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The Correlation of the Upper Cretaceous Zonal Schemes of the Eastern European Platform Based on Foraminifera, Radiolaria, and Nannoplankton

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Abstract—This article proposes a biostratigraphic scheme for the Upper Cretaceous of the East European Platform on the basis of the distribution in the sections of three groups of microfossils: foraminifera (both planktonic and benthic), radiolarians, and nannoplankton. Most of the stage and substage boundaries are confirmed by macropaleontological data. The most divided units are those distinguished based on benthic foraminifers and nannoplankton. The diversity of these microfossils and their constant presence allowed us to identify zones and subzones, while it is possible to subdivide only the beds by planktonic foraminifers and radiolarians. The most favorable stages in the development of plankton biota can be considered the Turonian–Coniacian interval when the basins of the East European Platform experienced an intensive influence from warm waters of the Tethys Ocean. The global Campanian cooling is clearly recorded, which affected the taxonomic diversity of all microfossil groups.

Keywords: East European Platform, Upper Cretaceous, foraminifera, nannoplankton, radiolarians, biostratigraphy

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INTRODUCTION

Upper Cretaceous deposits are common in the East European Platform (EEP). The biostratigraphy of Upper Cretaceous deposits in the EEP and adjacent regions has been traditionally based on the Western European macropaleontological standard because of the similarity between the taxonomic compositions of EEP and Western European marine biota referred to the Late Cretaceous. This is the reason that the EEP is usually included to the European Paleobiogeographic Area (EPR). However, the structural plan of the platform in the Late Cretaceous was quite complicated, with peculiarities at specific sites reflected in microfossil compositions. As an example, there are stratigraphic intervals where calcareous shells of microorganisms are absent; thus, subdivision is possible only on the basis of silicon microfossils, namely, radiolarians (Vishnevskaya, 2010). In some sections, foraminifera assemblages are represented by only benthic foraminifera, or rarely only by calcareous nannoplankton (Ovechkina, 2007).

This is determined by their high taxonomic diversity and the ability to identify evolutionary changes in different phylogenetic lines. At the same time, assemblages of planktonic foraminifers (PF) are characterized by low taxonomic diversity and a small number of specimens of each species. Rapidly evolving taxa are absent or rare. However, there are intervals where PF assemblages are more diverse, with zonal species from the schemes of the Crimean–Caucasian and other Mediterranean regions; therefore, the identified beds can be correlated to the zones of traditional planktonic schemes. A total of 12 beds were distinguished in Upper Cretaceous deposits in the EEP, (Kopaevich, 2011a); however, the BF-based scale is more detailed (Beniamovski, 2008a, 2008b). The correlation between distinguished units and boundaries of stages was established from comparison with macrofossils (ammonites, belemnites, inoceramids, and others) in the sections. These data enabled one to correlate the distinguished units to both radiolarian- and nannoplankton-based schemes.

It is necessary to make a composite scheme of subdivision of Upper Cretaceous deposits in the EEP

† Deceased.

based on foraminifera, radiolarians, and nannoplankton, with new data taken into consideration. This would considerably enhance its correlation potential, thus expanding the area to the Tethyan and Boreal regions, and even the Pacific region.

MATERIALS AND METHODS

In this work the data on different EEP structures are used (Olferiev and Alekseev, 2003). When distinguishing zones and beds, the sections of the Moscow syneclise (Olferiev et al., 2008), the Voronezh anteclise (Olferiev et al., 2005; Walaszczyk et al., 2004), the areas of the North Donets and Don rivers, and the Volga region near Ulyanovsk–Saratov Volga Region (Naidin and Ivannikov, 1980; Dmitrenko et al., 1988) have been used. The data on the Volga region near Volgograd and on the Ulyanovsk–Saratov depression, eastern Pre-Caspian syneclise, and southern parts and southeastern framework of the EEP have been extensively used (Alekseev et al., 1999; Benyamovskiy et al., 2012; Guzhikov et al., 2017; Kopaevich et al., 2007; Kopaevich, 2011a, 2011b; Olferiev et al., 2008; Pervushov et al., 2015). Reviews on nannoplankton and radiolarians of the EEP were published by M.N. Ovechkina (2007) and V.S. Vishnevskaya (2010), respectively.

The specimens were prepared and washed by traditional techniques for both foraminifers and radiolarians (Kopaevich and Vishnevskaya, 2016). Imaging of shells was performed using an XL30 ESEM electron microprobe (manufactured by Philips company) at the Belgian Royal Institute of Natural History (Brussels) using a scanning electron microscope at the Paleontological Institute of the Russian Academy of Sciences (Moscow) with subsequent computer processing, as well as using a JEOL JSM-6480LV electron microprobe at the Subdepartment of Petrology of the Department of Geology at Moscow State University.

THE CHARACTERISTICS OF THE BIOSTRATIGRAPHIC SCHEME OF THE EEP BASED ON MICROFOSSILS

The characteristics of different biostratigraphic schemes of the EEP on microfossils are presented in Table 1.

BF-Based Zones and Subzones

The stratigraphic scheme of Upper Cretaceous deposits of the EEP, which was officially adopted by the International Commission on Stratigraphy (ICS), contains two zonal schemes, that is, macro- and BF-based microfaunal, which are closely correlated with each other; thus, the ages of stratigraphic units on BF are dated quite precise (Olferiev and Alekseev, 2003).

Figure 1 demonstrates two BF-based schemes, of which one appears in the mentioned regional stratigraphic scheme and another is the infrazonal stratigraphic scheme for Upper Cretaceous from the East European Province adopted by the ICS for Russia at the extended meeting in February 2001. This BF-based infrazonal scheme of Upper Cretaceous from the East European Province was developed by V.N. Ben'yamovskii in the recent decade resulting from the detailed studies of tens of Upper Cretaceous reference sections for different structural–facial areas of the EEP. It is used to stratify the reference sections, to determine the extents of stratigraphic hiatuses and different events (Olferiev et al., 2008). This scheme has been applied to determine the position of the lower boundary of the Maastrichtian stage in the EEP with respect to the change of its traditional level at the base of a lanceolate chalk strata (Guzhikov et al., 2017).

The zones of the proposed detailed scheme are complex biostratigraphic zones. The principles of zone subdivision and possibilities of territorial application of this scheme have been described in the earlier works by the authors. For convenience of using the zonal subdivisions in publications on stratigraphy and geology, a code system was proposed: LC1a, LC1b, LC2a, LC2b, etc., where LC indicates Late Cretaceous, the numerals 1, 2, 3, and others denote the sequential numbers of zones, and the letter indices a, b, and c indicate the subzones. The detailed characteristics of zonal assemblages of the detailed scheme were published in (Beniamovski, 2008a, 2008b); thus, they will not be considered here. However, significant taxonomic corrections have been introduced to the scheme; thus, certain changes have been made in the names of zones and subzones. These corrections are illustrated in Fig. 1 (the column entitled Benthic foraminifera: Zones and subzones) as well as in Plate 1.

The sequence of zonal assemblages reflects the stages of BF evolution through the Late Cretaceous; it can be illustrated by the evolution of the Stensioeina genus. The *Protostensioeina* genus was distinguished by Polish micropaleontologists Z. Dubicka and D. Peryt (2014) as the ancestral form that reflects the first stage of group evolution. Beginning from the Late Coniacian, the evolution of *Stensioeina exsculpta exsculpta*, which is the type species of the Stensioeina genus, begins and the Protostensioeina stage is replaced with the Stensioeina stage. This is a key marker traced in the all EEP, from the Belorussian high and Lvov depression on the west to the Mangyshlak Peninsula on the east.

PF-Containing Layers

Layers with *Microhedbergella planispira* are found within the limits of the Voronezh high as well as in sections of the Pre-Caspian depression and Mangyshlak (Kopaevich, 2011; Olferiev et al., 2005; Walaszczyk et al., 2004). They coincide with the BF-based *Gavelinella cenomanica* (LC1) and *Lingulogavelinella globosa* (LC2) zones (Fig. 1). Hereinafter, the images of all index species are presented in Plate 2.

Table 1. The correlation between Upper Cretaceous zonal stratigraphic units based on BF, PF, radiolarians, and nannoplankton as exemplified by the Upper Cretaceous sections of the EEP

Ma	Stage	Substage	Benthic foraminifera (BF): EEP (Olferiev and Alekseev, 2003, 2005) Zones	Benthic foraminifera (BF): EEP and Mangyshlak Zones and subzones		Stages of BF evolution	Planktonic foraminifera (PF) Beds	Radiolarians Beds	Nannoplankton Zones
66	Maastrichtian	Upper	*Brotzenella praeacuta–Hanzawaia ekblomi*	*Falsoplanulina mariae* (= *Hanzawaia ekblomi*) (LC23)		Anomalinoides–Falsoplaunila	*Pseudotextularia elegans*		CC 26
				Brotzenella praeacuta (LC22)					CC 25 c; a–b
		Lower	*Brotzenella complanata*: *Bolivinoides draco draco*	*B. draco draco/Amonalinoides complanatus* (= *A. ukrainicus*) (LC21)			Rugoglobigerina	*Spongurus marcaensis–Rhombastrum russiense*	CC 24
			Brotzenella complanata: *Brotzenella complanata*	*Falsoplanulina multipunctata* (= *Brotzenella complanata*) (LC20)					CC 23 b
72.1			*Neoflabelina reticulata*	*Neoflabelina praereticulata/N. reticulata* (LC19)		Angulogavelinella–Bolivina	*Globotruncana morozovae*	*Archaeospongoprunum andersoni–A. hueyi*	CC 23 a
	Campanian	Upper	*Angulogavelinella gracilis*	*Angulogavelinella stellaria* (LC18)					CC 22b
			Globorotalites emdyensis: *Brotzenella taylorensis*	*Brotzenella taylorensis* (LC17)					
			Globorotalites emdyensis: *Bolivinoides draco draco miliaris*	*Bolivia incrassata–B. draco miliaris* (LC16)					
			Globorotalites emdyensis: *Globorotalites emdyensis*	*Globorotalites hiltermani* (= *G. emdyensis*) (LC15)		Brotzenella		*Prunobrachium articulatum*	CC 19–CC 22b
			Brotzenella monterelensis	*Brotzenella monterelensis* (LC14)			*Globigerinelloides multispinus*	*Prunobrachium mucronatum*	
		Lower	*Cibicidoides aktulagayensis*	*Bolivinoides decoratus*	*Cibicidoides involutes* (LC13b)	Cibicidoides	*Globotruncana arca*	*Lithostrobus rostovzevi–Archaeospongoprunum rumseyensis*	CC 18 b
			Cibicidoides temirensis		*Cibicidoides temirensis* (LC13a)				CC 18 a
83.6			*Gavelinella clementiana clementiana*	*Pseudovalvulineria clementiana clementiana* (LC12)		Pseudogavelinella			CC 17
	Santonian	Upper	*Gavelinella stelligera*: *Stensioeina pommerana*	*Stensioeina pommerana* (LC11)		Stensioeina	*Globotruncana bulloides*	*Crucella espartoensis–Alievium gallowayi*	CC 16
			Gavelinella stelligera: *Gavelinella stelligera*	*Pseudovalvulineria stelligera*/Bolivinoides *strigillatus* (LC10)					
				Stensioeina incodita (LC9)					CC 15
86.3		Lower	*Gavelinella infrasantonica*	*Pseudovalvulineria vombensis* (= *G. infrasantonika*)/*Stensioeina exsculpta* exsculpta (LC8)			*Globigerinelloides asper*	*Pseudoaulophacus floresensis–Archaeospongoprunum bipartitum*	CC 14
	Coniacian	Upper	*Gavelinella thalmanni*				*Archaeoglobigerina cretacea*	*Alievium praegallowayi Archaeospongoprunum triplum*	CC 13
		Middle		*Pseudovalvulineria yhalmanni/P. vombensis/Protostensioeina emscherica* (akme) (LC7)		Protostensioeina			
89.8		Early	*Gavelinella kelleri*	*Protostensioeina granulata granulata/P. emscherica/ Pseudovalvulineria praeinfrasantonica* (LC6)			*Marginotruncana coronata–M. renzi*		CC 12
	Turonian	Upper	*Gavelinella moniliformis*	*Protostensioeina praeexsculpta/Ataxophragmium compactum*	*Reussella kelleri* (LC5c)			*Crucella cachensis–Alievium superbum*	CC 11
					Ataxophragmium compactum (LC5b)				
					Protostensioeinapraeexsculpta/P. laevigata (LC5a)				
		Middle		*Gavelinella moniliformis moniliformis/G. ammonoides*	*Gavelinella moniliformis* (LC4b)	Marssonella–Gavelinella	*Marginotruncana pseudolinneiana*		
					Gavelinella ammonoides/Marsonella oxycona (LC4a)				
		Lower	*Gavelinella nana*	*Protostensioeina nana*	*Globorotalites hangensis* (LC3b)	Globorotalites	*Hedbergella holzli–Whiteinella archaeocretacea*		
93.9					*Reussella turonica* (LC3a)				
	Cenomanian	Upper	*Lingologavelinella globosa*	*Lingulogavelinella globosa*	*Berthelina berthelini/Gaudryina arenosa* (LC2b)	Berthelina		*Crucella messinae–Pseudodictyomitra pseudomacrocephala*	CC 10
		Middle			*Lingulogavelinella globosa/Cibicides polyrraphes polyrraphes* (LC1a)	Lingulogavelinella	*Microhedbergella planispira*		
		Lower	*Gavelinella cenomanica*	*Gavelinella cenomanica*	*Lingulogavelinella formosa* (LC1b)				CC 9
100.5					*Gavelinella cenomanica/Hoeglundina dorsoplana* (LC1a)				

Plate 1

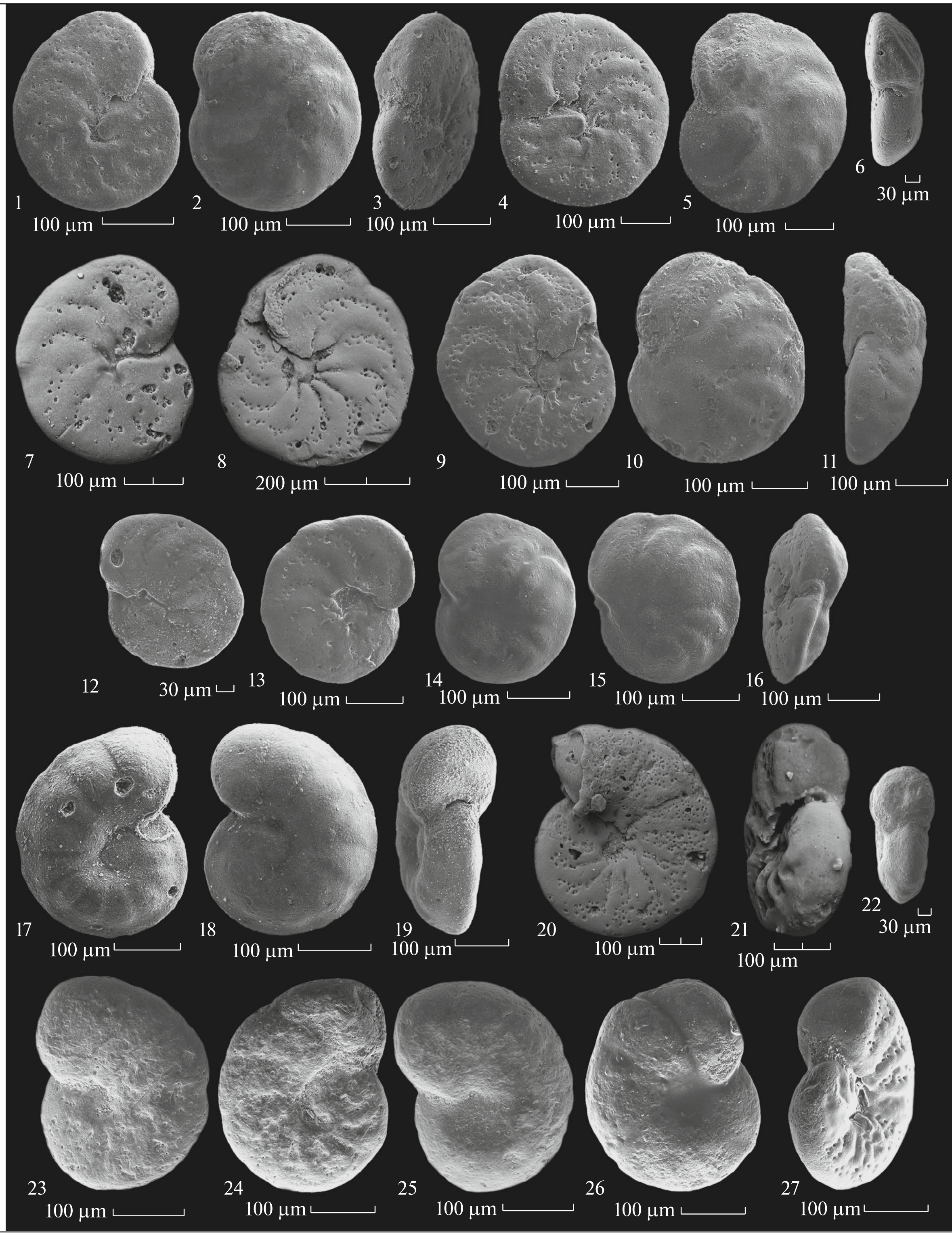

Plate 1. Revised BF species. Figures 1–11 correspond to *Falsoplanulina multipunctata* (Bandy, 1951), Krasnyi Oktyabr' (near the town of Volsk), Maastrichtian, *F. multipunctata* Zone (LC20), sample 11: Figures 1 and 4 show the ventral side; 2 and 5, dorsal side; 3 and 6, profile; Aktulagai 2013, sampling point 3019, *F. multipunctata* Zone (LC20), sample 77: Figures 7–9, ventral side; 10, dorsal side; 11, profile. Figures 12–16 correspond to *Falsoplanulina mariae* (Jones, 1852), Bol'shevik (near Volsk), *F. mariae* Zone (LC23), sample 66: Figures 12 and 13, ventral side; 14 and 15, dorsal side; 16, profile. Figures 17–27 correspond to *Anomalinoides complanatus* (Reuss, 1851), Krasnyi Oktyabr' (near the town of Volsk), *Bolivinoides draco/Anomalinoides complanatus* Zone (LC21), sample 30: Figure 17, ventral side; 18, dorsal side; 19, profile; Aktulagai-2013, sampling point 3019: Figure 20, ventral side; 21, profile; Western Ukraine, near Lviv, Maastrichtian: sample 85: Figure 22, profile, sample 87; Figures 23 and 25, dorsal side; 24 and 26, ventral side; 27, profile.

Layers with *Hedbergella holzli–Whiteinella archaeocretacea* are distinguished in deposits of the Cenomanian–Turonian boundary and correlate well to deposits of the *Whiteinella archaeocretacea* Zone of the Crimean–Caucasian region in both composition of the PF complex and geochemical characteristics (Kopaevich and Vishnevskaya, 2016).

Layers with *Marginotruncana pseudolinneiana* are distinguished in the Middle and, partially, Upper Turonian and are comparable to most of the BF-based *Gavelinella moniliformis* Zone (LC4).

Layers with *Marginotruncana coronata–M. renzi* (Kopaevich, 2011) are distinguished in the upper part of the Turonian–Lower Coniacian. They correspond to the upper part of the BF-based *Gavelinella moniliformis* (LC5) and *Gavelinella kelleri* zones (LC6) (Beniamovski, 2008a).

Layers with *Archaeoglobigerina cretacea* correspond to the BF-based *Gavelinella thalmanni* Zone from the scheme by Olferiev and Alekseev (2003), which is comparable in turn to the sequence of Middle–Upper Coniacian inoceramid zones: *Volviceramus koeneni–involutus* to *Magadyceramus subquadratus*.

Layers with *Globigerinelloides asper* correspond to the *Gavelinella infrasantonica* Zone from the scheme by Olferiev and Alekseev (2003) or to the upper part of the *Pseudovalvulineria vombensis/Stensioeina exsculpta* exsculpta Zone (LC8) from the BF-based scheme. The boundary with earlier layers is very indistinct.

Layers with *Globotruncana bulloides* correspond to the *Gavelinella stelligera* (s.l) Zone from the scheme by Olferiev and Alekseev (2003), or to the interval of LC9–LC11 zones from the BF-based scale and layers with *Crucella espartoensis–Alievium gallowayi* radiolarians (Fig. 1). It should be noted that in the Ulyanovsk and Saratov areas of the Volga region, beginning from the Coniacian–Santonian boundary, PF assemblages (as well as BF assemblages in some cases) are characterized by low taxonomic diversity, with radiolarians playing the leading role. In the sections of the Moscow syneclise, beginning from the Coniacian stage, the BF composition changes considerably, with the predominance of agglutinating benthic organisms that resemble the assemblages from West Siberia.

Layers with *Globotruncana arca* coincide to the levels where the first findings of Lower Campanian belemnites appear. They correspond to the BF-based *Gavelinella clementiana clementiana*, *Cibicidoides temirensis*, and *C. aktulagayensis* zones of the Lower Campanian from the scheme by Olferiev and Alekseev (2003), or to the interval of LC12–LC13 zones from the BF-based scheme, as well as to the layers with *Lithostrobus rostovzevi–Archaeospongoprunum rumseyensis* radiolarians. The PF complex is homogeneous here; findings of index species are ubiquitous, but the number of representatives is low. The predominant role is played by Archaeoglobigerina and Globigerinelloides. The lower boundary of the layers is indistinct.

Layers with *Globigerinelloides multispinus* are distinguished based on the occurrence of the index species (Kopaevich, 2011). This species has its last chamber divided into two globular ones and thus can be easily identified and used as an index species for deposits of the middle zone of the Campanian stage in Non-Carpathian Poland (Peryt, 1983).

Layers with *Contusotruncana morozovae* correspond to the *Belemnitella langei* Zone of the Upper Campanian, to the upper part of the *Brotzenella monterelensis* Zone as well as to the *Globorotalites emdyensis* and *Angulogavelinella gracilis* zones from the scheme by Olferiev and Alekseev (2003), or to the interval of the BF-based LC14 (upper parts)–LC19 (lower part) zones. However, this interval is not always identified in sections of the EEP, because the index species is rarely found, while it is more common in sections of the Pre-Caspian depression and Mangyshlak Peninsula.

Layers with *Rugoglobigerina* correspond to the belemnite zone *Belemnella lanceolata–B. sumensis* zones, as well as to the *Neoflabellina reticulata* and *Brotzenella complanata* zones from the scheme by Olferiev and Alekseev (2003) or to the interval of LC19–LC21 zones from the BF scheme. The lower limit of these layers is indistinct, while the upper one coincides with the occurrence of *Pseudotextularia elegans*.

Layers with *Psedotextularia elegans* are distinguished at the level of the *Neobelemnella kazimiroviensis* belemnite zone of the Upper Maastrichtian, as well as at that of the *Brotzenella praeacuta–Hanzawaia ekblomi* Zone from the scheme by Olferiev and Alekseev (2003) or the interval of LC22–LC23 zones from the BF-based scheme. It should be noted that the taxonomic diversity of PF increases in this interval; for example, in the Saratov area of the Volga region, in the Lokh, Klyuchi, and Teplovka sections, such species as *Globotruncanella havanensis* Voorwijk, *Globotruncana esnehensis* Nakkady, *G. mariei* Banner et Blow, *Globotruncanita stuarti* (Lapparent), and such multiseries forms of Heterohelicida as *Racemiguembelina poweli* Smith et Pessagno and *Planoglobulina brazoensis* Martin have been found (Alekseev et al., 1999; Kopaevich, 2011a).

Layers with Radiolarians

Based on radiolarians, ten units were distinguished; they can be correlated to the foraminifera- and nannoplankton-based units (Plate 3).

Layers with *Crucella messinae–Pseudodictyomitra pseudomacrocephala* (Cenomanian) are found in Bryansk oblast and are of a very constrained geographic extent, which is probably related to washing of the Cenomanian. The age was determined from the time of the existence of the index species (Vishnevskaya, 2010).

Plate 2

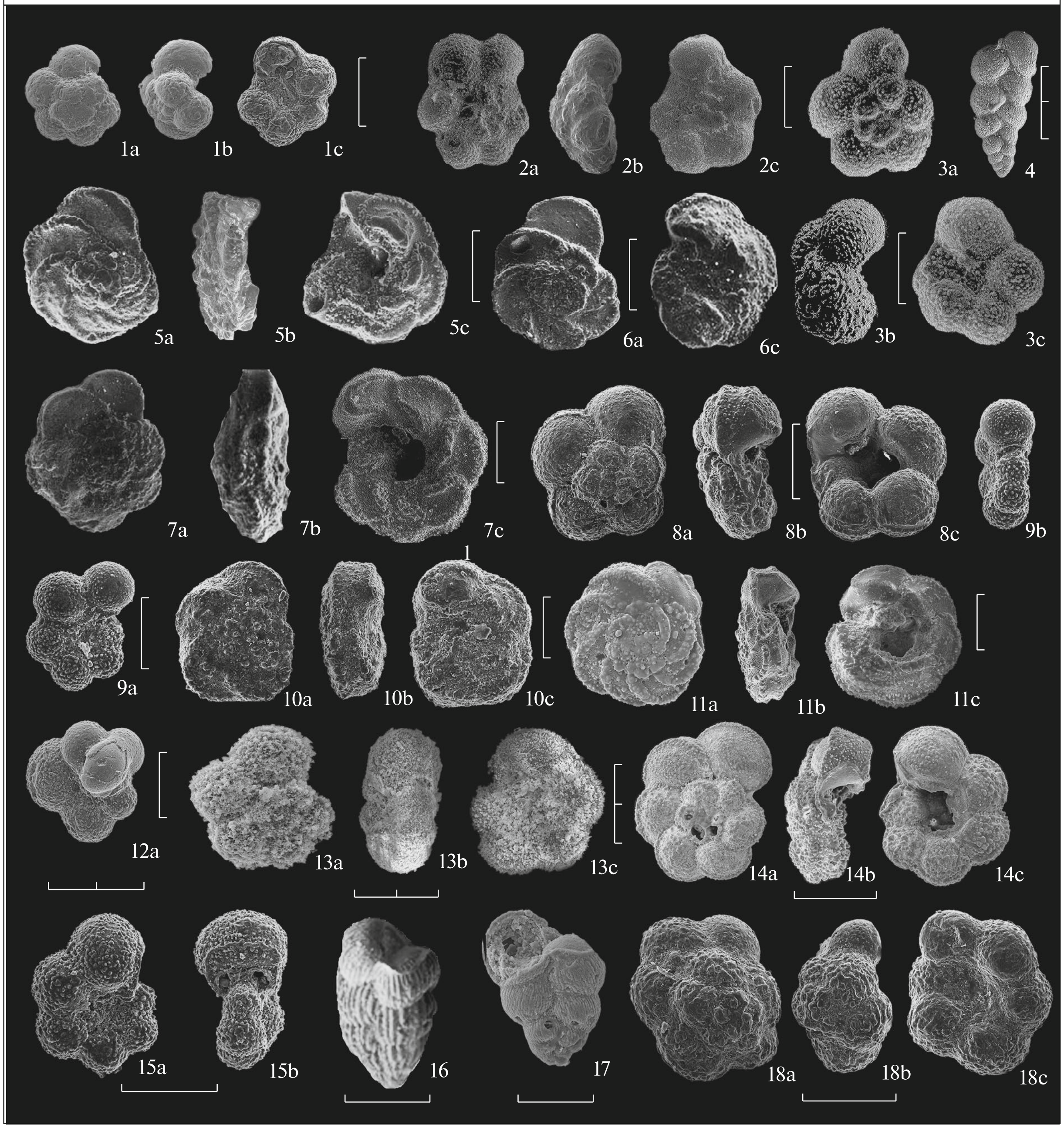

Plate 2. Index species of planktonic foraminifera: view from the dorsal side (a), from the peripheral edge (b), and from the ventral side (c); the scale bar is 200 μm long. Figures 1a–1c correspond to *Microhedbergella planispira* (Tappan, 1940), Voronezh high, Chernetovo section, Dyat'kovo Fm., Cenomanian; 2a–2c, *Hedbergella holzli* (Hagn et Zeil), Voronezh anteclise, Chernetovo section, Tuskar' Fm., Lower Turonain; 3a–3c, *Whiteinella brittonensis* (Loeblich et Tappan, 1961), Voronezh anteclise, Chernetovo section, Tuskar' Fm., Lower Turonain; 4, *Heterohelix moremani* (Cushman, 1938), Voronezh anteclise, Fokino section, Dyat'kovo Fm., Cenomanian; 5a–5c, *Marginotruncana pseudolinneiana* (Pessagno, 1967), Voronezh anteclise, Fokino section, Tuskar' Fm., Middle Turonain; 6a, 6c, *Marginotruncana renzi* (Gandolfi). Voronezh anteclise, Chernetovo section, Chernetovo Fm., Lower Coniacian; 7a–7c, *Marginotruncana coronata* (Bolli, 1966), Voronezh anteclise, Chernetovo section, Chernetovo Fm., Lower Coniacian; 8a–8c, *Archaeoglobigerina cretacea* (d'Orbigny, 1840), Donbass, Zakotnoe section, Lower Santonian; 9a–9b, *Globigerinelloides asper* (Ehrenberg), eastern Pre-Caspian depression, Uil section (well 68), Lower Santonian; 10a–10c, *Globotruncana bulloides* Vogler, 1941, northern Saratov oblast, Vishnevoe section, sample 51, Upper Santonian; 11a–11c, *Globotruncana arca* (Cushman, 1926), eastern Cis-Caspian depression, Uil section (well 68), Lower Campanian; 12a, *Globigerinelloides multispinus* (Laliker, 1948), northern Saratov region, Vishnevoe section, Ardym Fm., Upper Campanian; 13a–13c, *Rugoglobigerina rugosa* (Plummer, 1927), Saratov region, Lokh 1 section, Lower Maastrichtian; 14a–14c, *Marginotruncana marginata* (Reuss, 1845), Voronezh high, Chernetovo Fm., Lower Coniacian; 15a, 15c, *Globigerinelloides biforaminatus* (Hofker, 1956), Saratov region, Klyuchi 1 section, Upper Maastrichtian; 16, *Pseudotextularia elegans* (Rzehak, 1891), Saratov region, Klyuchi 1 section, Upper Maastrichtian; 17, *Heterohelix globulosa* (Cushman, 1938), southern part of the Volga River right bank in the Saratov area, Bannovka section, Upper Maastrichtian; 18a–18c, *Rugoglobigerina hexacamerata* Brönnimann, 1952, vicinities of Volsk, Bol'shevik quarry, Lower Maastrichtian.

Plate 3

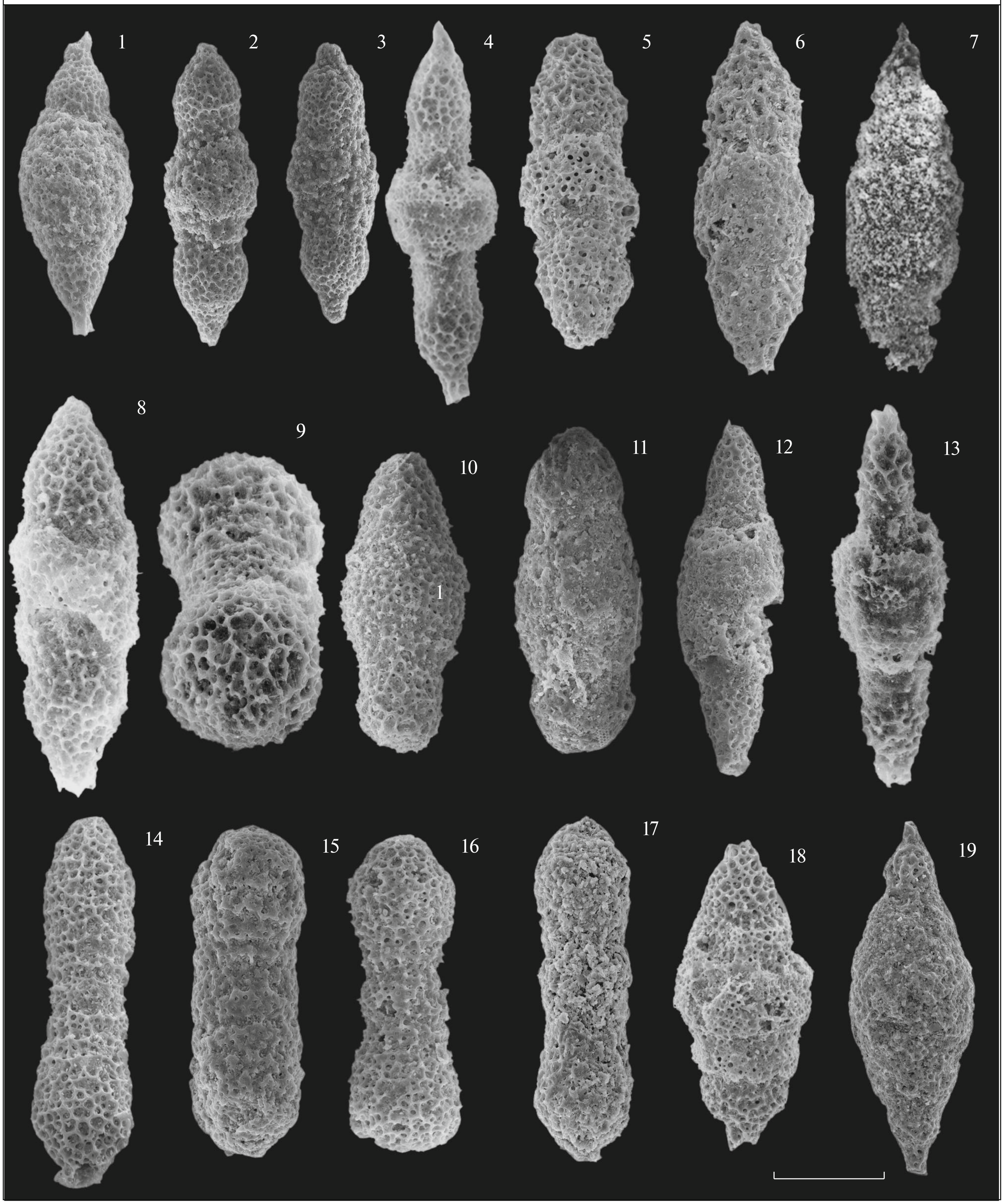

Plate 3. Campanian radiolarians of the Prunobrachidae family from the sections of North Caucasus, Saratov oblast, and Polar Urals; the scale bar is 100 μm long. Figure 1 corresponds to *Prunobrachium crassum* (Lipman, 1952); 2 and 3, *P. koslovae* Vishnevskaya, 2011; 4, *Spinibrachium amoni* Vishnevskaya, 2011; 5, 6, 8, *P. koslovae* Vishnevskaya, 2011; 7, *P. articulatum* (Lipman, 1952); 9, 14, and 15, *Pseudobrachium gracilis* Vishnevskaya, 2011; 10 and 11, *P. crassum* (Lipman, 1952); 12 and 13, *P. boreale* Vishnevskaya, 2011; 16 and 17, *Pseudobrachium trilobatum* Vishnevskaya, 2011; 18 and 19, *P. articulatum* (Lipman, 1952). The samples shown in images 1, 2, and 3 were collected in Saratov oblast, Bannovka section; 4–14, 16, and 18, Polar Urals, Well 22, 110–114 m depth; 7, Northern Caucasus, Urukh sections; 17 and 19, Saratov oblast, Lysaya Gora section; 15, Rostov-on-Don, Belaya Kalitva River section.

Layers with *Crucella cachensis–Alievium superbum* (Turonian) are found in the Sobolevskoe section; their age was determined by the *Alievium superbum* index species, which is the zonal one for the Turonian of the Gulf of California and Mediterranean, as well as by the first occurrence of *Crucella cachensis* (Vishnevskaya, 2010). The layers correlate well to the CC 11 nannoplankton zone.

Layers with *Alievium praegallowayi–Archaeospongoprunum triplum* (Coniacian) are found in the Sobolevskoe and Chernetovo sections. The epibole of the *Archaeospongoprunum triplum* species characterizes the lower subzone of the *Alievium praegallowayi* zone of the Coniacian from the zonal scheme for California (Pacific Province). The joint location of these species with *Inoceramus kleini* (Müller), *Cremnoceramus waltersdorfensis* f. *hannovrensis* (Heinz), and *C. deformis* f. *erectus* (Meek) supports the Coniacian age of the layers (Olferiev et al., 2005). The layers are quite correlatable to the CC 13 nannoplankton zone.

Layers with *Pseudoaulophacus floresensis–Archaeospongoprunum bipartitum* (Lower Santonian) are revealed in gaizes from the sections of Tambov oblast. The limits of the layers are made by the disappearance of *Archaeospongoprunum bipartitum*, whose evolution ended in the Santonian (Vishnevskaya, 2010).

Layers with *Crucella espartoensis–Alievium gallowayi* (Upper Santonian) are distinguished in the Vishnevoe section. The age of layers was determined by the presence of the index species from the *Alievium gallowayi* radiolarian zone (Santonian).

Layers with *Lithostrobus rostovzevi–Archaeospongoprunum rumseyensis* (Upper Santonian–Lower Campanian) are distinguished in the Vishnevoe section. This radiolarian assemblage correlates well to the *L. rostovzevi* complex of the Upper Santonian–Lower Campanian from the Moscow syneclise.

Layers with *Prunobrachium mucronatum* (uppermost Lower Campanian–lowermost Upper Campanian) are found in the Vishnevoe section near Shilovka sett. and the Ulyanovsk area of the Volga region and are correlated to the complex 2 from the Volgograd area of the Volga region (Vishnevskaya, 2010). They are probably equivalent to the *Archangelskiella specillata* nannoplantonic zone of the Lower Campanian (Dmitrenko et al., 1988).

Layers with *Prunobrachium articulatum* (Upper Campanian) are clearly traced in the sections of the EEP, West Siberia, and Subpolar Urals. This is a clear biostratigraphic marker of the terminal part of the Upper Campanian (*Prakticheskoe*..., 1999).

Layers with *Archaeospongoprunum andersoni–Archaeospongoprunum hueyi* (Upper Campanian, probably also the lowermost Maastrichtian) are found in the Efremovo–Stepanovka section. The age of the layers is Upper Campanian, or probably the very beginning of the Maastrichtian, according to the first occurrence of *Archaeospongoprunum andersoni* Pessagno and the last occurrence of *Archaeospongoprunum hueyi* Pessagno, which ceased to exist in the Campanian (Vishnevskaya, 2010). The layers are clearly correlated to the CC 22b nannoplankton zone.

Layers with *Spongurus marcaensis–Rhombastrum russiense* (lowermost Maastrichtian) are found in the Efremovo-Stepanovka section and are dated to the Early Maastrichtian (Guzhikov et al., 2017; Vishnevskaya, 2010).

Nannoplankton-Based Zones

The proposed zonal subdivisions are based on the publications by M.N. Ovechkina. Some specific intervals from the sections of the EEP in her works contain the comprehensive validation of ages of particular stratigraphic intervals of the Upper Cretaceous; all these data are summarized in (Ovechkina, 2007). The new comprehensive data, including the nannoplankton-based subdivision, can be found in the recent publications on Campanian and Maastrichtian sections from Ulyanovsk area of the Volga region (Olferiev et al., 2008; Pervushov et al., 2015). The sections of the southern EEP (Rostov oblast) are described in both joint publications and the monograph mentioned above (Benyamovskiy et al., 2012).

RESULTS AND DISCUSSION

The proposed scheme includes the stratigraphic units distinguished based on several microfossil groups and indicates the significant influence of the paleogeographic settings on the taxonomic diversity of BF, PF, and radiolarians. This is the reason that the distinguished zones, subzones, and layers differ from the analogous ones in more detailed schemes for southern regions; for example, the detailed PF-based scheme of Upper Albian and Cenomanian deposits for the Crimean–Caucasian region cannot be used for the EEP sections (Kopaevich and Vishnevskaya, 2016). The detailed scheme by O’Dogherty (1994) for the Mediterranean is based on radiolarians (O’Dogherty, 1994). In the Albian–lowermost Lower Cenomanian it is characterized by the *Thanarla spoletoensis* Zone that includes three subzones (from bottom to top: *Mallanites romanus*, *Pogonias missilis*, *Dorypyle* (?) *anisa*); however, these index species have not been reported in the EEP section (Bragina, 2016).

PF taxonomic diversity increases in the Turonian–Coniacian interval owing to the special morphotypes of the new Marginotruncanidae group that appeared in the Mediterranean belt and spread northwards (Coccioni and Premoli Silva, 2015; Kopaevich and Vishnevskaya, 2016; Robaszynski and Caron, 1995). This interval is characterized by stable PF/BF ratios as high as 50 to 70%, or sometimes higher (Kopaevich, 2011). The Turonian–Santonian interval is also characterized by a high level of diversity of radiolarian morphotypes; thus, the PF- and radiolarian-based layers distinguished at this level may be identified as zones during more detailed areal investigations.

Beginning from the end of the Santonian, the water masses of the East European Paleobasin gradually cooled. The deposits of the Santonian–Campanian boundary are characterized by taxonomically depleted PF complexes, because the diversity of the Marginotruncanidae group, to which the index species belonged, decreased and the new morphotypes of the Globotruncanidae group evolved gradually and did not quickly reach a high diversity level (Kopaevich and Vishnevskaya, 2016). Cooling at the Santonian–Campanian boundary is reliably supported by the depleted nannoplankton diversity (Ovechkina, 2007) and by the occurrence of Prunobrachidae family representatives that were adaptable to the boreal conditions in radiolarian assemblages. The BF composition in this interval is also characterized by the earlier occurrence of some taxa in the Crimean Paleobasin and by their later migration to the basins of the southern EEP (Beniamovsky and Kopaevich, 2016). The conducted analysis of PF and radiolarians distribution of the Baksan and Urukh reference sections (Northern Caucasus) has shown the joint presence of tropical and boreal species, which can be used as a link to correlate the boreal and Tethyan biostratigraphic schemes (Kopaevich and Vishnevskaya, 2016).

CONCLUSIONS

The traditional biostratigraphic scheme for subdivision of Upper Cretaceous deposits for the EEP, which is based on distribution of macrofaunal remains of inoceramids (Cenomanian–Coniacian) and belemnites (Campanian and Maastrichtian) in the sections and on the Western European standard (Olferiev and Alekseev, 2003, 2005), has been supplemented with microfossil-based biostratigraphic units. The new composite scheme of subdivision of Upper Cretaceous deposits based on microfossils for the EEP includes 12 PF-based units, as well as 23 BF-based, 10 radiolarian-based, and 16 nannoplankton-based units. The subdivision of Upper Cretaceous deposits of the EEP based on several groups of microfossils (foraminifera, radiolarians, and nannoplankton) makes the scheme even more reliable and enhances its correlation potential.

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