. (Geol.–Mineral.) Dissertation*, Tbilisi: Geol. Inst. Akad. Nauk Gruz. SSR, 1986.
- Minashvili, Ts.D., Nannoplankton assemblage from Tarkhanian deposits of Western Georgia, *Soobshch. Akad. Nauk Gruz. SSR. Geol.*, 1981, vol. 103, no. 2, pp. 357–360.
- Minashvili, Ts.D., Nannoplankton assemblages of the Sarmatian Regional Stage of Western Georgia, *Soobshch. Akad. Nauk Gruz. SSR. Geol.*, 1983, vol. 3, no. 2, pp. 333–340.
- Minashvili, Ts.D. and Ananiashvili, G.D., On the biostratigraphy of Tarkhanian–Chokrakian deposits of the Crimean–Caucasian region, *Zb. Nauk. Prats. Inst. Geol. Nauk Nats. Akad. Nauk Ukr.*, 2013, vol. 6, pp. 152–159.
- Minashvili, T. and Ananiashvili, G., Problem of stratigraphic boundary between the Paleogene and Neogene systems in the Eastern Paratethys, *Bull. Georgian Natl. Acad. Sci.*, 2017, vol. 11, no. 3, pp. 106–111.
- Mitsul, E.Z., Palynological characteristics of Miocene deposits of Moldova, *Extended Abstract of Cand. Sci. (Geol.–Mineral.) Dissertation*, Kiev: Inst. Geol. Nauk. Akad. Nauk Ukr. SSR, 1973.
- Moghadam, I.M., Stratigraphy of Neogene deposits in Northern Iran, *Middle-East J. Sci. Res.*, 2013, vol. 15, no. 6, pp. 846–852.
- Molchanov, S.O., Badenian to the early Sarmatian stage of the evolution of the vegetation cover and climate of Transcarpathia, *Extended Abstract of Cand. Sci. (Geol.) Dissertation*, Kiev: Inst. Geol. Nauk Natl. Akad. Nauk Ukr., 2002.
- Molostovskii, E.A. and Khramov, A.N., *Magnetostratigrafiya i ee znachenie v geologii* (Magnetostratigraphy and Its Significance in Geology), Saratov: Izd. Sarat. Univ., 1997.
- Monari, S., Phylogeny and biogeography of pholadid bivalve Barnea (Anchomasa) with considerations on the phylogeny of Pholadoidea, *Acta Palaeontol. Pol.*, 2009, vol. 54, no. 2, pp. 315–335.
- Musatov, V.A., *Braarudosphaera bigelowii* Beds in the Upper Akchagylia of Kalmykia, in *Osnovy sovremennoi mikropaleontologii. Sistematicheskii, biotsenologicheskii i evolyutsionnyi aspekty. Tezisy Dokl. 11 Vses. Mikropaleontol. Soveshch.* (Fundamentals of Modern Micropaleontology. Systematic, Biocenological, and Evolutionary Aspects. Proc. 11th All-Union Micropaleontol. Conf.), Moscow, 1990, pp. 88–89.
- Muzylev, N.G. and Golovina, L.A., Communication between the Eastern Paratethys and World Ocean in the Early–Middle Miocene, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1987, no. 2, pp. 62–74.
- Muzylev, N.G., Golovina, L.A., and Roshka, V.Kh., New data on the stratigraphy of Badenian deposits of Moldavia, *Paleontol.-Stratigr. Issled. Mezozoya Kainozoya*, 1986, pp. 35–62.
- Negru, A.G., *Meoticheskaya flora Severo-Zapadnogo Prichernomor'ya* (Maeotian Flora of the Northwestern Black Sea Region), Kishinev: Shtiintsa, 1986.
- Negru, A.G., Miocene flora of the village of Bursuk in Moldavia, *Bot. Zh.*, 1969, vol. 54, no. 11, pp. 1727–1738.
- Negru, A.G., On a new locality of Sarmatian flora in Moldova, *Uch. Zap. Tirasp. Gos. Pedagog. Inst.*, 1970, vol. 17, pp. 89–95.
- Neogene of the Mediterranean Tethys and Paratethys: Stratigraphic Correlation Tables and Sediment Distribution Maps*, Steininger, F.F. and Seneš, J., Eds., Univ. Wien, Paläontol. Inst, 1985.
- Neogenovaya sistema (Stratigrafiya SSSR)* (Neogene System (Stratigraphy of the USSR)), Moscow: Nedra, 1986, vol. 2.
- Nevesskaya, L.A. and Stevanovic, P.M., Pontian Stage of development of the Paratethys, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1985, no. 9, pp. 36–51.
- Nevesskaya, L.A., Bogdanowicz, A.K., Vyalov, O.S., Zhizhchenko, B.P., Il'ina, L.B., Nosovskii, M.F., and Paramonova, N.P., Stage scale of Neogene deposits in the south of the USSR, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1975, no. 2, pp. 104–120.
- Nevesskaya, L.A., Goncharova, I.A., Il'ina, L.B., Paramonova, N.P., Popov, S.V., Bogdanowicz, A.K., Gabuniya, L.K., and Nosovskii, M.F., Regional stratigraphic scale of the Neogene of the Eastern Paratethys, *Sov. Geol.*, 1984, no. 9, pp. 37–49.
- Nevesskaya, L.A., Goncharova, I.A., Il'ina, L.B., Paramonova, N.P., Popov, S.V., Babak, E.V., Bagdasaryan, K.G., and Voronina, A.A., History of Neogene mollusks of the Paratethys, in *Tr. Paleontol. Inst. Akad. Nauk SSSR* (Trans. Paleontol. Inst. USSR Acad. Sci.), 1986, vol. 220, pp. 1–208.
- Nevesskaya, L.A., Goncharova, I.A., Paramonova, N.P., Popov, S.V., et al., Key to Miocene bivalve mollusks of Southwestern Eurasia, in *Tr. Paleontol. Inst. Akad. Nauk SSSR* (Trans. Paleontol. Inst. USSR Acad. Sci.), 1993, vol. 247, pp. 1–412.
- Nevesskaya, L.A., Paramonova, N.P., and Babak, E.V., Key to Pliocene bivalve mollusks from Southwestern Eurasia, in *Tr. Paleontol. Inst. Akad. Nauk SSSR* (Trans. Paleontol. Inst. USSR Acad. Sci.), 1997, vol. 269, pp. 1–267.
- Nevesskaya, L.A., Paramonova, N.P., and Popov, S.V., History of Lymnocypridae (Bivalvia, Cypridae), *Paleontol. J.*, 2001, vol. 35, Suppl. 3, pp. S147–S217.

- Nevesskaya, L.A., Goncharova, I.A., Il'ina, L.B., et al., The Neogene Stratigraphic Scale of the Eastern Paratethys, *Stratigr. Geol. Correl.*, 2003, vol. 11, no. 2, pp. 105–127.
- Nevesskaya, L.A., Kovalenko, E.I., Beluzhenko, E.V., Popov, S.V., Goncharova, I.A., et al., *Ob'yasnitel'naya zapiska k unifikirovannoi regional'noi stratigraficheskoi skheme neogenovykh otlozhenii yuzhnykh regionov evropeiskoi chasti Rossii* (Explanatory Note to the Unified Regional Stratigraphic Scheme of Neogene Deposits in the Southern Regions of the European Part of Russia), Moscow: Paleontol. Inst. Rus. Akad. Nauk, 2004.
- Nevesskaya, L.A., Goncharova, I.A., and Il'ina, L.B., Types of Neogene marine and nonmarine basins exemplified by the Eastern Paratethys, *Paleontol. J.*, 2005, vol. 39, no. 3, pp. 227–235.
- Nosovskii, M.F., Equivalents of chronostratigraphic stages of the Neogene of the Mediterranean in the Miocene and Pliocene of the Kerch Peninsula, *Geol. Razved.*, 1998, no. 5, pp. 29–34.
- Nosovskii, M.F., On the age of the Tarkhanian Regional Stage and its position in the Neogene Paratethys scale, *Izv. Vyssh. Uch. Zaved., Geol. Razved.*, 2001, no. 3, pp. 137–139.
- Nosovsky, M.F. and Bogdanowicz, A.K., The Caucasian—a new regional stage of the Eastern Paratethys, in *Ann. Geol. Pays Hell, Proc. 7th Int. Congr. Mediter. Neogene*, Athens, 1979, vol. 2, pp. 899–907.
- Nosovskii, M.F. and Bogdanowicz, A.K., Caucasian Regional Stage of the Lower Miocene of the Eastern Paratethys, in *Stratigrafiya kainozoya Severnogo Prichernomor'ya i Kryma* (Stratigraphy of the Cenozoic of the Northern Black Sea Region and Crimea), Dnepropetrovsk: Izd. Dnepropetr. Univ., 1980, pp. 3–8.
- Nosovskii, M.F. and Bogdanowicz, E.M., On the problem of correlation of the Tarkhanian Regional Stage based on nannoplankton, *Dokl. Akad. Nauk SSSR*, 1984, vol. 275, no. 2, pp. 440–441.
- Nosovskii, M.F. and Ivanova, T.A., On the problem of age and correlation of the Tarkhanian Regional Stage of the Eastern Paratethys, *Byull. Mosk. Obshch. Ispyt. Prir., Otd. Geol.*, 2005, vol. 80, no. 2, pp. 68–73.
- Nosovskii, M.F., Barg, I.M., Pishvanova, L.S., and Andreeva-Grigorovich, A.S., On the volume of the Tarkhanian Stage in the south of the USSR, in *Stratigrafiya kainozoya Severnogo Prichernomor'ya i Kryma* (Stratigraphy of the Cenozoic of the Northern Black Sea Region and Crimea), Dnepropetrovsk: Izd. Dnepropetr. Univ., 1976, pp. 22–31.
- Nosovskii, M.F., Barg, I.M., and Konenkova, I.D., Stratigraphy of Miocene deposits of the Kerch Peninsula, in *Stratigrafiya kainozoya Severnogo Prichernomor'ya i Kryma* (Stratigraphy of the Cenozoic of the Northern Black Sea and Crimea), Dnepropetrovsk: Izd. Dnepropetr. Univ., 1978, pp. 10–21.
- Okada, H. and Bukry, D., Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973, 1975), *Mar. Micropaleontol.*, 1980, vol. 5, pp. 321–325.
- Osipov, S.S., Karaganian and Konkian stage, in *Rukovodstvo k iskopayemye neftenosnykh raionov Krymsko-Kavkazskoi oblasti* (Leading Fossils of Oil-bearing Areas of the Crimean–Caucasian Region), Moscow: Otd. Nauchno-Tekh. Inf., 1932, vol. 3/4.
- Ovechkina, M.N., Calcareous nannoplankton of the Upper Cretaceous (Campanian and Maastrichtian) in the south and east of the Russian Platform, in *Tr. Paleontol. Inst. Akad. Nauk SSSR* (Trans. Paleontol. Inst. USSR Acad. Sci.), 2007, vol. 288, pp. 1–352.
- Ozdínová, J., Soták Oligocene–Early Miocene planktonic microbiostratigraphy and paleoenvironments of the South Slovakian Basin (Lučenec Depression), *Geol. Carpathica*, 2014, vol. 65, no. 6, pp. 451–470.
- Paillard, D., Labeyrie, L., and Yiou, P., Macintosh program performs timeseries analysis, *Trans. Am. Geophys. Union.*, 1996, vol. 77, p. 379.
- Palcu, D., Tulbure, M., Bartol, M., Kouwenhoven, T.J., and Krijgsman, W., The Badenian–Sarmatian extinction event in the Carpathian foredeep basin of Romania: paleogeographic changes in the Paratethys domain, *Global Planet. Change*, 2015, vol. 133, pp. 346–358.
- Palcu, D., Golovina, L.A., Vernyhorova, Y.V., Popov, S.V., and Krijgsman, W., Middle Miocene paleoenvironmental crises in Central Europe caused by changes in Paratethys gateway configuration, *Global Planet. Change*, 2017, vol. 158, pp. 57–71.
- Palcu, D.V., Popov, S.V., Golovina, L.A., Kuiper, K.F., Liu, S., and Krijgsman, W., The shutdown of an anoxic giant: magnetostratigraphic dating of the end of the Maikopian Sea, *Gondwana Res.*, 2019a, vol. 67, pp. 82–100.
- Palcu, D.V., Vasiliev, I., Stoica, M., and Krijgsman, W., The end of the great Khersonian drying of Eurasia: magnetostratigraphic dating of the Maeotian transgression in the Eastern Paratethys, *Basin Res.*, 2019b, vol. 31, pp. 33–58.
- Palcu, D.V., Patina, I.S., Şandric, I., Lazarev, S., Vasiliev, I., Stoica, M., and Krijgsman, W., Multiple mega-lake desiccations spark the late Miocene rise of open landscapes in Central Eurasia, *Proc. Natl. Acad. Sci.*, 2021 (in press).
- Palibin, I.V., Sarmatian flora of Eastern Georgia, in *Mater. Tsent. Nauchno-issled. Geol. Razved. Inst. Paleontol. Stratigr.* (Mater. Centr. Sci. Res. Geol. Explor. Inst. Paleontol. Stratigr.), 1933, pp. 25–43.
- Papaianopol, J., Studiul stratigrafic al neogenului din molasă pericarpatica, *Extended Abstract of Doctoral Dissertation*, Al. I. Cuza University, Iaşi, 1992.
- Papaianopol, I., Paleobiogeography of Dacian mollusca on the Moesian platform, *Rom. J. Paleontol.*, 1995, vol. 76, pp. 121–126.
- Papp, A. and Schmid, M.E., Die fossilen Foraminiferen des Tertiären Beckens von Wien: Revision der Monographie von Alcide d'Orbigny (1846), *Abh. Geol. Bundesanst.*, vol. 37, 1985, pp. 1–311.
- Paramonova, N.P., History of Sarmatian and Akchagylia mollusks, in *Tr. Paleontol. Inst. Akad. Nauk SSSR* (Trans. Paleontol. Inst. USSR Acad. Sci.), 1994, vol. 260, pp. 1–212.
- Paramonova, N.P. and Belokry, L.S., On the volume of the Sarmatian Stage, *Byull. Mosk. Obshch. Ispyt. Prir., Otd. Geol.*, 1972, vol. 47, no. 3, pp. 36–47.
- Pashkov, G.D., On a new find of Neogene flora in the Northern Caucasus, *Bot. Zh.*, 1959, vol. 49, no. 5, pp. 659–660.
- Pashkov, G.D., Finds of new plants of the Sarmatian flora of Western Ciscaucasia, *Bot. Zh.*, 1965, vol. 50, no. 8, pp. 37–49.

- Percival, S.F., Indigenous and reworked coccoliths from the Black Sea, *Initial Rep. Deep Sea Dril. Proj.*, Washington: U.S. Govern. Print. Off., 1978, pp. 773–781.
- Pevzner, M.A., Stratigraphy of the Middle Miocene–Pliocene of the South of Europe (based on paleomagnetic data), *Doctoral (Geol.–Mineral.) Dissertation*, Moscow: Geol. Inst. Akad. Nauk SSSR, 1986.
- Pevzner, M.A. and Chikovani, A.A., Paleomagnetic studies of Upper Miocene and Lower Pliocene marine deposits of the Taman Peninsula, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1978, no. 8, pp. 61–66.
- Pevzner, M.A., Vangengeim, E.A., and Semenenko, V.N., Position of the Pontian of the Eastern Paratethys in the magnetostratigraphic scale, *Stratigr. Geol. Correl.*, 2003, vol. 11, no. 5, pp. 482–491.
- Pevzner, M.A., Semenenko, V.N., Vangengeim, E.A., Sadchikova, T.A., Kovalenko, V.A., and Lyul'eva, S.A., On the Marine genesis and pontian age of deposits from the Lyubimovka reference section in the Crimea, *Stratigr. Geol. Correl.*, 2004, vol. 12, no. 5, pp. 523–533.
- Pilipenko, O.V. and Trubikhin, V.M., Petromagnetic and magnetostratigraphic studies of Upper Sarmatian deposits of the Popov Kamen reference section (Taman Peninsula), *Vestn. Uchebno-Nauchn. Tsentra. Nauki Zemle*, 2014, no. 24, pp. 85–94.
- Piller, W.E., Harzhauser, M., and Mandic, O., Miocene Central Paratethys stratigraphy: Current status and future directions, *Stratigraphy*, 2007, vol. 4, pp. 151–168.
- Pimenova, N.V., Poltava sands and Poltava Stage of the Dnieper–Donetsk depression, *Sov. Geol.*, 1941, no. 1, pp. 14–22.
- Pimenova, N.V., Sarmatian Flora of Amvrosievka, *Trudy Inst. Geol. Nauk Akad. Nauk Ukr. SSR. Ser. Stratigr. Paleontol.*, 1954, vol. 8, pp. 1–96.
- Pinchuk, T.N., Biostratigraphy of the Cenozoic of Russia and neighboring regions based on foraminifers: Western Caucasus and Ciscaucasia (Oligocene and Neogene), in *Prakticheskoe rukovodstvo po mikrofaune SSSR. Foraminifery kainozoya* (Practical Guide to the Microfauna of the USSR. Cenozoic Foraminifers), St. Petersburg: Nedra, 2006, pp. 91–98.
- Pinchuk, T.N., Changes in Early Miocene foraminiferal assemblages in the Belaya River section (Western Ciscaucasia), in *Tr. XVII Vseross. Mikropaleontol. Soveshch. "Sovremennaya mikropaleontologiya—problemy i perspektivy"* (Proc. 17th All-Russ. Micropaleontol. Conf. "Modern Micropaleontology: Problems and Prospects"), Moscow: Paleontol. Inst. Ross. Akad. Nauk, 2018, pp. 106–109.
- Pinchuk, T.N., Foraminifers of the Taman Peninsula, in *Sovremennyye problemy stratigrafii neogena i kvartera Rossii* (Modern Problems of Stratigraphy of the Neogene and Quaternary of Russia), Moscow: GEOS, 2011, pp. 76–84.
- Pinchuk, T.N., Planktonic foraminifers of Karaganian deposits of Western Ciscaucasia, in *Mater. 38 Sess. Paleontol. Obshch. Nats. Akad. Nauk Ukr.* (Proc. 38th Sess. Paleontol. Natl. Acad. Sci. Ukr.), Kiev: Inst. Geol. Nauk, 2017, pp. 133–134.
- Pisera, A., Miocene reefs of the Paratethys: a review, in *Models for Carbonate Stratigraphy from Miocene Reef Complexes of Mediterranean Regions*, Franseen, E.K., et al., Eds., Tulsa, 1996, pp. 97–104 (*SEPM Concepts in Sediment. Paleontol.*, vol. 5).
- Pobedina, V.M., Voroshilova, A.G., Rybina, O.I., and Kuznetsova, Z.V., *Spravochnik po mikrofaune Azerbaidzhana* (Handbook on the Microfauna of Azerbaijan), Baku: Neft. Nauchno-Tekh. Lit., 1956.
- Pontien, *Chronostratigraphie und Neostatotypen Neogen der Westlichen ("Zentrale") Paratethys*, Vol. 8, Zagreb–Beograd: JAZU et SANU, 1989.
- Popescu, S.-M., Late Miocene and early Pliocene environments in the southwestern Black Sea region from high-resolution palynology of DSDP Site 380A (leg 42B), *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2006, vol. 238, pp. 64–77.
- Popescu, G. and Crihan, I.-M., Middle Miocene globigerinids of Romania, *Acta Palaeontol. Rom.*, 2011, vol. 7, pp. 291–314.
- Popescu, S.-M., Suc, J.-P., and Loutre, M.-F., Early Pliocene vegetation changes forced by eccentricity–precession. Example from Southwestern Romania, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2006, vol. 238, pp. 340–348.
- Popescu, S.-M., Dalesme, F., Jouannic, G., Escarguel, G., Head, M.J., Melinte-Dobrinescu, M.C., Suto-Szentai, M., Clauzon, G., and Suc, J.-P., *Galeacysta etrusca* complex: dinoflagellate cyst marker of Paratethyan influxes to the Mediterranean Sea before and after the peak of the Messinian salinity crisis, *Palynology*, 2009, vol. 33, no. 2, pp. 105–134.
- Popescu, S.-M., Biltekin, D., Winter, H., Suc, J.-P., Melinte-Dobrinescu, M.C., Klotz, S., Combourieu-Nebout, N., Rabineau, M., Clauzon, G., and Deaconu, F., Pliocene and Lower Pleistocene vegetation and climate changes at the European scale: long pollen records and climatostratigraphy, *Quat. Int.*, 2010, vol. 219, pp. 152–167.
- Popescu, S.-M., Melinte-Dobrinescu, M. C., Suc, J.-P., Comment objective utilization of data from DSDP Site 380 (Black Sea), *Terra Nova*, 2016, vol. 28, no 3, pp. 228–229.
- Popov, S.V., Mollusks of Kotsakhurian deposits of the Kartli depression, *Paleontol. Zh.*, 1983, no. 3, pp. 29–38.
- Popov, S.V. and Nevesskaya, L.A., Brackish-water Late Miocene mollusks and the history of the Aegean basin, *Stratigr. Geol. Correl.*, 2000, vol. 8, no. 2, pp. 195–205.
- Popov, S.V. and Voronina, A.A., Kotsakhurian Stage of development of the Eastern Paratethys, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1983, no. 1, pp. 58–67.
- Popov, S.V. and Zastrozhnov, A.S., *Opornye razrezy neogena Vostochnogo Paratetisa (Tamanskii poluostrov). Putevoditel' ekskursii* (Reference Sections of the Neogene of the Eastern Paratethys (Taman Peninsula). Excursion Guide), Volgograd–Taman, 1998.
- Popov, S.V., Akhmetiev, M.A., Zaporozhets, N.I., et al., History of the Eastern Paratethys in the Late Eocene–Early Miocene, *Stratigr. Geol. Korrel.*, 1993a, vol. 1, no. 6, pp. 10–39.
- Popov, S.V., Voronina, A.A., and Goncharova, I.A., *Stratigrafiya i dvustvorchatye mollyuski oligotsena–nizhnego miotsena Vostochnogo Paratetisa* (Stratigraphy and Bivalves of the Oligocene–Lower Miocene of the Eastern Paratethys), Moscow: Nauka, 1993b (Tr. Paleontol. Inst. Ross. Akad. Nauk, vol. 256).
- Popov, S.V., Goncharova, I.A., Kozyrenko, T.F., et al., Neogene Stratigraphy and Palaeontology of the Taman and Kerch peninsulas, in *Excursion Guidebook*, Moscow: Paleontol. Inst. Ross. Akad. Nauk, 1996.

- Popov, S.V., Bugrova, E.M., Amitrov, O.V., et al., Biogeography of the northern Peri-Tethys from the Late Eocene to the Early Miocene. Pt. 3. Late Oligocene–Early Miocene. Marine basins, *Paleontol. J.*, 2004a, vol. 38, Suppl. 6, pp. S653–S716.
- Popov, S.V., Ilyina, L.B., Paramonova, N.P., Goncharova, I.A., et al., Lithological–Paleogeographic maps of Paratethys, *Cour. Forschungsinst. Senckenberg.*, 2004b, vol. 250, pp. 1–46.
- Popov, S.V., Nevesskaya, L.A., Goncharova, I.A., and Il'ina, L.B., Biogeography of the Eastern Paratethys in the Neogene based on mollusks, in *Biosfera–Ekosistema–Biota v proshlom Zemli: paleobiogeograficheskie aspekty* (Biosphere–Ecosystem–Biota in the Past of the Earth: Paleobiogeographical Aspects), Moscow: Nauka, 2005, pp. 309–337.
- Popov, S.V., Sychevskaya, E.K., Akhmetiev, M.A., Zaporozhets, N.I., and Golovina, L.A., Stratigraphy of the Maikopian Group and Pteropoda Beds in Northern Azerbaijan, *Stratigr. Geol. Correl.*, 2008, vol. 16, no. 6, pp. 664–677.
- Popov, S.V., Akhmetiev, M.A., Lopatin, A.V., Bugrova, E.M., Sychevskaya, E.K., Shcherba, I.G., and Kopp, M.L., Paleogeography and Biogeography of Paratethys Basins. Part 1: Late Eocene–Early Miocene, in *Tr. Paleontol. Inst. Ross. Akad. Nauk* (Trans. Paleontol. Inst. Russ. Acad. Sci.), 2009a, vol. 292, pp. 1–178.
- Popov, S.V., Vernigorova, Yu.V., Goncharova, I.A., and Pinchuk, T.N., Stratigraphy of Middle–Upper Miocene sections of Taman based on mollusks and foraminifers, in *Aktual'nye problemy neogen–chetvert. stratigr. i ikh obsuzhdenie na 33 Mezhdunarod. Geol. Kongr.* (Topical Problems of Neogen–Quaternary Stratigraphy and Their Discussion at 33th Int. Congr.), Moscow: GEOS, 2009b, pp. 96–100.
- Popov, S.V., Antipov, M.P., Zastrozhnov, A.S., Kurina, E.E., and Pinchuk, T.N., Sea level fluctuations on the northern shelf of the Eastern Paratethys in the Oligocene–Neogene, *Stratigr. Geol. Correl.*, 2010, vol. 18, no. 2, pp. 200–224.
- Popov, S.V., Akhmetiev, M.A., Golovina, L.A., Goncharova, I.A., Radionova, E.P., Filippova, N.Yu., and Trubikhin, V.M., Regional Stage stratigraphic scale of the Neogene of the southern part of Russia: state and prospects, in *Vseross. Konf. "Obshchaya stratigraficheskaya shkala Rossii: sostoyaniye i perspektivy obustroystva"* (All-Russ. Conf. "General Stratigraphic Scale of Russia: State and Prospects of Development"), Moscow, May 23–25, 2013, *Geol. Inst. Ross. Akad. Nauk, St. Petersburg: LEMA*, 2013a, pp. 356–359.
- Popov, S.V., Filippova, N.Yu., Golovina, L.A., Goncharova, I.A., Radionova, E.P., Tesakov, A.S., and Trubichin, V.M., Eastern Paratethys stratigraphic scale of Neogene: correlation possibilities, *14th Congr. Reg. Com. Mediter. Neogene Stratigr., Abstr., Neogene to Quaternary Geolical Evolution of Mediterranean, Paratethys and Black Sea*, Istanbul. Sept. 8–12, 2013b, p. 209.
- Popov, S.V., Golovina, L.A., and Goncharova, I.A., Miocene deposits, mollusks, and calcareous nannofossils of the Eastern Paratethys in Northern Iran, in *Stratigraficheskie i paleogeograficheskie problemy neogena i kvartera Rossii* (Stratigraphic and Paleogeographic Problems of the Neogene and Quaternary of Russia), Moscow: GEOS, 2015, pp. 34–38.
- Popov, S.V., Rostovtseva, Yu.V., Filipova, N.Yu., et al., Paleontology and stratigraphy of the Middle–Upper Miocene of the Taman Peninsula. Pt. 1. Description of key-sections and benthic fossil groups, *Paleontol. J.*, 2016, vol. 50, no. 10, pp. 1039–1206.
- Popov, S.V., Golovina, L.A., Radionova, E.P., Goncharova, I.A., Filippova, N.Yu., Rostovtseva, Yu.V., and Palcu, D., Stratotypes and reference sections of Neogene regional stages in the south of Russia and problems of their boundaries, in *Neogen i kvarter Rossii: stratigrafiya, sobytiya i paleogeografiya* (Neogene and Quaternary of Russia: Stratigraphy, Events, and Paleogeography), Moscow: GEOS, 2018, pp. 47–54.
- Popov, S.V., Tabachnikova, I.P., Bannikov, A.F., Sychevskaya, E.K., Pinchuk, T.N., Akhmetiev, M.A., Zaporozhets, N.I., Boon, A., Kraishman, V., Stolyarov, A.S., and Krkhovski, Ya., Lectostratotype of the Maikopian Group in the Belaya River Section Upstream of the Town of Maikopian (Western Ciscaucasia) in the Oligocene Part, *Stratigr. Geol. Correl.*, 2019, vol. 27, no. 3, pp. 339–360.
- Prakticheskaya palinostratigrafiya* (Practical Palynostratigraphy), Panova, L.A., Oshurkova, M.V., and Romanovskaya, G.M., Eds., Leningrad: Nauka, 1990.
- Prisyazhnyuk, V.A., Lyul'eva, S.A., Slivinskaya, G.V., and Syabryai, S.V., Paleontological and geophysical characteristics of Pontian deposits in the reference section of the village of Vinogradovka (Northern Black Sea region), *Dokl. Akad. Nauk Ukr. SSR, Ser. B*, 1994, no. 7, pp. 99–103.
- Prisyazhnyuk, V.A., Lyul'eva, S.A., and Syabryai, S.V., New data on the paleontology and stratigraphy of Miocene deposits of the Ustechkivsky graben in Volhynia-Podolia, *Geol. Zh.*, 1997, nos. 1–2, pp. 57–64.
- Prisyazhnyuk, V.A., Kovalenko, V.A., Lyul'eva, S.A., and Syabryai, S.V., Section of Sarmatian deposits in the Mikhailovsky quarry—the unique point of direct correlation of marine and continental deposits, *Geol. Zh.*, 2006, no. 1, pp. 64–75.
- Prokopov, K.A., Alkun-Assinsk area (Ingushetia, Northern Caucasus), in *Geologicheskie issledovaniya v Chernykh gorakh Terskoi neftenosnoi oblasti* (Geological Studies in the Black Mountains of the Terek Oil-bearing Area), *Tr. Groznefti*, 1937a, no. 5, pp. 27–73.
- Prokopov, K.A., Essay on geological formations along the Kuban River between Sulimov and Krasnogorskaya, *Trudy Geol. Sluzhby Groznefti*, 1937b, no. 6, pp. 30–63.
- Prokopov, K.A., A brief outline of Upper Paleogene and Lower Miocene deposits of the Northern Caucasus, *Trudy Neft. Geol.-Razved., Ser. A*, 1938, vol. 104 (Study of the Maikopian Formation in the Northern Caucasus), pp. 3–14.
- Pronin, K.K. and Kalinichenko, G.P., Nannoplankton in the lectostratotype of the Pontian stage near the city of Odessa, *Dokl. Akad. Nauk Ukr. SSR. Ser. B*, Kiev, 1988, vol. 5, pp. 13–15.
- Pronina, M.T., Middle Miocene deposits with the fauna of new *Rotalia* species of the Dzhebrailsky area (Azerbaijan), *Izv. Akad. Nauk Azerb. SSR, Ser. Geol.–Geogr. Nauki, Baku*, 1959, vol. 1, pp. 55–61.
- Radionova, E.P. and Golovina, L.A., New data on the study of diatoms and calcareous nannofossils from Maeotian–Pontian deposits of the Taman Peninsula, in *Problemy Stratigrafii Fanerozoia Ukrainy. Tr. Inst. Geol. Nauk Nats. Akad. Nauk Ukr.* (Problems of the Stratigraphy of the Phanerozoic of Ukraine. Proc. Inst. Geol. Sci Natl. Acad. Sci. Ukr.), Kiev, 2004, pp. 180–184.

- Radionova, E.P. and Golovina, L.A., Upper Maeotian–Lower Pontian “Transitional Strata” in the Taman Peninsula: Stratigraphic position and paleogeographic interpretations, *Geol. Carpathica*, 2011, vol. 62, no. 1, pp. 77–90.
- Radionova, E.P., Golovina, L.A., Filippova, N.Yu., Trubikhin, V.M., Popov, S.V., Goncharova, I.A., Vernigoreva, Yu.V., and Pinchuk, T.N., Middle–Upper Miocene stratigraphy of the Taman Peninsula, Eastern Paratethys, *Cent. Eur. J. Geosci.*, 2012, vol. 4, no. 1, pp. 188–204.
- Raffi, I., Precision and accuracy of nannofossil biostratigraphic correlation, *Philos. Trans. R. Soc., A*, 1999, vol. 357, pp. 1975–1993.
- Raffi, I., Backman, J., Fornaciari, E., Palike, H., Rio, D., Lourens, L., and Hilgen, F., A review of calcareous nannofossil astrobiochronology encompassing the past 25 million years, *Quat. Sci. Rev.*, 2006, vol. 25, pp. 3113–3137.
- Raffi, I., Agnini, C., Backman, J., Catanzariti, R., and Palike, H., A Cenozoic calcareous nannofossil biozonation from low and middle latitudes: a synthesis, *Nannoplankton Res.*, 2016, vol. 36, *Proc. Int. 15th Int. Neonatol. Assoc. Conf.*, Bohol, Philippines, pp. 121–132.
- Ratiani, N.K., On the history of some Tertiary relics of floras of Western Georgia, *Tr. Sukhum. Bot. Sada*, 1975, no. 21, pp. 54–69.
- Richards, K., Studies in Caspian palynology: Six million years of vegetation, climate and sea level change, *Doctoral Dissertation*, Amsterdam, 2018.
- Rio, D., Sprovieri, R., and Raffi, I., Calcareous plankton stratigraphy and biochronology of the Pliocene–lower Pleistocene succession of the Capo Rossello area, Sicily, *Mar. Micropaleontol.*, 1984, vol. 9, pp. 135–180.
- Rögl, F., On the Pontian Correlation in the Aegean (Aegina Island), *Newsl. Stratigr.* 1991. vol. 24. no 3. pp. 137–158.
- Rögl, F. and Nagymarosy, A., Biostratigraphy and correlation of the Lower Miocene Michelstetten and Ernstbrunn sections in the Waschberg Unit, Austria (Upper Egerian to Eggenburgian, Central Paratethys), *Cour. Forsh.-Inst. Senckenberg.*, 2004, vol. 246, pp. 129–151.
- Rögl, F., Spezzaferri, S., and Čorič, S.S., Micropaleontology and biostratigraphy of the Karpatian–Badenian transition (Early–Middle Miocene boundary) in Austria (Central Paratethys), *Cour. Forschungsinst. Senckenberg.*, 2002, vol. 237, pp. 47–67.
- Rögl, F., Čorič, S.S., Hohenegger, J., Pervesler, P., Roetzel, R., Scholger, R., Spezzaferri, S., and Stingl, K., Cyclostratigraphy and transgressions at the Early/Middle Miocene (Karpatian/Badenian) Boundary in the Austrian Neogene Basins (Central Paratethys), *Scr. Sci. Geol.*, 2007, vol. 36, *Natl. Masaryk. Univ.*, Brno, pp. 7–13.
- Rostovtseva, Yu.V., Middle Sarmatian facies of the Taman Trough, *Lithol. Miner. Resour.*, 2009a, vol. 44, no. 4, pp. 367–378.
- Rostovtseva, Yu.V., Lower Meotian facies of the Taman trough, *Lithol. Miner. Resour.*, 2009b, vol. 44, no. 5, pp. 451–464.
- Rostovtseva, Yu.V., Upper Meotian facies of the Taman Trough, *Lithol. Miner. Resour.*, 2009c, vol. 44, no. 6, pp. 531–543.
- Rostovtseva, Yu.V., Sedimentogenesis in the basins of the Middle and Late Miocene of the Eastern Paratethys (stratotype Kerch–Taman region), *Doctoral (Geol.–Mineral.) Dissertation*, 2012.
- Rostovtseva, Yu.V. and Goncharova, I.A., Structure of relatively deep-water deposits of the Lower Maeotian of the Black Sea region (Taman Peninsula: section of Cape Popov Kamen), in *Biostratigraficheskie osnovy postroeniya stratigraficheskikh skhem Ukrainy. Sb. Nauchn. Trudov Inst. Geol. Nauk Nats. Akad. Nauk Ukr.* (Biostratigraphic Bases for Constructing Stratigraphic Schemes of Ukraine. Coll. Sci. Works Inst. Geol. Sci. Natl. Acad. Sci. Ukr.), Kiev, 2008, pp. 270–275.
- Rostovtseva, Yu.V. and Kosorukov, V.L., Clay minerals in Middle–Upper Miocene deposits of the Taman trough: composition and paleogeographic significance, *Lithol. Miner. Resour.*, 2012, vol. 47, no. 3, pp. 234–252.
- Rostovtseva, Yu.V. and Kozyrenko, T.F., Geological-lithological features of Late Miocene diatom sedimentation in the Kerch–Taman Depression, *Vestn. Mosk. Univ.*, Ser. 4., 2006, no. 4, pp. 20–29.
- Rostovtseva, Yu.V. and Rybkina, A.I., Cyclostratigraphy of Pontian deposits of the Eastern Paratethys (Zheleznyi Rog section, Taman Region), *Moscow Univ. Geol. Bull.*, 2014, vol. 69, no. 4, pp. 236–241.
- Rostovtseva, Yu.V. and Rybkina, A.I., The Messinian event in the Paratethys: Astronomical tuning of the Black Sea Pontian, *Mar. Pet. Geol.*, 2017, vol. 80, pp. 321–332.
- Rostovtseva, Yu.V., Koiava, K.P., and Rybkina, A.I., The Cyclostratigraphy of the Konkian Deposits of Eastern Georgia (Eastern Paratethys, Kura Basin), *Moscow Univ. Geol. Bull.*, 2020, vol. 75, no. 6, pp. 579–588.
- Roveri, M., Flecker, R., Krijgsman, W., Lofi, J., Lugli, S., Manzi, V., Sierro, F.J., Bertini, A., Camerlenghi, A., Lange de, G., Govers, R., Hilgen, F.J., Hübner, C., Meijer, P.T., and Stoica, M., The Messinian Salinity Crisis: Past and future of a great challenge for marine sciences, *Mar. Geol.*, 2014, vol. 352, pp. 25–58.
- Rückert-Ülkümen, N., Carangidae, Priacanthidae, Scorpaenidae und Sparidae (Pisces) aus den sarmatischen Schichten von Pinarhisar (Thrakien, Türkei), *Mitt. Bayer. Staatssaml. Paläontol. Hist. Geol.*, 1995, vol. 35, pp. 65–86.
- Rybkina, A.I. and Rostovtseva, Yu.V., Astronomically-tuned cyclicity in Upper Maeotian deposits of the eastern paratethys (Zheleznyi Rog section, Taman), *Moscow Univ. Geol. Bull.*, 2014, vol. 69, no. 4. pp. 341–346.
- Rybkina, A.I., Kern, A.N., and Rostovtseva, Yu.V., New evidence of the age of the lower Maeotian substage of the Eastern Paratethys based on astronomical cycles, *Sediment. Geol.*, 2015, vol. 330, pp. 122–131.
- Satanovskaya, Z.N., New locality of Chokrakian foraminifers in the Northern Black Sea region, *Geol. Zh.*, Kiev, 1994, nos. 4–6, pp. 67–72.
- Savopulo, S.A., Babarykina, K.A., et al., *Obobshchenie rezul'tatov poiskovykh i razvedochnykh rabot v predelakh perspektivnykh regionov Krasnodarskogo kraia (ploshchad' Kubanskaya, skv. sputnik № 2, SG-12 000)* (Generalization of the Results of Studies and Prospecting and Exploration within the Promising Regions of Krasnodar Region (Kubanskaya Area, Borehole: Sputnik no. 2, SG-12 000), Krasnodar, 1991.
- Schulz, M. and Mudelsee, M., REDFIT: Estimating red-noise spectra directly from unevenly spaced paleoclimatic time series, *Comp. Geosci.*, 2002, vol. 28, pp. 421–426.
- Semenenko, V.N., Geology and stratigraphy of Kimmerian and Kuyalnikian deposits of the Northern Cis-Azov region,

Extended Abstract of Cand. Sci. (Geol.—Mineral.) Dissertation, Odessa, 1966.

Semenenko, V.N., *Stratigraficheskaya korrelyatsiya verkhnego miotsena i pliotsena Vostochnogo Paratetisa i Tetisa* (Stratigraphic Correlation of the Upper Miocene and Pliocene of the Eastern Paratethys and Tethys), Kiev: Naukova Dumka, 1987.

Semenenko, V.N., Pliocene of Crimea. Pliocene of the Black Sea depression, in *Stratigrafiya USSR. T. 10. Neogen* (Stratigraphy of the Ukrainian SSR, vol. 10: Neogene), Kiev: Naukova Dumka, 1975, pp. 24–31, 70–81.

Semenenko, V.N. and Lyul'eva, S.A., Experience of direct correlation of the Mio–Pliocene of the Eastern Paratethys and Tethys, in *Stratigrafiya kainozoya Severnogo Prichernomor'ya i Kryma. Vyp. 2* (Stratigraphy of the Cenozoic of the Northern Black Sea Region and Crimea), Dnepropetrovsk: Izd. Dnepropetr. Univ., 1978, pp. 95–105.

Semenenko, V.N. and Lyul'eva, S.A., Problems of Direct Correlation of the Upper Miocene and Pliocene of the Eastern Paratethys and Tethys, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1982, no. 9, pp. 61–70.

Semenenko, V.N. and Lyul'eva, S.A., Global marker of the Miocene–Pliocene boundary of *Ceratolithus acutus* (nanoplankton) in the Black Sea basin, *Geol. Zh.*, 2006, no. 2–3, pp. 150–159.

Semenenko, V.N. and Pevzner, M.A., Correlation of the Upper Miocene and Pliocene of the Pontian–Caspian based on biostratigraphic and paleomagnetic data, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1979, no. 1, pp. 5–15.

Semenenko, V.N., Lyul'eva, S.A., Mos'kina, O.D., and Matsui, V.M., New data on Pontian deposits of southwestern Crimea, *Dokl. Nats. Akad. Nauk Ukr.*, 1999, no. 6, pp. 132–138.

Semenenko, V.N., Andreeva-Grigorovich, A.S., Maslun, N.V., and Lyul'eva, S.A., Direct correlation of the Eastern Paratethys Neogene with the International Oceanic scale based on planktonic microfossils, *Geol. Zh.*, 2009, no. 4, pp. 9–27.

Seneš, J., Regional stages of the Central Paratethys Neogene and the definition of their lower boundaries, in *Proc. 6 Congr. RCMNS*, Veda: Bratislava, 1975, pp. 259–265.

Shackleton, N.J., Hall, M.A., and Pate, D., Pliocene stable isotope stratigraphy of Site 846, *Proc. Ocean Drill. Program: Sci. Results*, 1995, vol. 138, pp. 337–353.

Shackleton, N.J., Crowhurst, S.J., Weedon, G.P., and Laskar, J., Astronomical calibration of Oligocene–Miocene time, *Philos. Trans. R. Soc., A*, 1999, vol. 357, pp. 1907–1929.

Shackleton, N.J., Hall, M.A., Raffi, I., Tauxe, L., and Zachos, J., Astronomical calibration age for the Oligocene–Miocene boundary, *Geology*, 2000, vol. 28, pp. 447–450.

Shtefyrtsa, A.G., Conifers, boxwood, and palm of the Miocene flora of Bursuk in Moldova, *Bot. Zh.*, 1972, vol. 57, no. 4, pp. 458–468.

Shtefyrtsa, A.G., *Rannesarmatskaya flora Bursuka* (Early Sarmatian Flora of Bursuk), Kishinev: Shtiintsa, 1974.

Shtefyrtsa, A.G., Comparative analysis of the Early Sarmatian flora of Bursuk (Republic of Moldova) and paleofloristic assemblages similar in age and locality, *Bot. Zh.*, 1999, vol. 84, no. 9, pp. 1–9.

Shumenko, S.I., Coccoliths from the Tortonian deposits of Moldova, *Dopov. Akad. Nauk Ukr. SSR, Ser. B*, 1975, pp. 512–514.

Shumenko, S.I. and Ushakova, M.G., Calcareous nannofossils in deep-water drilling cores, in *Geologicheskaya istoriya Chernogo morya po rezul'tatam glubokovodnogo bureniya* (Geological History of the Black Sea Based on the Results of Deep-water Drilling), Moscow: Nauka, 1980, pp. 71–73.

Simionescu, J.Th., Contribution a la geologie de la Moldavie, *Ann. Sci. Technol. Innovation Jassi. Univ.*, 1903, vol. 2, Fasc. 3–4, pp. 234–250.

Sintsov, I.F., Description of new and little-studied shell forms from the Tertiary formations of Novorossia. Article 4, *Zap. Novoross. Ob-va Estestvoispyt.*, 1883, vol. 8, no. 2.

Sintsov, I.F., *Gidrogeologicheskoe opisanie odesskogo gradonachal'stva* (Hydrogeological Description of the Odessa City Administration), Odessa: Odess. Gor. Obshchestv. Upr., 1894.

Sintsov, I.F., Report on geological studies performed on behalf of the Novorossian Society of Naturalists in Bessarabia in 1873, *Zap. Novoross. Ob-va Estestvoispyt.*, 1875, vol. 3, no. 1, pp. 31–46.

Snel, E., Marunteanu, M., and Meulenkamp, J.E., Calcareous nannofossil biostratigraphy, magnetostratigraphy of the Upper Miocene and Lower Pliocene of the Northern Aegean, Greece, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2006, vol. 238, pp. 125–150.

Sokolov, N.A., Beds with *Venus konkensis* (Mediterranean sediments on the Konka River, *Tr. Geol. Kom.*, 1899, vol. 9, no. 5.

Spezzaferri, S., Ćorić, S., and Stingl, K., Palaeoenvironmental reconstruction of the Karpatian–Badenian (Late Burdigalian–Early Langhian) transition in the Central Paratethys. A case study from the Wagna Section (Austria), *Acta Geol. Pol.*, 2009, vol. 59, no. 4, pp. 523–544.

Staroverov, V.N. and Zhidovinov, N.Ya., Use of geological event levels in stratigraphy and correlation (based on the example of Akchagylian deposits of the Eastern Paratethys), *Vestn. Voronezh. Univ. Geol.*, 2002, no. 2, pp. 20–27.

Staroverov, V.N., Pervushov, E.M., and Khokhlov, A.E., Features of the structure of Akchagylian deposits in the lower reaches of the Tereshka River (Saratov Right Bank), *Vestn. Voronezh. Univ. Geol.*, 2000, no. (5)10, pp. 210–212.

Stefano Di, A. and Sturiale, G., Refinements of calcareous nannofossil biostratigraphy at the Miocene/Pliocene Boundary in the Mediterranean Region, *Geobios*, 2010, vol. 43, pp. 5–20.

Stefano Di, A., Foresi, L.M., Lirer, F., Iaccarino, S.M., Turco, E., Amore, F.O., Mazzei, R., Morabito, S., Salvatore, G., and Abdul Aziz, H., Calcareous plankton high resolution bio–magnetostratigraphy for the Langhian of the Mediterranean area, *Riv. Ital. Paleontol. Stratigr.*, 2008, vol. 114, no. 1, pp. 51–76.

Steininger, F. and Rögl, F., Stratigraphic correlation of the Tethys–Paratethys Neogene: Project 25, *Geol. Correl., Spec. Iss.*, 1983, pp. 65–66.

Steininger, F.F., Aubry, M.-P., Berggren, W.A., Biolzi, M., Borsetti, A.M., Cartlidge, J.E., et al., The Global Stratotype Section and Point (GSSP) for the base of the Neogene, *Episodes*, 1997, vol. 20, no. 1, pp. 23–28.

- Stevanovic, P.M., *Донђи плиоцен Србије и суседних области*, Belgrad, 1951, Srp. Akad. Nauk Posebna, vol. 187, Geol. Inst., vol. 2.
- Stoica, M., Krijgsman, W., Fortuin, A., and Gliozzi, E., Paratethyan ostracods in the Spanish Lago-Mare: more evidence for interbasinal exchange at high Mediterranean sea level, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2016, vol. 441, pp. 854–870.
- Stoica, M., Lazăr, I., Krijgsman, W., Vasiliev, I., Jipa, D., and Floroiu, A., Paleoenvironmental evolution of the East Carpathian foredeep during the late Miocene–early Pliocene (Dacian Basin; Romania), *Global Planet. Change*, 2013, vol. 103, pp. 135–148.
- Stolyarov, A.S. and Ivleva, E.I., Lower Miocene sediments of the Maikop group in the Central Eastern Paratethys, *Lithol. Miner. Resour.*, 2006, vol. 41, pp. 54–72.
- Stratigraficheskie slovar' SSSR. Paleogen, neogen, chetvertichnaya sistema* (Stratigraphic Dictionary of the USSR. Paleogene, Neogene, and Quaternary System), Leningrad: Nauka, 1982.
- Stratotypes of the Neogene Stages of the Mediterranean*. Vol. 2, Bratislava: Veda, 1975.
- Studencka, B., Gontsharova, I.A., and Popov, S.V., The bivalve faunas as a basis for reconstruction of the Middle Miocene history of the Paratethys, *Acta Geol. Pol.*, 1998, vol. 48, no. 3, pp. 285–342.
- Subbotina, N.N., On a find of foraminifers in the Upper Maikopian in the Northern Caucasus, *Tr. Neft. Geol.-Razved., Ser. B*, 1936, no. 60.
- Subbotina, N.N., Pishvanova, L.S., and Ivanova, L.V., Stratigraphy of Oligocene and Miocene deposits of Ciscarpathia based on foraminifers, in *Tr. Vseross. Neft. Nauchno-Issled. Geol. Inst.* (Trans. All-Russ. Petrol. Res. Explor. Inst.), 1960, no. 153, pp. 6–156.
- Suc, J.-P., Gillet, H., Çağatay, M.N., Popescu, S.-M., Lericolais, G., Armijo, R., Melinte-Dobrinescu, M.C., Şen, Ş., Clauzon, G., Sakinç, M., Zabci, C., Ukarkus, G., Meyer, B., Çakir, Z., Karakaş, Ç., Jouannic, G., and Măcalet, R., The region of the Strandja Sill (North Turkey) and the Messinian events, *Mar. Pet. Geol.*, 2015, vol. 66, pp. 149–164.
- Sudo, M.M., On stages of the development of the Karaganian basin and range of the Karaganian Stage, *Dokl. Akad. Nauk SSSR*, 1961, vol. 139, no. 6, pp. 1442–1444.
- Suess, E., Untersuchungen über den Charakter der österreichischen Tertiärbildungen II. Über die Bedeutung der sogenannten “brackischen Stufe” oder der “Cerithien-schichten,” *Sitzungsber. Akad. Wis., Mathem.-Naturwis. Kl.*, 1866, vol. 54, pp. 218–259.
- Švábenická, L., Calcareous nannofossils of the Upper Karpatian and Lower Badenian deposits in the Carpathian Foredeep, Moravia (Czech Republic), *Geol. Carpathica*, 2002, vol. 53, pp. 197–210.
- Sytchevskaya, E.K., Late Oligocene–Early Miocene history of the ichthyofauna of Eastern Paratethys, *Kaupia. Darmst. Beitr. Naturges.*, 2005, no. 14, pp. 65–67.
- Sytchevskaya, E.K. and Prokof'ev, A.M., Sea mouse (Perciformes, Callionymidae) from the Middle Miocene of the south of Russia, *Vopr. Ikhtiol.*, 2007, vol. 47, no. 6, pp. 750–756.
- Takhtadzhyan, A.L., Neogene flora of the Goderdzi pass. Part I, *Trudy Bot. Inst. Akad. Nauk SSSR*. 1963, Ser. 8 (Paleobotany, vol. 4), pp. 189–204.
- Taktakishvili, I.G., *Sistematika i filogeniya pliotzenovykh kardiid Paratetisa* (Systematics and Phylogeny of Pliocene Cardiids of the Paratethys), Tbilisi: Metsniereba, 1987.
- Tari, G., Fallah, M., Kosi, W., Floodpage, J., Baur, J., Bati, Z., and Sipahioğlu, N.Ö., Is the impact of the Messinian Salinity Crisis in the Black Sea comparable to that of the Mediterranean? *Mar. Pet. Geol.*, 2015, vol. 66, pp. 135–148.
- Tari, G., Fallah, M., Schell, C., Kosi, W., Bati, Z., Sipahioğlu, N.Ö., Krezsek, Cs., Schleder, Zs., Kozuharov, E., and Kitchka, A., Why are there no Messinian evaporites in the Black Sea? *Pet. Geosci.*, 2016, vol. 22, pp. 381–391.
- ter Borgh, M., Vasiliev, I., Stoica, M., Knežević, S., Matenco, L., Krijgsman, W., Rundić, L., Cloetingh, S., The isolation of the Pannonian basin (Central Paratethys): New constraints from magnetostratigraphy and biostratigraphy, *Global Planet. Change*, 2013, vol. 103, pp. 99–118.
- Ter-Grigor'yants, L.S., Stratigraphic subdivision of Maikopian deposits of the northern Stavropol region, in *Tr. Vseross. Nauchno-Issled. Geol. Inst.* (Trans. All-Russ. Petrol. Res. Explor. Inst.), Moscow, 1961, vol. 30, pp. 263–273.
- Ter-Grigor'yants, L.S., Foraminifers of Maikopian deposits of the Stavropol region and their stratigraphic significance, in *Maikopskie otlozheniya i ikh vozrastnye analogi na Ukraine i v Srednei Azii* (Maikopian Deposits and Their Age Analogs in the Ukraine and Central Asia), Kiev: Naukova Dumka, 1964, pp. 36–52.
- Tesakov, A.S., Biostratigraphy of the Middle Pliocene–Eopleistocene of the south of Eastern Europe (based on small mammals), *Extended Abstract of Cand. Sci. (Geol–Mineral.) Dissertation*, Moscow: Geol. Inst. Ross. Akad. Nauk, 2002.
- Teslenko, Yu.V., On the age of fossil floras of the village of Aleksandrova and town of Amvrosievka, *Byull. Mosk. Obshch. Ispyt. Prir., Nov. Ser., Otd. Geol.*, 1957, vol. 32, no. 3, pp. 175–176.
- Theodoridis, S., Calcareous nannofossil biozonation of the Miocene and revision of the helicoliths and discoasters, *Utrecht Micropaleontol. Bull.*, 1984, vol. 32, pp. 1–271.
- Trubikhin, V.M., Paleomagnetism and Stratigraphy of Akchagylia Deposits of Western Turkmenistan, *Tr. Geol. Inst. Akad. Nauk SSSR*, 1977, vol. 301, pp. 1–77.
- Trubikhin, V.M., Paleomagnetic data for the Pontian, in *Chronostratigr. Neostratotypen*, vol. 8, Pontien, Zagreb–Beograd, 1989, pp. 76–79.
- Trubikhin, V.M., Paleomagnetic scale and stratigraphy of Neogene–Quaternary deposits of the Paratethys, in *Opornye razrezy neogena Vostochnogo Paratetisa (Tamanskii poluostrov)* (Reference Sections of the Neogene of the Eastern Paratethys (Taman Peninsula)), Volgograd–Taman, 1998, pp. 13–17.
- Trubikhin, V.M. and Pilipenko, O.V., Rock magnetism and paleomagnetism of Maeotian deposits of the Popov Kamen reference section (Taman Peninsula), *Izv., Phys. Solid Earth*, 2011, vol. 47, pp. 233–245.
- Trudy 6 Kongressa Regional'nogo komiteta po stratigrafii sredizemnomorskogo neogena. T. 2* (Proc. 6th Congr. Reg. Com. Stratigr. Mediterr. Neogene), Bratislava, 1976.
- Tugolesov, D.A., Gorshkov, A.S., Meisner, L.B., et al., *Tektonika mezokainozoiskikh otlozhenii Chernomorskoj*

vpadiny (Tectonics of Meso-Cenozoic Deposits of the Black Sea Depression), Moscow: Nedra, 1985.

Ulanovskaya, T.E., Shilin, A.V., and Solov'ev, Yu.Yu., Maikopian Series (Oligocene–Lower Miocene) in the southern seas of Ukraine and Russia (Black Sea, Sea of Azov, and Caspian Sea), in *Fanerozoi Volgo-Ural'skoi, Pri-kaspiiskoi i Severo-Kavkazskoi neftegazonosnoi provintsii: stratigrafiya, litologiya, paleontologiya. Mater. 2-oi Nauchno-Prakt. Stratigr. Konf. (Saratov, 6–9 dek. 2004 g.)* (Phanerozoic of the Volga–Ural, Pre-Caspian, and Northern Caucasian Oil and Gas Zones: Stratigraphy, Lithology, and Paleontology. Proc. 2nd Sci.-Pract. Stratigr. Conf. (Saratov, December 6–9, 2004)), Saratov, 2004, pp. 106–107.

Unifitsirovannaya regional'naya stratigraficheskaya skhema neogenovykh otlozhenii yuzhnykh regionov Evropeiskoi chasti Rossii i ob'yasnitel'naya zapiska k nei (Unified Regional Stratigraphic Scheme of Neogene Deposits in the Southern Regions of the European Part of Russia and an Explanatory Note to the Scheme), Moscow: Paleontol. Inst. Ross. Akad. Nauk, 2004.

Uznadze, M.D., Flora of the Goderdzi Formation, *Soobshch. Akad. Nauk Gruz. SSR*, 1946, vol. 7, no. 7, pp. 447–453.

Uznadze, M.D. and Tsagareli, E.A., Sarmatian flora of the Dzindza River gorge (Goderdzi flora), in *Tr. Geol. Inst. Akad. Nauk Gruz. SSR. Nov. Ser.* (Trans. Geol. Inst. Georgian SSR. New Ser.), 1979, vol. 4, pp. 35–52.

Van Baak, C., Mediterranean–Paratethys connectivity during the late Miocene to Recent: Unravelling geodynamic and paleoclimatic causes of sea-level change in semi-isolated basins, *Doctoral Dissertation*, Utrecht: Utrecht Univ., 2015.

Van Baak, C., Mandic, O., Lazar, I., Stoica, M., and Krijgsman, W., The Slanicul de Buzau section, a unit stratotype for the Romanian stage of the Dacian Basin (Pliocene–Pleistocene, Eastern Paratethys), *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 2015a, vol. 440, pp. 594–613.

Van Baak, C., Radionova, E.P., Golovina, L.A., Raffi, I., Kuiper, K.F., Vasiliev, I., and Krijgsman, W., Messinian events in the Black Sea, *Terra Nova*, 2015b, vol. 27, pp. 433–441.

Van Baak, C., Krijgsman, W., Magyar, I., Sztano, O., Golovina, L.A., Grothe, A., et al., Paratethys response to the Messinian salinity crisis, *Earth Sci. Rev.*, 2017, vol. 172, pp. 193–223.

Van Baak, C., Grothe, A., Richards, K., Stoica, M., Aliyeva, E., Davies, G., Kuiper, K.F., and Krijgsman, W., Flooding of the Caspian Sea at the intensification of Northern Hemisphere Glaciations, *Global Planet. Change*, 2019, vol. 174, pp. 153–163.

Van Vugt, N., Langereis, C.G., and Hilgen, F.J., Orbital forcing in Pliocene–Pleistocene Mediterranean lacustrine deposits: dominant expression of eccentricity versus precession, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 2001, vol. 172, nos. 3–4, pp. 193–205.

Vasiliev, I., Krijgsman, W., Langereis, C.G., Panaiotu, C.E., Matenco, L., and Bertotti, G., Towards an astrochronological framework for the Eastern Paratethys Mio–Pliocene sedimentary sequences of the Focsani basin (Romania), *Earth Planet. Sci. Lett.*, 2004, vol. 227, pp. 231–247.

Vasiliev, I., Leeuw de, A., Filipescu, S., Krijgsman, W., Kuiper, K., Stoica, M., and Briceag, A., The age of the Sar-

matian–Pannonian transition in the Transylvanian Basin (Central Paratethys), *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 2010, vol. 297, pp. 54–69.

Vasiliev, I., Iosifidi, A.G., Khramov, A.N., Krijgsman, W., Kuiper, K., Langereis, C.G., Popov, V.V., Stoica, M., Tomsha, V.A., and Yudin, S.V., Magnetostratigraphy and radioisotope dating of upper Miocene–lower Pliocene sedimentary successions of the Black Sea Basin (Taman Peninsula, Russia), *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 2011, vol. 310, nos. 3–4, pp. 163–175.

Vassoevich, N.B. and Eberzin, A.G., On the stratigraphy of the Middle Pliocene of the Black Sea basin, *Tr. Neft. Geol. Razved. Inst., Ser. A*, 1930, vol. 1, pp. 1–40.

Veber, V.V., Geological map of Kabristan, *Tr. Neft. Geol. Razved. Inst., Ser. A*, 1935, no. 62.

Vernigorova, Yu.V., Features of distribution of foraminifers and some issues of stratigraphy of Konkian deposits of the Northern Black Sea region, in *Biostratyhrafichni osnovy pobudovy stratyhrafichnykh skhem fanerozoju Ukrainy* (Biostratigraphic Basis for Constructing Stratigraphic Schemes of the Phanerozoic of Ukraine), Kiev: Inst. Geol. Nauk., Nats. Akad. Nauk. Ukr., 2008, pp. 212–219.

Vernigorova, Yu.V., Karaganian and Konkian regional stages of the Eastern Paratethys: Issues of their range and stratigraphic independence, *Geol. Zh.*, 2009, no. 2, pp. 34–47.

Vernigorova, Yu.V., To the modernization of the stratigraphic scheme of Neogene deposits in the Northern Black Sea region and adjacent part of the Ukrainian shield, in *Evolutsiya orhanichnoho svitu ta etapy heolohichnoho rozvytku Zemli* (The evolution of the Organic World and the Stages of Geological Development of the Earth), Kiev: Inst. Geol. Nauk., Nats. Akad. Nauk. Ukr., 2014, pp. 103–104.

Vernigorova, Yu.V., Criteria for the stratigraphic subdivision of Konkian deposits of the Eastern Paratethys based on mollusks and foraminifers, *Geol. Zh.*, 2015, vol. 353, no. 4, pp. 77–86.

Vernigorova, Yu.V. and Ryabokon', T.S., *Maikopskie otlozheniya (oligotsen, nizhnii miotsen) Kerchenskogo poluos-trova: istoriya izucheniya, polemika, stratigrafiya* (Maikopian Deposits (Oligocene–Lower Miocene) of the Kerch Peninsula: History of Study, Polemics, and Stratigraphy), Kiev: Inst. Geol. Sci., Nats. Acad. Sci. Ukr., 2018.

Vernigorova, Yu.V., Golovina, L.A., and Goncharova, I.A., On the characteristics of the Konkian deposits of the Taman Peninsula, in *Biostratyhrafichnyy kryterii rozchlenuvannya ta korelyatsiya vidkladiv fanerozoju Ukrayiny* (Biostratigraphic Criteria for Subdivision and Correlation of Phanerozoic Deposits of Ukraine), Kiev: Gnozis, 2006, pp. 231–242.

Vernigorova, Yu.V., Fikolina, L.A., and Obsharskaya, N.N., Structural-facies zoning of Neogene deposits of the Kerch Peninsula, *Geol. Zh. Nats. Akad. Nauk Ukr.*, 2012, no. 3, pp. 74–94.

Vernigorova, Yu.V., Golovina, L.A., Popov, S.V., Goncharova, I.A., and Palcu, D., On the issue of the range and boundaries of the Konkian Regional Stage (based on the example of the Zelensky Hill reference section, Taman Peninsula), in *Mater. 38 Sess. Paleontol. Obshch. Nats. Akad. Nauk Ukr.* (Proc. 38th Sess. Paleontol. Soc. Nats. Acad. Sci. Ukr.), Kiev: Inst. Geol. Sci., 2017, pp. 136, 137.

Vernyhoroova, Yu.V., Middle Miocene (Konkian of the Eastern Paratethys) foraminifera assemblages from the

- Southern Ukraine, in *Intern. Workshop "Neogene of Central and South-Eastern Europe,"* Velika, Croatia, 2017, Poster.
- Vernyhorova, Yu.V. and Ryabokon, T.S., The stratigraphy of the Oligocene–lower Miocene deposits of southern Ukraine, *Turk. J. Earth Sci.*, 2020, vol. 29, pp. 170–207.
- De Verteuil, L., Palynological delineation and regional correlation of Lower through Upper Miocene sequences in the Cape May and Atlantic City Boreholes, in *New Jersey Coastal Plain, Proc. Ocean Drill. Program: Sci. Results*, Miller, K.G. and Snyder, S.W., Eds., 1997, vol. 150X, pp. 129–145.
- De Verteuil, L. and Norris, G., Miocene dinoflagellate stratigraphy and systematics of Maryland and Virginia, *Micropaleontology*, 1996, vol. 42 (Suppl.), pp. 1–172.
- Vlček, T., Hudáčková, N., Jamrich, M., Halášová, E., Franců, J., Nováková, P., Kováčová, M., and Kováč, M., Hydrocarbon potential of the Oligocene and Miocene sediments from the Modrany-1 and Modrany-2 wells (Danube Basin, Slovakia), *Acta Geol. Slovaca*, 2020, vol. 12, no. 1, pp. 43–55.
- Volkova, N.S., Fauna of the Lower Miocene deposits of the Northern Caucasus, in *Paleontol. Sb. 3. Tr. Vseross. Neft. Nauchno-Issled. Geol. Inst.* (Coll. Sci. Works in Paleontology, no. 3, Trans. All-Russ. Petrol. Res. Explor. Inst.), 1962, vol. 196, pp. 383–419.
- Voloshinova, N.A. and Dain, L.G., *Nonionides, cassidulinids, and chilostomellids*, *Tr. Vses. Neft. Nauchno-Issled. Geol. Inst., Nov. Ser.* 1952, vol. 63 (Fossil Foraminifers of the USSR), pp. 1–114.
- Voronina, A.A., Popov, S.V., Panova, L.A., Pechenkina, A.P., and Tabachnikova, I.P., Stratigraphy of Maikopian deposits of Eastern Georgia, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1991, no. 10, pp. 19–33.
- Voronina, A.A., Kalugin, V.P., Popov, S.V., and Trubikhin, V.M., Aktepe Formation of the Kopetdag and position of the boundary between the Paleogene and Neogene, *Stratigr. Geol. Korrel.*, 1993, vol. 1, no. 3, pp. 309–318.
- Wade, B.S., Pearson, P.N., Berggren, W.A., and Pälike, H., Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale, *Earth-Sci. Rev.*, 2011, vol. 104, no. 1, pp. 111–142.
- Weedon, G.P., *Time Series Analysis and Cyclostratigraphy*, Cambridge Univ. Press, 2003.
- Wójcik, A., Jugowiec, M. The youngest members of the folded Miocene in the Andrychów region (Southern Poland), *Przegląd Geol.* 1998, vol. 46, No. 8/2, pp. 763–770.
- Yakubovskaya, T.A., Sarmatian flora of the Moldavian SSR, in *Flora i sistematika vysshikh rastenii. Tr. Bot. Inst. Akad. Nauk SSSR* (Flora and Systematics of Higher Plants. Trans. Bot. Inst. USSR Acad. Sci.), 1955, vol. 11, pp. 7–108.
- Zaporozhets, N.I., Palynostratigraphy and dinocyst zonation of the Middle Eocene–Lower Miocene deposits at the Belaya River (Northern Caucasus), *Stratigr. Geol. Korrel.*, 1999, vol. 7, no. 2, pp. 161–178.
- Zaporozhets, N.I. and Akhmetiev, M.A., Paleobotanical study of a section of the Oligocene–Lower Miocene Maikopian Group along the Belaya River above the city of Maikop, Ciscaucasia, *Stratigr. Geol. Korrel.*, 2017, no. 6, pp. 638–658.
- Zevenboom, D., Dinoflagellate cysts from the Mediterranean Late Oligocene and Miocene, *Doctoral Dissertation*, Utrecht Univ., 1995.
- Zhgenti, E.M., On a find of the genus *Alveinus* in the Middle Miocene of the Paratethys, *Byull. Akad. Nauk Gruz. SSR*, 1976a, vol. 83, no. 2, pp. 505–508.
- Zhgenti, E.M., *Lutetiids of the Middle Miocene, Their Evolution and Stratigraphic Significance*, Tbilisi: Metsniereba, 1976b.
- Zhgenti, E.M., *Evolutsiya i stratigraficheskoe znachenie molluskovoi fauny konkskogo yarusa Gruzii* (Evolution and Stratigraphic Significance of the Mollusk Fauna of the Konkian Stage of Georgia), Tbilisi: Metsniereba, 1991.
- Zhgenti, E.M., On the phenomenon of neoteny during the evolution of the superfamily Veneracea, in *Problemy Paleobiologii, T. 1* (Problems of Paleobiology. Vol. 1), Tbilisi: Metsniereba, 1999, pp. 144–159.
- Zhgenti, E.M. and Maisuradze, L.S., *Karaganskii, kartvel'skii i konkskii regiony Gruzii: istoriya razvitiya molluskov i foraminifer i ikh stratigraficheskoe znachenie* (Karagian, Kartvelian, and Konkian Regional Stages of Georgia: History of Development of Mollusks and Foraminifers and Their Stratigraphic Significance), Tbilisi: Izd. Universal, 2016.
- Zhizhchenko, B.P., New data on Miocene mollusks of Eastern Ciscaucasia, *Tr. Geol. Sluzhby Gruzii*, 1937, no. 6, pp. 123–130.
- Zhizhchenko, B.P., Lower and Middle Miocene, in *Stratigrafiya SSSR* (Stratigraphy of the USSR), vol. 12: *Neogene SSSR*, Moscow: Izd. Akad. Nauk SSSR, 1940, pp. 11–227.
- Zhizhchenko, B.P., Materials for the development of a unified scheme of division of Cenozoic deposits in the south of the European part of the USSR and in the Northern Caucasus, in *Vopr. Geol. Geokhim. Nefti Gaza (Probl. Oil Gas Geol. Geochem.)*, Moscow, Leningrad: Gostoptekhizdat, 1953, pp. 183–224.
- Zhizhchenko, B.P., *Atlas srednemiosenoj fauny Severnogo Kavkaza i Kryma* (Atlas of the Middle Miocene Fauna of the Northern Caucasus and Crimea), Moscow: Gosnauchtekhizdat, 1959.
- Zonneveld, K.A.F., Marret, F., Versteegh, G.J.M., Bonnet, S., Bouimetarhan, I., Crouch, E., Vernal de, A., Elshanawany, R., Edwards, L., Esper, O., Forke, S., Grösfeld, K., Henry, M., Holzwarth, U., Kieft, J.-F., Kim, S.-Y., Ladouceur, S., Ledu, D., Chen, L., Limoges, A., Londeix, L., Lu, S.H., Mahmoud, M.S., Marino, G., Matsuoka, K., Matthiessen, J., Mildenhall, D.C., Mudie, P., Neil, H.L., Pospelova, V., Qi, Y., Radi, T., Richerol, T., Rochon, A., Sangiorgi, F., Solignac, S., Turon, J.-L., Verleye, T., Wang, Y., Wang, Z., and Young, M., Atlas of modern dinocyst distribution based on 2405 datapoints, *Rev. Palaeobot. Palynol.*, 2013, no. 191, pp. 1–197.
- Zubakov, V.A. and Kochegura, V.V., Eastern Black Sea region. Middle–Late Miocene, in *Geokhronologiya SSSR* (Geochronology of the USSR), vol. 3: Modern Stage, Leningrad: Nedra, 1984, pp. 102–111.

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