Foraminifers and Radiolarians across the Albian–Cenomanian and Cenomanian–Turonian Boundaries (Northern Peri-Tethys)

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Abstract—Changes in morphological diversity and taxonomic composition of late Albian–early Turonian foraminiferal and radiolarian assemblages from the northern Peri-Tethys are considered. Several stages are defined in evolution of planktonic foraminifers: polytaxic (Albian–Cenomanian), oligotaxic (Cenomanian–Turonian boundary period), and polytaxic (Turonian). The Albian–Cenomanian stage was characterized by intense development of rotaliporids representing an intricate group of planktonic foraminifers, which became extinct in the terminal Cenomanian. An intense speciation of the radiolarian genus *Crolanium* and last occurrences of its most species, the index species *C. cuneatum* included, was characteristic of the terminal Albian. Spheroid and discoid radiolarians were dominant in the Cenomanian, while the Turonian was marked by intense development of all the radiolarian morphotypes.

INTRODUCTION

The Albian–Cenomanian and Cenomanian–Turonian boundaries mark significant tectonic and paleogeographic events in the Peri-Tethys such as formation of a new system of rift basins accompanied by intense volcanism and sharp changes in oceanic environments and current system. In the Crimea–Caucasus region, intense rifting and associated volcanism of the Albian–Cenomanian boundary time greatly influenced the character of sedimentation. In this region, deposits of the terminal Albian frequently contain admixture of tuffaceous material, e.g., in Crimea, or tuff layers as in the Caucasus (Baraboshkin et al., 1998).

Both boundary periods were characterized by changes in aeration regime of oceanic waters. For example, the terminal Albian and Cenomanian–Turonian transition corresponded to the Ocean Anoxic Events (OAE) 1 and 2, respectively. All these important abiotic events exerted influence upon evolutionary trends of biota, foraminifers and radiolarians included. Radiolarians, which are better represented than foraminifers in sediments accumulated during anoxia events, are of particular stratigraphic significance.

The *Albian–Cenomanian boundary* separates two series of the Cretaceous System. In many regions of Europe, it marks a sharp change in sedimentation, the transition from clayey–sandy sediments to purely carbonate facies. Remarkable events in evolution of

ammonites, inoceramids, planktonic foraminifers, radiolarians, and other fossil groups were associated with the Albian–Cenomanian boundary period. As is mentioned, the terminal Albian corresponded to the last phase of the OAE 1. This specific paleogeographic phenomenon lasted since the Barremian until the terminal Albian. In the Caucasus region, the relevant event was most intense at the time of the *Mortoniceras (M.) rostratum* Zone with *Chondrite*-type fucoids, black shale interbeds, and elevated C_{org} contents up to 5.3% (Baraboshkin et al., 1998, 2003).

The events under consideration are of particular interest in connection with recent work on determination of the Albian–Cenomanian boundary, which is in progress under supervision of the International Subcommission on Cretaceous Stratigraphy (Rawson et al., 1996). The work is aimed at searching the new global stratotype sections and points (GSSP) for the boundary in most complete sections with representative paleontological remains.

Ammonites, planktonic foraminifers, and radiolarians facilitating the high-resolution stratigraphic subdivision of the Albian–Cenomanian boundary interval are appropriate fossil groups for substantiating the boundary position between the stages. By the end of the last century, zonation of planktonic foraminifers was elaborated in fine detail (Caron, 1985; Sliter, 1989; Robaszynski et al., 1990; Bralower et al., 1995;

Substage	Ammonite zonation	Biotic events	Planktonic foraminifer subzones	Boundaries based on planktonic foraminifers
Lower Cenomanian	Mantelliceras mantelli	R. ticinensis / R. gandolfi / R. globotruncanoides	R. globotruncanoides	R. globotruncanoides (mass quantity)
Upper Albian	Stoliczkaia dispar	Planomalina buxtorfi / R. appenninica	R. appenninica	R. globotruncanoides
			R. appenninica/ ticinensis	
			R. appenninica/ P. buxtorfi	
	Mantelliceras perinflatum	Rotalipora ticinensis	Rotalipora ticinensis	R. appenninica

Fig. 1. Stratigraphy of upper Albian–lower Cenomanian sediments based on ammonites and planktonic foraminifers.

Robaszynski and Caron, 1995). Based on certain biotic events, e.g., on appearance and extinction of orthostratigraphic foraminiferal and radiolarian taxa, even subzones have been defined in zonal units (O'Doherty, 1994; Gale et al., 1996).

In the recent zonations of planktonic foraminifers, the terminal Albian interval corresponding to the *Stoliczkaia dispar* ammonoid zone is correlated with the foraminiferal *Rotalipora appenninica* Zone (Fig. 1). Range of the latter is between first appearance datums (FAD) of zone index species and *Rotalipora globotruncanoides* Sigal (Robaszynski and Caron, 1995; Gale et al., 1996). According to some authors, the zone base coincides with the FAD of *Planomalina praebuxtorfi* Wonders and *P. buxtorfi* Gandolfi, and marks gradual disappearance of *Biticinella* and *Ticinella* forms. *Schackoina cenomana* (Schacko) with radially elongated chambers appears in this zone as well. Tendency toward elongation of chambers is also observable in some species of the genus *Hedbergella* (Gorbachik and Aleksandrova, 2001).

The zone interval is marked by succession of events recorded in the Mont Risou section (France) that is proposed for the GSSP of Albian–Cenomanian boundary (Gale et al., 1996) and in a relatively complete upper Albian sections of the northern Caucasus (Baksan, Kheu, and others). In the lower part of the zone, the index species occurs in association with planispiral keeled form *Planomalina buxtorfi* Gandolfi (*Rotalipora appenninica–Planomalina buxtorfi* Subzone). The next event is the last appearance datum (LAD) of *Planomalina buxtorfi*. Co-occurrence of *Rotalipora appenninica* (Renz) and *R. ticinensis* Gandolfi marks the *R. appenninica–ticinensis* Subzone, and the LAD the last species coincides with the base of the *Rotalipora appenninica* Subzone. In the Caucasus, the appearance of *R. gandolfii* Luterbacher et Premoli Silva is confined to the interval under consideration.

The Albian–Cenomanian boundary is placed at the base of the *Rotalipora globotruncanoides* Zone corresponding to the FAD of its index species (Fig. 1). In the radiolarian scale, this boundary coincides with the LAD of *Crolanium cuneatum*.

The *Cenomanian–Turonian boundary.* Substantial paleoclimatic and paleoecological changes, which influenced practically the entire Peri-Tethys, were in progress at the Cenomanian–Turonian boundary time. The Cenomanian–Turonian boundary sections, which accumulated in different paleogeographic settings from shallow epicontinental basins to oceans, frequently enclose black bituminous layers, origination of which is usually related to anoxic environments. During the boundary period, oxygen deficiency in waters favored accumulation of unoxidized organic matter. Signs of such sedimentation are recorded in sections of the Tethys and its marginal zones, and in deep-sea drilling holes in the Atlantic and Pacific oceans.

The relevant short-term episode (approximately 1 myr) is termed as the Ocean Anoxic Event 2 (OAE 2). The Cenomanian–Turonian sections of mostly light limestones and marls enclose from one to several dark-
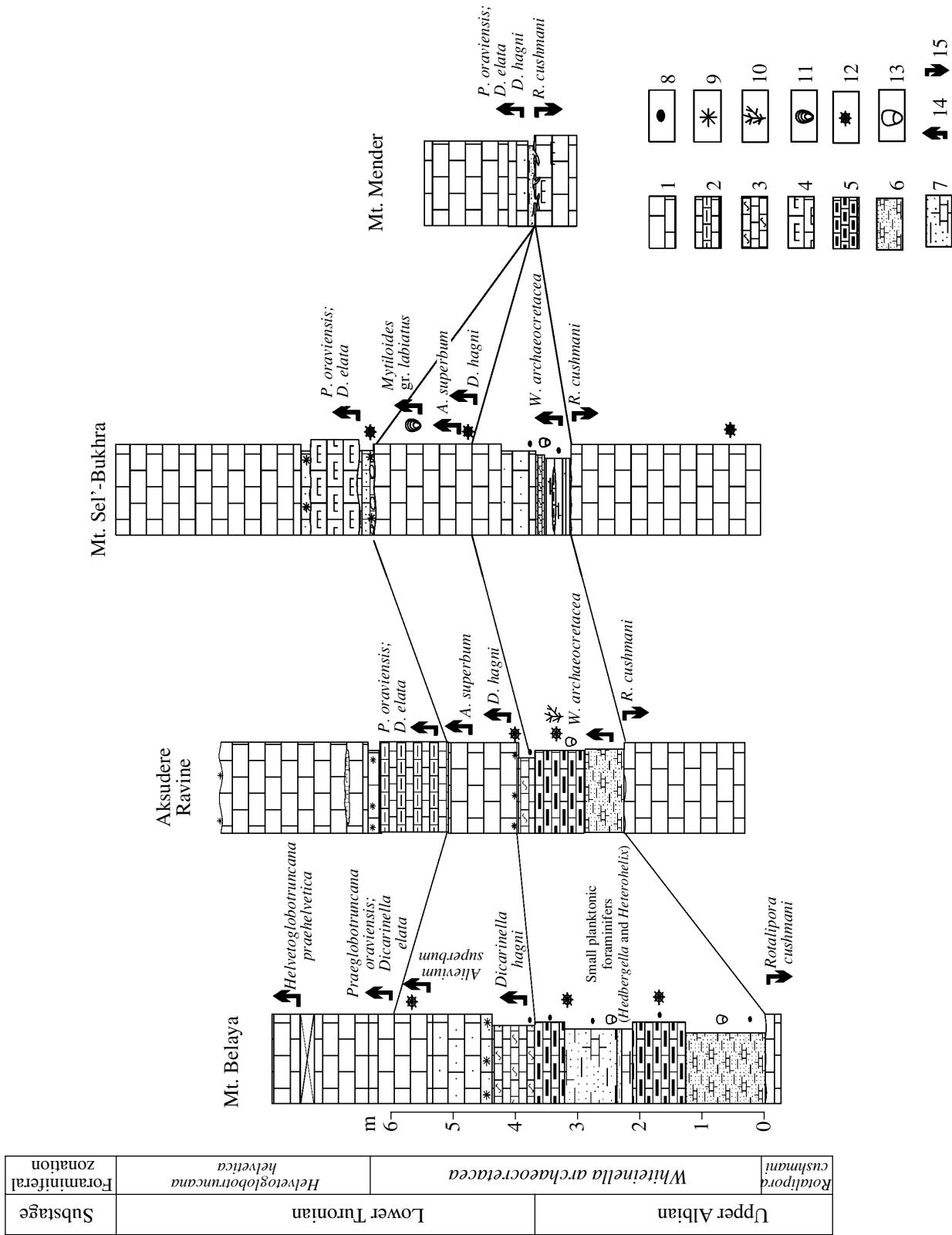
Fig. 2. Signs of the Cenomanian–Turonian anoxic event in Crimean sections and correlation with other biotic events: (1) limestone; (2) rhythmically alternating light-colored and darker limestones; (3) bioturbated limestone; (4) silicified limestone; (5) bituminous interbeds; (6) carbonate clay; (7) limestone with admixture of siliciclastic material; (8) pyrite concretions; (9) glauconite; (10) *Chondrites*; (11) inoceramids; (12) radiolarians; (13) fish scale; (14) first occurrence of taxa; (15) last occurrence of taxa.

Substage	Ammonite zonation	Planktonic foraminifer zonation	Biotic events				
			Ammonites	Planktonic foraminifers	Nanno-fossils	Inocerams	Radiolarians
Lower Turonian	*Mammites nodosoides*	*Helvetoglobotruncana helvetica*					
Lower Turonian	*Watinoceras coloradoense*	*Helvetoglobotruncana helvetica*	*Watinoceras coloradoense*	*Helvetoglobotruncana helvetica* / *Dicarinella hagni*	*Quadrum gartneri*	*Mytiloides labiatus*	*Alievium superbum* / *Crucella cashensis*
Upper Cenomanian	*Neocordioceras juddii*	*Whiteinella archaeocretacea*		*Whiteinella archaeocretacea*			
Upper Cenomanian	*Metoicoceras geslinianum*	*Whiteinella archaeocretacea*		*Rotalipora cushmani*			
Upper Cenomanian	*Calycoceras naviculare*	*Rotalipora cushmani*		*Heterohelix reussi* / *Dicarinella* spp.			

Fig. 3. Standard zonation of the Cenomanian and Turonian stages.

colored interbeds with a high concentration of organic carbon from 1–2 to 20%. Thin lamination and lack of bioturbation in the interbeds indicate disappearance of crawling and fossorial benthic organisms. Even if the Cenomanian–Turonian boundary sediments are lacking dark coloration, they contain specific microfossil assemblages and reveal isotopic signatures indicative of anomalous paleogeographic settings. The elevated $\delta^{13}C$ values ranging from to +4‰–+5‰ in distinction from background values of +2‰–+3‰ typical of underlying and overlying limestones are interpreted as indicating a rapid burial of tremendous volumes of organic matter in sediments and a high bioproductivity in the World Ocean (Schlanger and Jenkins, 1976; Leckie, 1987).

The elevated carbon content is recorded in sediments accumulated on oceanic plateaus, in pelagic areas, continental margins, and shelf seas. Signs of the Cenomanian–Turonian anoxic event are established in C_{org}-rich sediments of many localities: the western, central, and eastern margins of the Mediterranean (Italy, Spain, Switzerland, Libya, Tunisia, Morocco) (Schlanger and Jenkins, 1976; Butt, 1982; Thurow et al., 1982; Arthur et al., 1986; Schlanger et al., 1986; Wiedmann et al., 1986; Jarvis et al., 1988; Robaszynski et al., 1990, 1994, and others; Kuhnt et al., 1992; Premoli Silva and Sliter, 1995; Salaj, 1996); sections of the epiplatform cover in central and northern areas of West Europe (North Sea, Germany, France) (Ernst et al., 1979; Sholle and Arthur, 1980; Burnhill and Ramsay, 1981; Hilbrecht and Hoefs, 1986); East Europe (Poland, former Yugoslavia, former Czechoslovakia) (Peryt, 1980; Salaj, 1996); the Atlantic region (England, several deep-sea holes) (Jarvis et al., 1988; Erbacher and Thurow, 1997); western coast of Africa (Nigeria, Senegal) (Kuhnt et al., 1992); the seaway that existed in central part of North America (Interior basins of the United States and Canada, Alaska, the Canadian Arctic Islands) (Eicher and Worstell, 1970); South and Central America, the Caribbean region (Mexico, Venezuela, Honduras, Guiana) (Finch, 1981; Renz, 1981); the Pacific region (Toshimitsu et al., 1995); the southeastern coast of Africa (Zaire, Mozambique) and underwater Naturalist Plateau near southwestern Australia (Davies et al., 1974); the southern extremity of India (Venkatachalapathy and Ragothaman, 1995).

In the eastern Mediterranean and northern Peri-Tethys, similar rocks are known in sections of the Crimea (Fig. 2), northern Caucasus, Mangyshlak, Kopetdagh, and Central Asia (Tajik Depression, eastern and western areas, Amu-Dar'ya syncline) (Naidin and Alekseev, 1981; Dzhalilov et al., 1986; Alekseev et al., 1997; Korchagin, 1998; Tur, 1998; Kopaevich and Kuzmicheva, 2002).

Some materials from these regions are interpreted based on comprehensive analysis of lithological, micropaleontological, and geochemical data, and researchers reconstructed specific paleogeographic and paleotectonic settings. Widespread bituminous facies imply that their deposition was controlled by anoxic conditions rather than by local configuration of basins. These facies accumulated under influence of two main factors: the Late Cretaceous transgression that widened shallow epicontinental and marginal seas, being accompanied by enhanced production of organic carbonate, and a uniform global climate that reduced reserves of cold oxygen-enriched bottom waters in the World Ocean.

The Cenomanian stratigraphy is based on evolutionary morphological changes of the genus *Rotalipora.*

Stage	*Member, submember	Macrofossil zonation	Planktonic foraminifer zonation	Nannofossil zonation	Bioevents
Turonian	X	*Inoceramus costellatus*	*Marginotruncana lapparenti*	*Tetralithus obscurus*	
		Inoceramus lamarcki-apicalis			
	IX	*Mytiloides hercynicus*	*Dicarinella elata*	*Quadrum gartneri*	
	VIII				
	VII	*Mytiloides mytiloides*	**D. hagni*		
Cenomanian	VI-3		**Dicarinella imbricata*	*Microrabdulus decoratus*	
	VI-2				
	VI-1				
	V		*Rotalipora cushmani*	*Chiastozygus cuneatus*	
	IV-2	*Turrilites costatus*			
	IV-1				
	III	*Mantelliceras mantelli*	*Rotalipora deeckei*	*Chiastozygus amphipons*	
	II				
	I		*Rotalipora appeninnica*		

Bioevents (vertical, left to right): *D. hagni*, *P. oraviensis*, *M. gr. labiatus*, *R. cushmani*, *W. archaeocretacea*, *D. elata*, *Quadrum gartneri*, *Alievium superbum*.

* Members and submemebers after Alekseev et al. (1997); ** *Dicarinella imbricata* and *Dicarinella hagni* subzones
are after Kopaevich and Kuzmicheva (2002).

Fig. 4. Stratigraphy of Cenomanian and Turonian sediments of the southwestern Crimea based on macro- and microfossils.

Extinction of the genus representatives at the Cenomanian–Turonian boundary time was antedated by quantitative and qualitative changes in the structure of foraminiferal assemblages. The present-day zonation of Cenomanian sediments is as follows (Figs. 3, 4).

The *Rotalipora globotruncanoides* Zone spans interval up to the FAD of *Rotalipora reicheli* (Mornod), which appears near the lower–middle Cenomanian boundary.

The *Rotalipora reicheli* Zone is defined close to the lower boundary of the *Acanthoceras rhotomagense* ammonite zone. Its upper boundary corresponds to the FAD of *Rotailpora cushmani* (Morrow). The last index species occurs together with first *Rotalipora cushmani* in the middle part of the *Acanthoceras rhotomagense* Zone.

The *Rotalipora cushmani* Zone extends from the FAD of its index species to the upper part of the upper Cenomanian *Metoicoceras gestlinianum* Zone of ammonite scale. All representatives of the genus *Rotalipora* became extinct precisely at this level before the terminal Cenomanian.

The next *Whiteinella archaeocretacea* Zone (the uppermost Cenomanian–lower Turonian) corresponds to a short period of specific paleogeographic situation, when the OAE 2 settings were responsible for extinction of highly specialized *Rotalipora* species and favorable for development of non-keeled taxa belonging to genera *Hedbergella, Whiteinella*, and *Heterohelix*. The termination of anoxic event at the beginning of the Turonian coincided with appearance and development of other planktonic foraminifers of genera *Helvetoglobotruncana, Dicarinella*, and *Marginotruncana*.

FORAMINIFRAL ASSEMBLAGES OF THE PERI-TETHYS

Morphological changes in foraminiferal tests during the late Albian–Cenomanian. The Albian–Cenomanian stratigraphy is based on evolution, phylogeny and morphological changes of foraminifers representing an individual group of planktonic microorganisms. Their development commenced in the Early Mesozoic and was associated with appearance and perfection of adaptive means for floating in pelagic zone. Based on morphological features, they are classed with the superorder Globiderinoida, orders Globigerinida and Heterochelicida (Maslakova, 1995). The first order more diverse in terms of morphology and taxonomy than the second one is of special interest from the viewpoint of evolution, paleogeography, and stratigraphy. During the Jurassic and Cretaceous, globigerinids evolved toward a high taxonomic diversity and abundance in populations and colonizing new geographic areas.

Evolution of globigerinids was accompanied by formation and perfection of various structural features of their tests and cytoplasm meant for the planktonic way of life. Newly formed test morphotypes allowed globigerinids to colonize new bathymetric zones and areas of the World Ocean remote from the shore (Hart and Bailey, 1979; Gorbachik, 1886, 1989; Leckie, 1987). The gradual evolution of globigerinids is divisible into
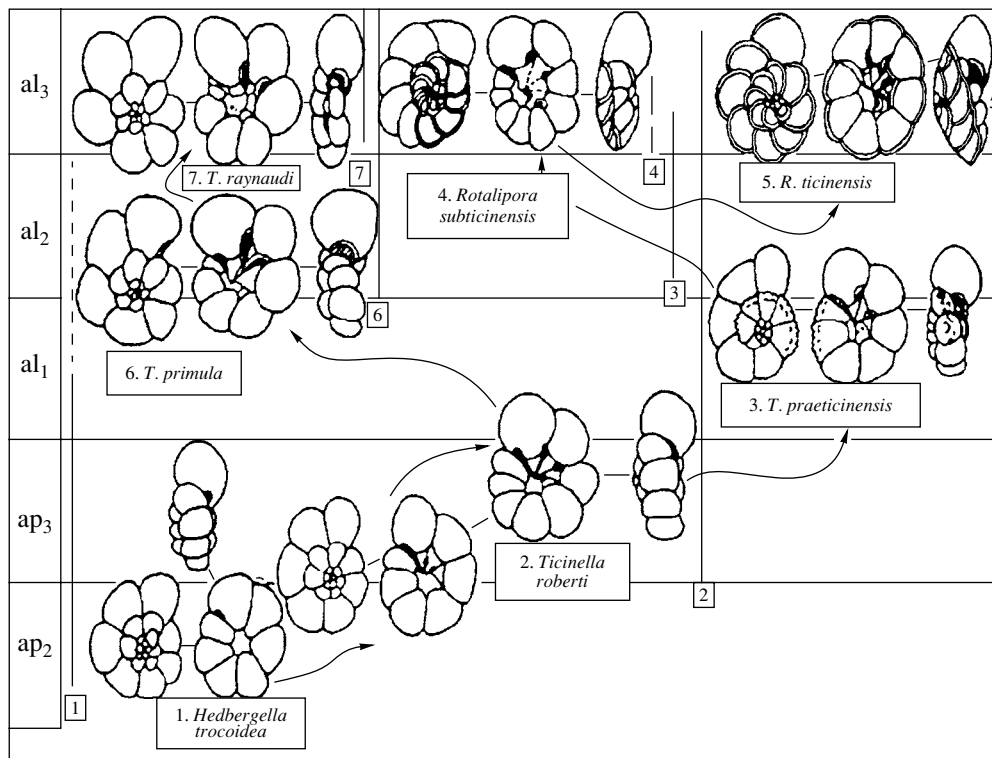
**Fig. 5.** Phylogenetic lineages of some representatives of genera *Hedbergella, Ticinella,* and *Rotalipora*.

periods of alternating higher and reduced taxonomic diversity in respnse to major paleogeographic reorganizations on the Earth. The Albian–Cenomanian was one of remarkable periods in development history of globigerinids. This period corresponded to commencement of globigerinid flourishing and rapid evolution of the family Rotaliporidae with diverse morphological features. When analyzing morphological peculiarities of globigerinid species, which successively appeared during the Albian–Cenomanian, we can observe new features or their new combinations characterizing evolutionary trend of these foraminifers.

By the beginning of the late Albian, main features characteristic of different globigerinid taxa: type of test and wall structure, peripheral edge patterns, aperture, umbo, sculpture, test shape, number of chambers, and others, were already formed. Many of these features are correlative between each other. Globigerinids of two structural types (planispiral and conispiral or trochoid) continued to exist in the late Albian–early Cenomanian. Among globigerinids of the last type, genera *Blefuscuiana* and *Hedbergella* were most conservative and longlived, while *Rotalipora* and *Ticinella* were most advanced, characterized by short existence periods.

In the course of their phylogenetic development in the Albian–Cenomanian, two last genera demonstrated the following morphological changes (Fig. 5, Plates I, II): (1) transformation of subspherical chambers into flattened ones that commenced in the late Aptian and

terminated in the Cenomanian (evolutionary lineage *Hedbergella trocoidea–Ticinella roberti–Ticinella praeticinensis–Rotalipora* spp.); (2) extension of the umbonal area and formation of relevant plates with additional apertures (evolutionary lineage *Ticinella roberti–Ticinella praeticinensis–Rotalipora subticinensis*); (3) transformation of additional umbonal apertures into umbonal–sutural apertures typical of some *Ticinella* species, i.e., of *Ticinella praeticinensis–Ticinella primula, T. raynaudi* during the middle and late Albian and of early *Rotalipora subticinensis* and *R. ticinensis* during the late Albian; (4) formation of additional sutural apertures beyond the umbo in Cenomanian species *Rotalipora gandolfii* and others; (5) transformation of the rounded wide peripheral edge at the later ontogeny stages into tapered one of early *Rotalipora* species and into sharply keeled of the late Albian (*R. subticinensis–R. ticinensis*) and Cenomanian *Rotalipora* forms. Keel of *Ticinella–Rotalipora* transitional species developed first due to formation of spinose sculpture along the peripheral edge and then due to flattening of chambers on umbonal and spiral sides also along the peripheral edge. As a result, biconvex tests characteristic of *Rotalipora* forms in the terminal Albian gave way to variable spiral–convex species of the Cenomanian time. The Cenomanian *Rotalipora* species had a combination of the following features: relatively wide umbo, sutural additional apertures, keel, flattened chambers, and spiral-convex shape
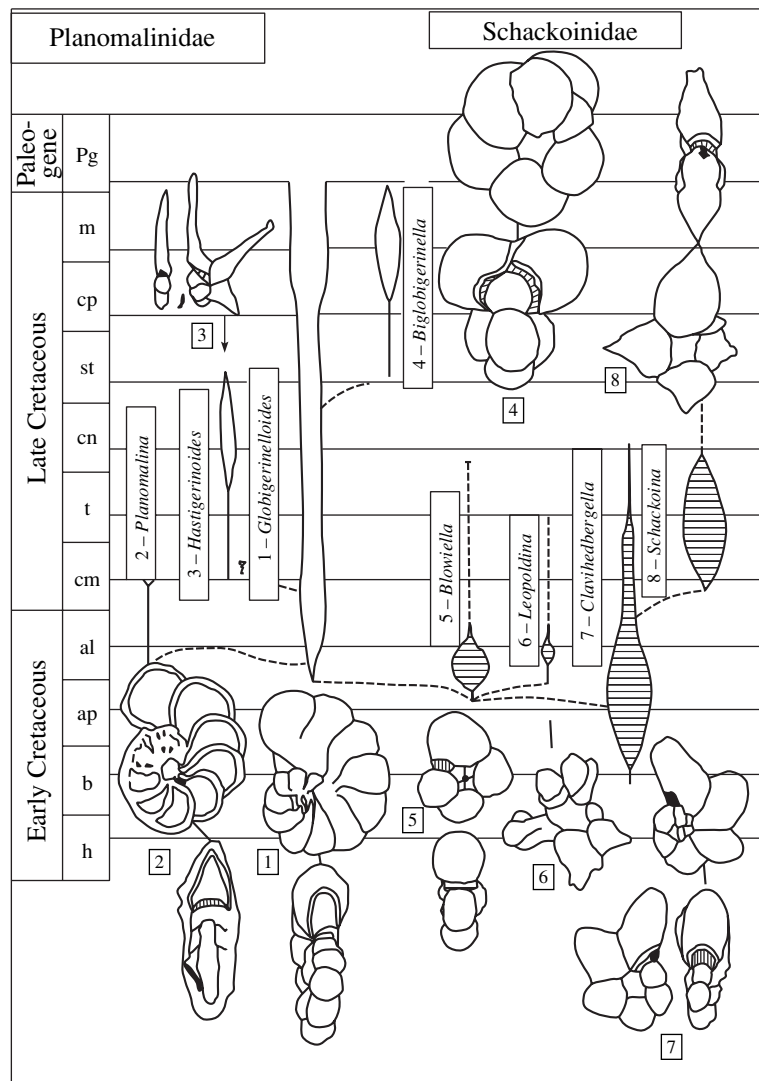
Plate I
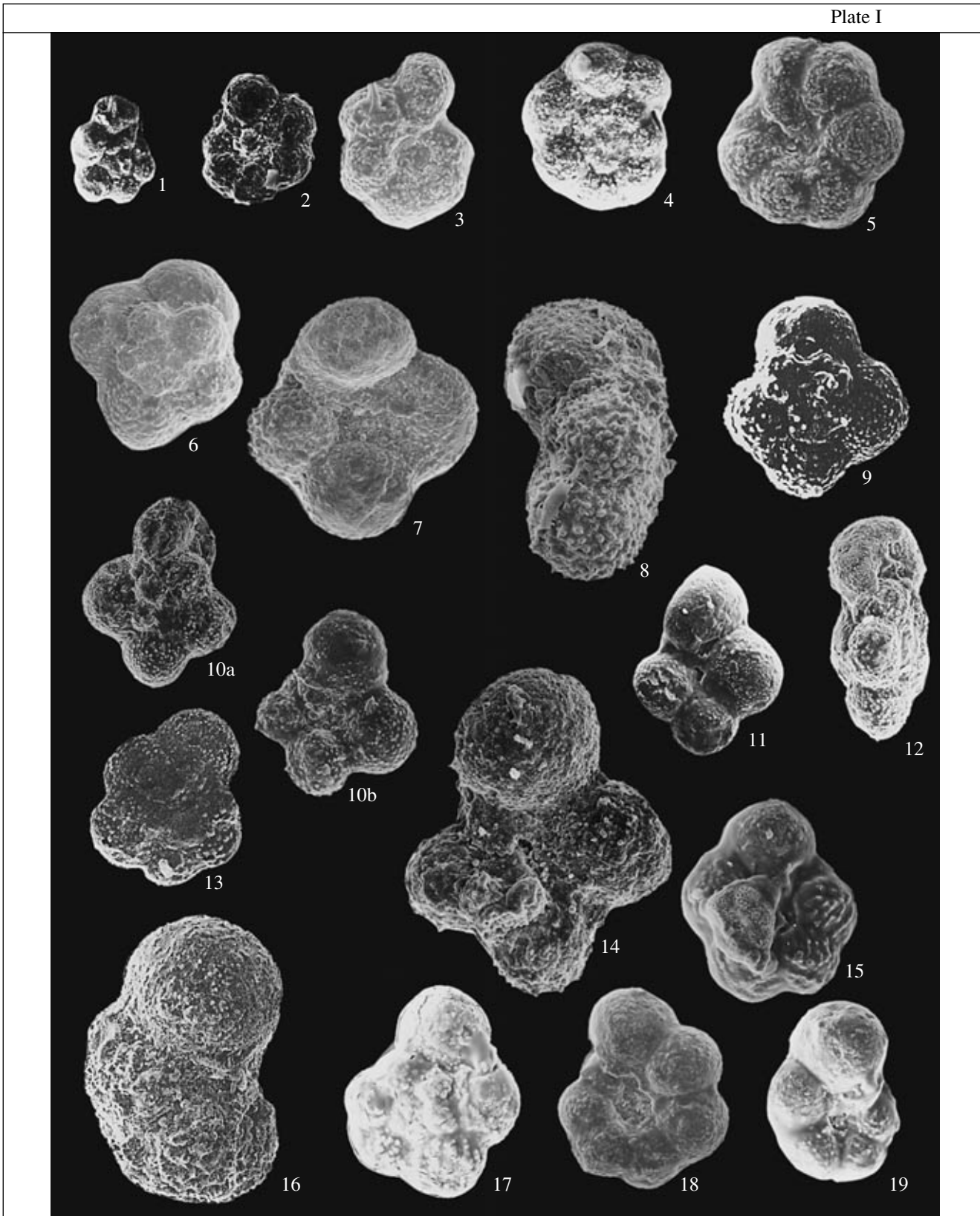
Fig. 6. Phylogenetic development of planomalinids and schackoinids at the generic level.

of tests. Other keeled forms appeared in the late Albian; these are *Praeglobotruncana* with a well-developed keel, though lacking additional apertures and, among planispiral forms, *Planomalina* with a keel and relict apertures at the base of septal sutures. Representatives of the last genus appeared in the late Albian (Figs. 6, 7).
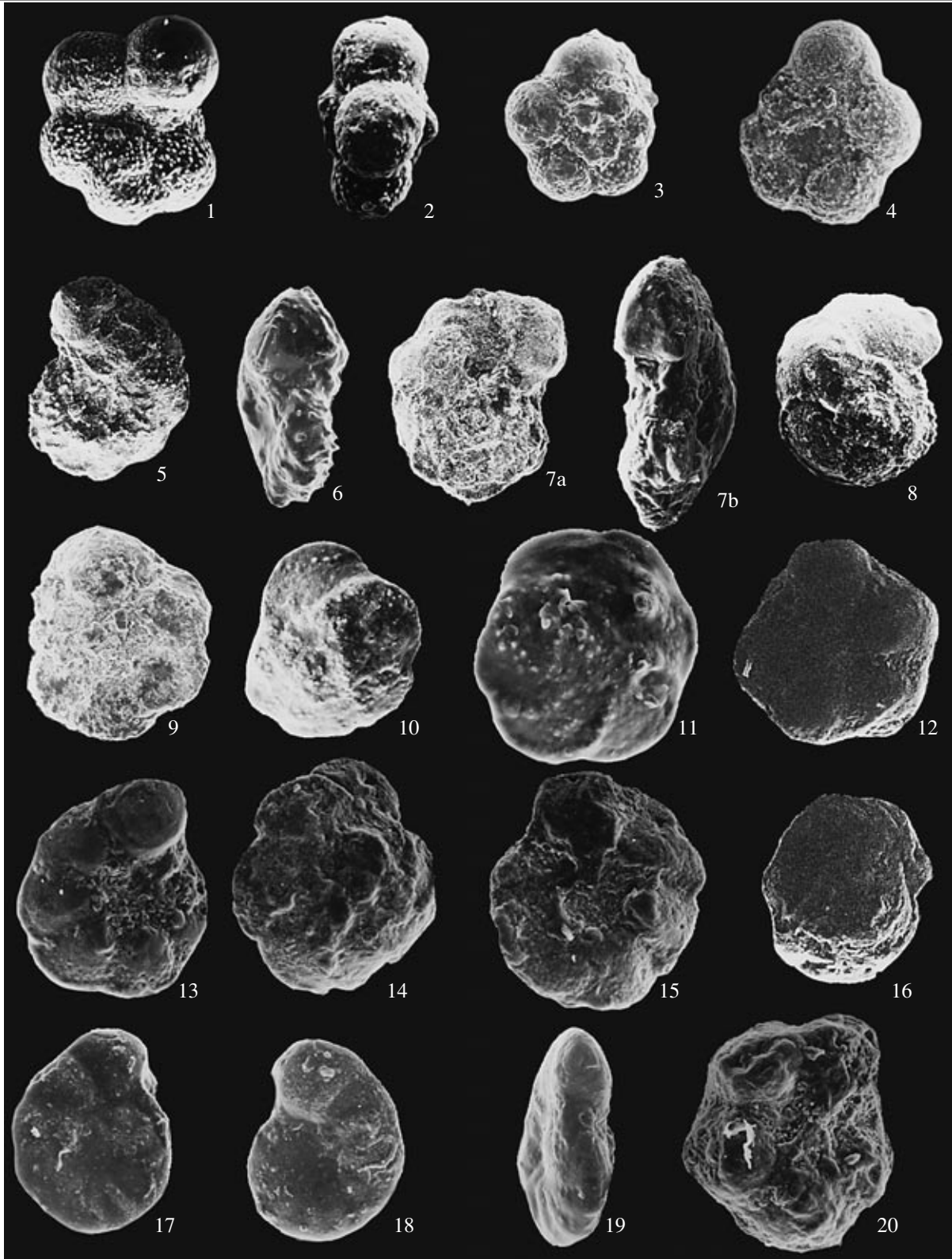
Thus, evolution of planktonic foraminifers through the late Albian and early Cenomanian resulted in appearance
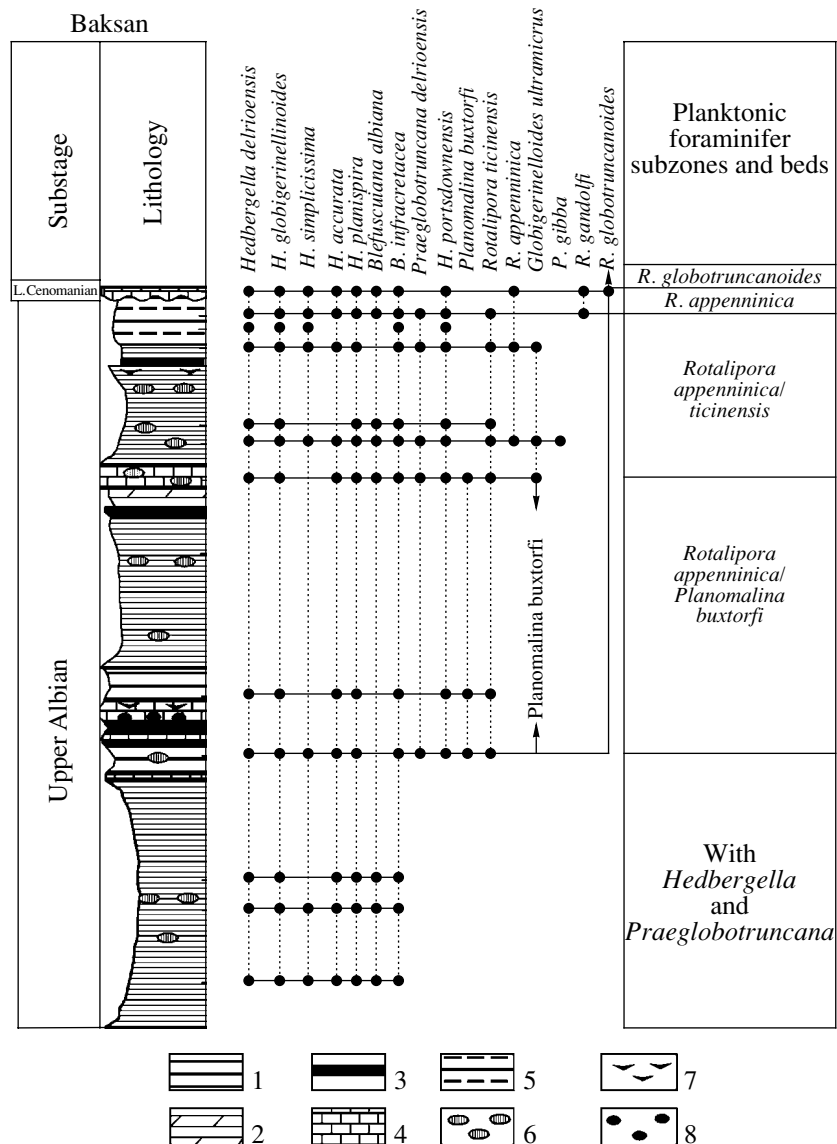
Plate II

Fig. 7. Distribution of foraminifers in the Baksan section (stratigraphy after E.Yu. Baraboshkin): (1) carbonate clay; (2) marl; (3) bituminous interbeds; (4) limestone; (5) clayey marl; (6) pyrite nodules; (7) tuff interbeds; (8) phosphorite nodules.

of morphotypes, which occupied both shallow-water zones of sea basins (non-keeled taxa) and their relatively deep areas (keeled taxa) (Hart and Bailey, 1979; Hart, 1980; Caron and Homewood, 1983, 1987).

Thus, among events that happened in evolution of planktonic foraminifers during the late Albian and early Cenomanian, changes in the aperture structure were most remarkable. For instance, formation of additional

Plate II. Foraminifers from upper Albian–Cenomanian boundary sediments of the northern Caucasus:

(1–4) *Blefusciuana aptiana* (Bartenstein) *orientalis* Boudagher-Fadel et al.: (1) specimen 285-6, umbonal side, ×140, Kheu River, Sample 26, (2) specimen 285-7, peripheral edge, ×140, Podkumok River, Sample 1, (3) specimen 285-11, spiral side, ×130, Baksan River, Sample 2, (4) specimen 285-10, umbonal side, ×200, Baksan River, Sample 37; (5–7) *Planomalina buxtorfi* (Gandolfi): (5) specimen 285-1, lateral side, ×85, (6) specimen 285-9, peripheral edge, ×135, (7a, b) specimen 285-6, (a) lateral side, ×90, (b) peripheral edge, ×120, Kheu River, Sample 26; (8, 9) *Rotalipora appenninica* (Renz): (8) specimen 285-7, spiral side, ×110, Kheu River, Sample 26, (9) specimen 285-8, umbonal side, ×115, Kheu River, Sample 24; (10–13) *Rotalipora ticinensis* (Gandolfi): (10) specimen 285-10, spiral side, ×115, Baksan River, Sample 44, (11) specimen 287-15, spiral side, ×115, Baksan River, Sample 51, (12) specimen 287-16, umbonal side, ×115, Baksan River, Sample 19, (13) specimen 287-17, umbonal side, ×115, Baksan River, Sample 16; (14, 15) *Rotalipora globotruncanoides* Sigal: (14) specimen 287-18, spiral side, ×115, Baksan River, Sample 51, (15) specimen 287-19, umbonal side, ×115, Baksan River, Sample 51; (16, 20) *Rotalipora gandolfii* Luterbacher et Premoli Silva: (16) specimen 287-20, spiral side, ×115, Baksan River, Sample 51, (20) specimen 287-21, umbonal side, ×115, Kheu River, Sample 34; (17–19) *Gavelinella baltica* (Brotzen): (17) specimen 285-12, spiral side, ×200, (18) specimen 285-13, umbonal side, ×150, (19) specimen 285-14, peripheral edge, ×160, Baksan River, Sample 54; collections of foraminifers nos. 285 and 287 at the Chair of Paleontology, Geological Faculty, Moscow State University.

umbonal-sutural apertures in non-keeled forms commenced in the middle (*Ticinella praeticinensis*) and terminated in the late Albian (*Ticinella primula–raynaudi*). Development of similar additional apertures characterized also the late Albian keeled (completely or partly) species of the genus *Rotalipora* (*R. subticinensis, R. ticinensis*). Entirely sutural apertures unrelated to the umbo appeared first at several ultimate chambers (*Rotalipora ticinensis, R. appenninica*) in the terminal Albian and then at all chambers of the last whorl (*Rotalipora gandolfii*) in the early Cenomanian. Combination of such features as the keel and sutural additional apertures originated at the beginning of the Cenomanian. Such a combination appeared for the first time in the evolution of planktonic foraminifers.

During the subsequent evolution of the genus *Rotalipora*, additional sutural apertures became gradually isolated from the main aperture. It is assumed that development of this lineage was blocked by oxygen deficiency that progressed in water basins in both the vertical and lateral directions. Mechanism of this influence on the highly specialized group of foraminifers is unclear: it can be related to reproduction and selection or bloom of some algae. It is only obvious that primitive taxa survived this event and continued their development.

Of interest is the comparative analysis of the anoxia influence on evolution of foraminiferal groups. For example, the OAE 1 sharply reduced diversity of benthic foraminifers, although development of planktonic morphotypes was in progress, and they reached a substantially high diversity in the late Albian, especially at the time of the *Stoliczkaia dispar* Zone (Leckie, 1987; Gorbachik and Kopaevich, 1992).

In addition, an innovation in development of globigerinids was their sculpturing in a form of regular polygonal cells typical of *Favusella washitensis* tests of the late Albian. In the same period, representatives of many genera that existed at that time had perforation of greater size and more chambers per a whorl.

DISCUSSION

From the viewpoint of morphological–functional analysis, we can conclude that morphological features newly formed or transformed during the late Albian–early Cenomanian facilitated adaptation of globigerinids to pelagic environments. Owing to additional apertures and large pores, their tests were lighter, more buoyant and enhancing exchange of cytoplasm with external medium. The sculpturing elements such as keels, tubercles, spines, and ridges typical, for example, of *Costellagerina lybica* (Barr) increased surface of tests, improved their contact with surrounding seawater, and enhanced the floating ability.

Last rotaliporids occur in the upper Cenomanian sediments of the *Metoicoceras geslinianum* ammonoid zone. The *Whiteinella archaeocretacea* Zone corre-

sponds to the section interval containing black interbeds enriched in organic matter. The foraminiferal assemblage of this zone consists of cosmopolitan species resistant to significant changes in hydrological parameters such, e.g., to a temperature fall due to upwelling or to oxygen deficiency because of a poor water aeration. This level is marked by sharp impoverishment of benthic foraminiferal communities up their complete extinction. According to comparison, foraminiferal assemblages of the *Whiteinella archaeocretacea* Zone from different regions differ slightly from each other in taxonomic composition and abundance. The only feature in common is obvious prevalence of non-keeled forms belonging to genera *Hedbergella, Whiteinella*, and *Heterohelix*. The uppermost part of the *Whiteinella archaeocretacea* corresponds to the time of anoxia termination and commencement of intense development and diversification of marginotruncans. Representatives of this group have a keeled test with an intricate aperture. The main aperture is usually covered by portici, while additional apertures tower above umbo. These forms represent a new evolutionary lineage in development of planktonic foraminifers, which originated from the genus *Praeglobotruncanella* and reached maximal diversity in the Coniacian–Santonian.

RADIOLARIAN ASSEMBLAGES OF THE PERI-TETHYS

Albian–Turonian radiolarians are comprehensively studied in sections of West Europe, West Mediterranean, and North America, while information on East Mediterranean radiolarians is fragmentary. In the southwestern Crimea, radiolarians are known from relatively complete Cenomanian–Turonian sections only, which represent a perfect object for biostratigraphic and paleogeographic analysis. In the western Caucasus, radiolarians are known for a long time in cherts and bituminous marls of the Ananuri Horizon deposited at the time of the OAE 2. Study of these deposits is necessary for understanding the global regularities in geological development of anoxic environments in the terminal Cenomanian–initial Turonian. All the abiotic events affected evolutionary trends of radiolarians, which are well represented, in contrast to foraminifers, in sections of above regions, the intervals corresponding anoxic event included. Consequently, radiolarians are appropriate for biostratigraphic analysis.

The well-known radiolarian assemblages are described from the upper Albian clays in southeastern outskirts of Simferopol (Alekseev et al., 1997; Gorbachik and Kazintsova, 1998), Cenomanian–Turonian sections of the Crimean Mountains (Vishnevskaya and Sedaeva, 1987; Vishnevskaya and Kazintsova, 1990; Bragina, 2001, 2004), eastern (Azizbekova and Abbasov, 1990) and western (Vishnevskaya, 2001; Bragina and Agarkov, 2005) Caucasus, and Ciscaucasia (Vishnevskaya and Agarkov, 1998).

Crimean Province

Presence of radiolarians in Albian sediments of the Crimea was first established at the end of the last century (Gorbachik and Kazintsova, 1998). Cretaceous radiolarians first found in the Crimean Mountains have been attributed to the Albian–Turonian *Pseudodictyomitra pseudomacrocephala* assemblage (Vishnevskaya and Kazintsova, 1990). After a thorough study of Crimean sections, several others radiolarian assemblages can be distinguished.

The *Crolanium cuneatum* Beds. Upper Albian.

Paleogeographic reorganizations of the Albian–Cenomanian transitional period resulted in extinction of almost all representatives of the genus *Crolanium*, and the extinct species *Crolanium cuneatum* is used now as a zonal taxon. The *Orbiculiforma nevadaensis–Dictyomitra kanakhendensis* assemblage was first defined based on flattened discoid radiolarian skeletons abundant in all the examined samples (Gorbachik and Kazintsova, 1998). The late Albian assemblage from the piedmont areas of the Crimean Mountains (Simferopol) is composed largely of discoid species *Orbiculiforma multangula* Pessagno, *O. nevadaensis* Pessagno, *O. impressa* (Lipman), *Crucella crux* (Lipman), *Hexapyramis pantanelli* Squinabol, and *Cenodiscus cenomanicus* Aliev). Cyrtoid species are rare in this assemblage, being of a high stratigraphic significance however. They are represented by characteristic Albian species *Dictyomitra kanakhendensis* Aliev and *Crolanium cuneatum* (Smirnova et Aliev), which became extinct in the terminal Albian.

The *Holocryptocanium barbui* Beds. Lower Cenomanian.

Limestones from the upper part of the Lower Cenomanian Sel'-Bukhra section (Member 4) contain abundant radiolarians. Their skeletons are entirely replaced by pyrite, which is, in turn, replaced to the variable degree by Fe hydroxides. The assemblage includes *Acaeniotyle diaphorogona* Foreman, *A. longispina* (Squinabol), *Cyclastrum infundibuliforme* Rust, *C. (?) luminosum* Jud, *C. satoi* (Tumanda), *Falsocromyodrimus cardulus* O'Dogherty, *Halesium sexangulum* Pessagno, *Hexapyramis perforatum* Bragina, *Paronaella spica* Bragina, *Patellula spica* O'Dogherty, *P. verteroensis* (Pessagno), *Patulibracchium woodlandensis* Pessagno, *Pseudoaulophacus* ex gr. *venadoensis* Pessagno, *Petasiforma foremanae* Pessagno, *P. glascockensis* Pessagno, *Savaryella navalensis* (Squinabol), *Staurosphaeretta wisniowskii* (Squinabol), *Triactoma* cf. *fragilis* Bragina, *Stichomitra communis* Squinabol, *Holocryptocanium barbui* Dumitrica, and *Xitus spicularius* (Aliev) (Bragina, 2005). This assemblage is traceable in the Greater Caucasus (Vishnevskaya, 2001) and its species are widespread in the Cenomanian sediments of the Mediterranean belt: in Azerbaijan (Azizbekova and Abbasov, 1990), Italy, Spain (O'Dogherty, 1994), Turkey, Crimean Mountains

(Bragina, 2004), and in the Atlantic (Erbacher and Thurow, 1987).

The *Triactoma parva–Patulibracchium ingens* Beds. Upper Cenomanian.

Bragina (2004) who defined these beds above the FAD of their index species correlated them with the lower part of the *Whiteinella archaeoctretacea* foraminiferal zone. At the Mt. Sel'-Bukhra site, the uppermost Cenomanian yields characteristic radiolarian species *Archaeocenosphaera ? mellifera* O'Dogherty (early Albian–early Turonian), *Pyramispongia glascockensis* Pessagno (middle Cenomanian–Campanian), *Orbiculiforma cachensis* Pessagno (lower Cenomanian–Coniacian), *Diacanthocapsa euganea* (Squinabol) (late Albian–early Turonian), *Pseudoeucyrtis pulchra* (Squinabol) (late Cenomanian–early Turonian), *Pseudodictyomitra pseudomacrocephala* (Squinabol) (late Albian–early Turonian), *Holocryptocanium barbui* Dumitrica (Aptian–Coniacian), *Xitus spicularius* (Aliev) (Valanginian–early Turonian), *Sethocapsa orca* Foreman (Valanginian–Cenomanian), *Sethocapsa simplex* Taketani (Albian–Cenomanian), *Cryptamphorella conara* Foreman (Albian–Maestrichtian), *Hiscocapsa asseni* (Tan) (Aptian-Cenomanian), and many others(Plate III). As is evident from stratigraphic ranges of the mentioned species, three of them indicated in brackets and representatives of the family Rotaformidae became extinct in the terminal Cenomanian, i.e., they did not survive the anoxic event.

In the *upper Cenomanian* Aksudere section, less abundant calcareous planktonic microfossils and radiolarians from the bituminous member, a marker of anoxic event (Fig. 2), are largely represented by dwarfish specimens. Remarkable are abundant small planktonic foraminifers of the genus *Hedbergella* comparable in size with radiolarians and monstrous specimens of the genus *Rotalipora* sp. Radiolarians are accompanied by abundant siliceous sponge spicules often of irregular shape that is probably indicative of abnormal salinity in the basin of sedimentation. Radiolarians are largely represented by simple discoid forms and primitive *Dictyomitra* species. Their assemblage consists of *Anachoreta sagitta* O'Dogherty (late Albian–early Cenomanian), *Holocryptocanium geysersensis* Pessagno (Albian–early Cenomanian), *Dictyomitra crassispina* (Squinabol) (late Cenomanian), *D. crebrisulcata* (Squinabol), *D. turritum* (Squinabol), *Dactyliodiscus lenticulatus* (Jud) (Albian–Cenomanian), *Amphipyndax stocki* (Campbell et Clark) (mostly Late Cretaceous), and many other species of wide stratigraphic ranges.

The *late Cenomanian* suppressed assemblage with rare discoid and spheroid forms is established in the Mt. Belaya section. Species of the assemblage are *Mallanites ? triquetrum* (Squinabol) (late Albian–Cenomanian), *Patellula* cf. *planoconvexa* Pessagno (Cenomanian–Turonian), *Squinabollum fossile* (Squinabol) (Albian–Coniacian), *Praeconocaryomma californiaensis* Pessagno, *P. lipmanae* Pessagno (late Cenomanian–

Plate III
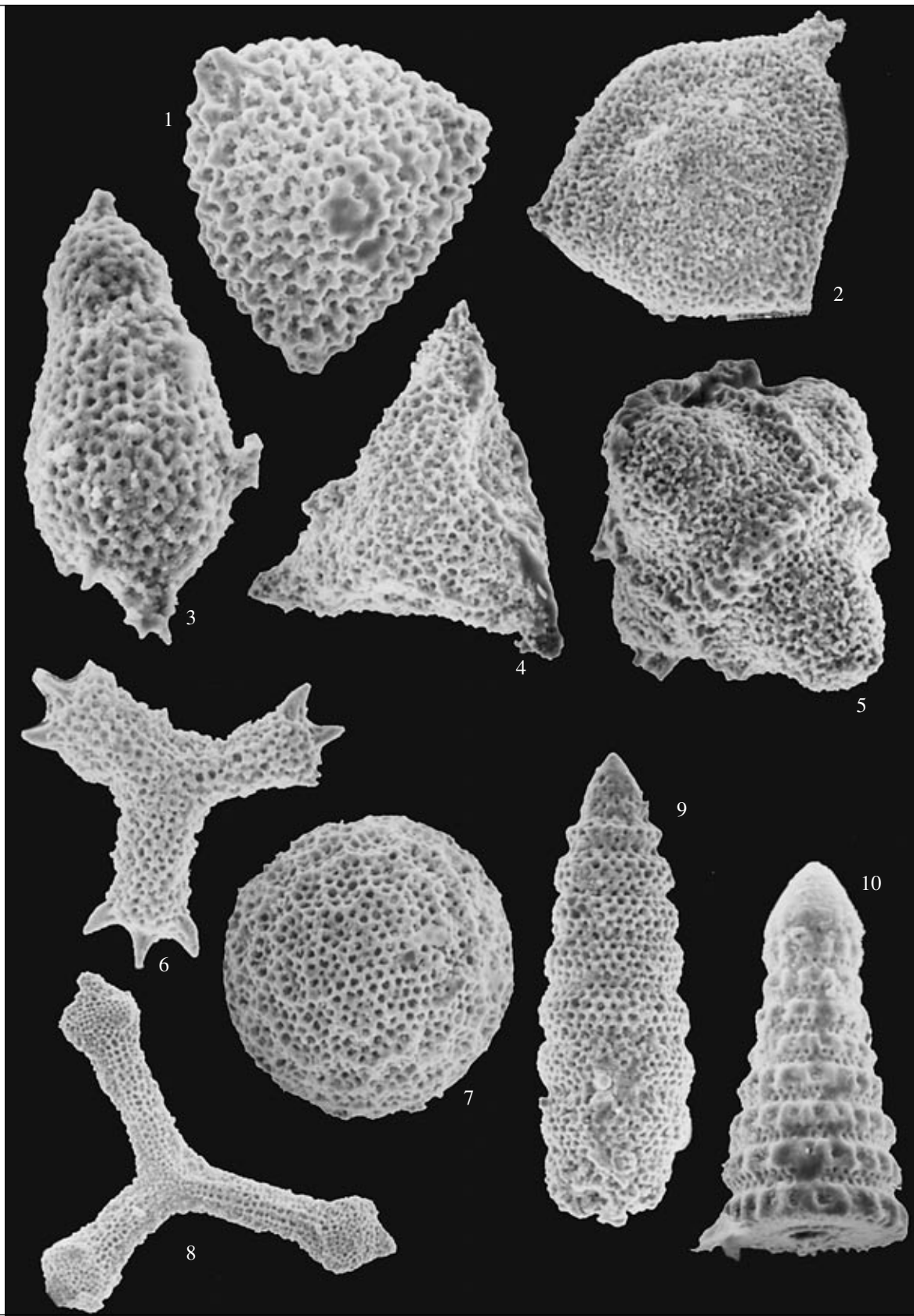
early Senonian), *Amphipyndax stocki* (Campbell at Clark) (mostly Late Cretaceous), and many other species of the wide stratigraphic ranges (genera *Lipmanium, Guttacapsa, Obeliscoites*).

Thus, radiolarians from the uppermost Cenomanian sediments (anoxic facies of the Aksudere, Sel'-Bukhra, and Belaya sections in the Crimea, Fig. 2) are characterized in general by dwarfed skeletons, increased abundance of spongy spumellarian and nassellarian forms against the background of reduced morphological diversity, smoothed external sculpture, and by distorted porosity system (frequently with irregular transition between spongy and pseudoaulophacoid structure). Monstrous (irregular discs with protuberances of unequal length and width) and abundant cryptocephalic forms appeared among them (Plates III, IV). At the same time, conserving properties of sediments enriched in organic matter, P, Ag, and other elements were favorable for retention of *Pseudodictyomitra pseudomacrocephala* (Squinabol) and *Diacanthocapsa euganea* (Squinabol) with intact apertural tubes (Vishnevskaya, 2001, plate 129), which evidence presence of organic matter in large quantity and anoxic environments in conservation medium.

The *Alievium superbum* **Zone (lower part)** is traceable in sections of the Crimean Mountains immediately above the anoxic member (Mt. Sel'-Bukhra, Mt. Belaya, and Aksudere Ravine sections). The zone is correlative with the upper part of the foraminiferal *Whiteinella archaeocretacea* Zone. The early Turonian radiolarian assemblage from this zone includes taxa, which do not occur in underlying sediments, e.g., *Alievium superbum* (Squinabol), the Turonian–Coniacian index species, and *Acanthocircus tympanum* O'Dogherty characteristic of the early Turonian. Other taxa of the assemblage occur in the underlying sediments *Triactoma parva–Patulibracchium ingens* Beds (Plate IV).

The *Praeconocaryomma universa–Dictyomitra densicostata* **Beds** (middle part of the *Alievium superbum* Zone; Bragina, 2004) correspond in range to the middle and upper parts of the lower Turonian. The unit is correlative with the *Helvetoglobotruncana Helvetica* foraminiferal zone, except for its upper portion. The radiolarian assemblage well represented in the Mt. Belaya and Aksudere Ravine sections is less diverse as compared with the early Turonian one.

Caucasian Province

Radiolarians of the Greater Caucasus and Ciscaucasia attracted attention of geologists since the 1930s. The known radiolarian species are described mostly from the Cenomanian–Turonian Ananuri Horizon that extends along the southern slope of the Greater Caucasus from Tuapse via Abkhazia, the Kutaisi area, South Osetiya to Ananuri and further via Kakhetiya to southeastern Azerbaijan and North Osetiya.

The *Pseudodictyomitra pseudomacrocephala–Holocryptocanium barbui* Beds (late Albian–Cenomanian) are widespread in the Greater and Lesser Caucasus (Vishnevskaya, 2001). The beds are defined based on mass abundance of cryptocephalic forms and disappearance of genera *Mirifusus, Pantanellium, Podobursa,* and *Parvicingula.* They also contain abundant foraminiferal species *Praeglobotruncana gibba* Klaus, *Guembelitria cenomana* Keller, *Gavelinella (Anomalina) cenomanica* (Brotzen), and others. Several radiolarian assemblages are distinguishable.

The *Crolanium cuneatum (=Dictyomitra disparlita–Crolanium triangulare)* assemblage of the upper Albian is represented by numerous high-conical nassellarians. It has been described from clays of the *Aucellina* Horizon of the Mt. Kelevudag site (*Practical Guide…*, 1999).
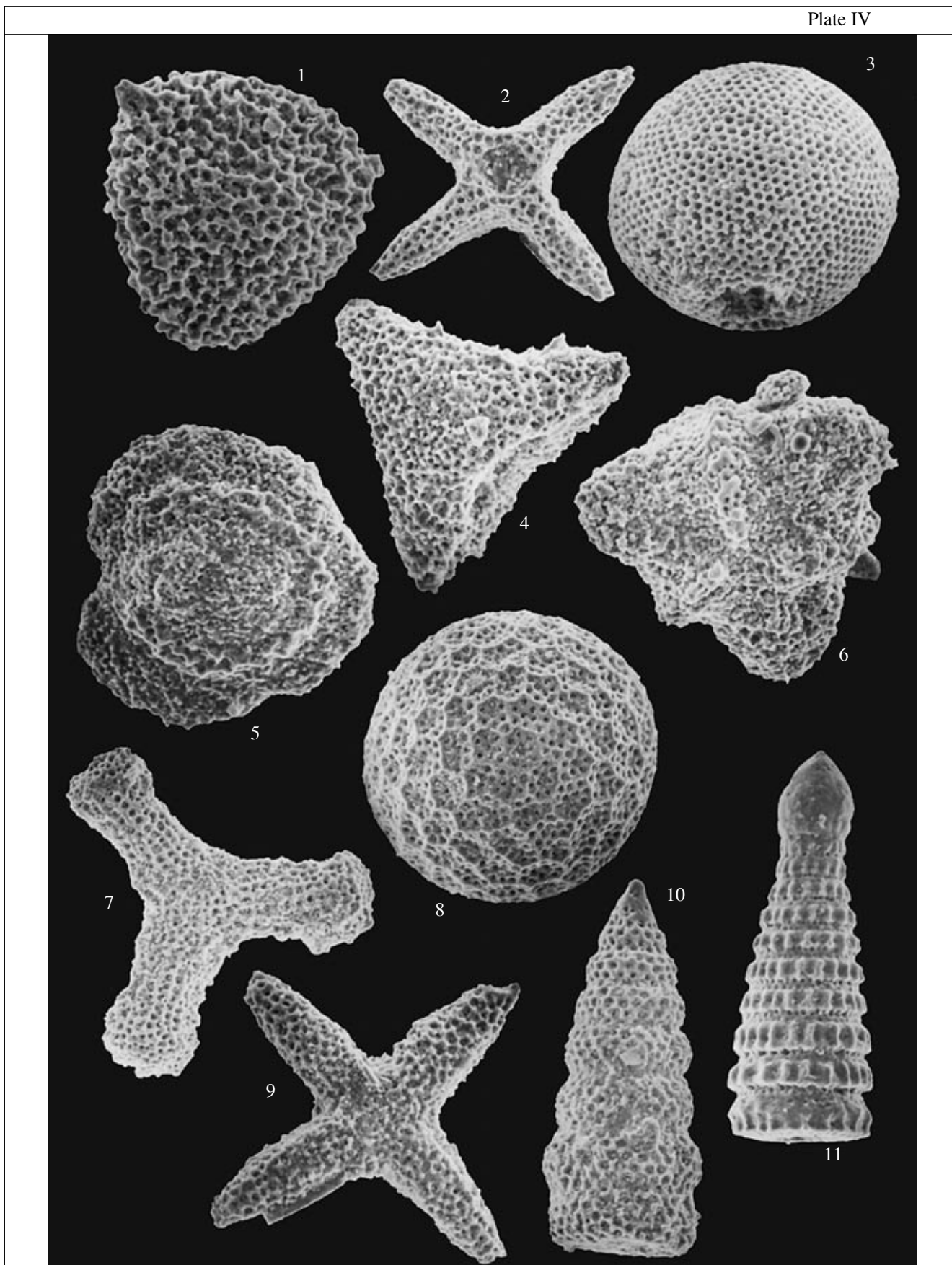
The *Holocryptocanium barbui* assemblage of the lower Cenomanian (Azizbekov and Abbasov, 1990) is established in the Mt. Dibrar section of carbonate–clayey sediments (eastern flank of the Greater Caucasus). It is correlated with the *Thalmanninella brothzeni* foraminiferal zone. The characteristic feature of this assemblage is presence of abundant subspherical two- and three-chamber skeletons.

The upper Cenomanian *Diacanthocapsa euganea–Pseudodictyomitra pseudomacrocephala* assemblage is defined in the carbonate–siliciclastic section of Mt. Kelevudag, the Greater Caucasus eastern spurs. The late Cenomanian age of radiolarians is proved by coexisting foraminifers.

In the northern Caucasus, the late Albian index species *Crolanium cuneatum* is described from light-colored clayey limestones developed in the southeastern slope of the Borgustan Ridge (northern outskirts of the town of Podkumok). The late Albian assemblage represented by *Crolanium cuneatum* and high-conical *Pseudodictyomitra pseudomacrocephala* (Squinabol), *Dictyomitra ferosia* Aliev, *D. sagitafera* Aliev, *Xitus tekschaensis* (Aliev), and *X. spicularius* (Aliev) is

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Plate III. Cenomanian and Turonian radiolarians of the Crimean Mountains:

(1) *Alievium sculptus* (Squinabol); (2) *Cavaspongia euganea* Squinabol; (3) *Diacanthocapsa euganea* Squinabol; (4) *Cavaspongia antelopensis* Pessagno; (5) *Pyramispongia glascockensis* Pessagno; (6) *Halesium sexangulum* Pessagno; (7) *Archaeocenosphaera ? melifera* O'Dogherty; (8) *Patulibrachium* sp.; (9) *Stichomitra communis* Squinabol; (10) *Pseudodictyomitra pseudomacrocephala* (Squinabol). All specimens (except for fig. 6) are from Sample 136 (upper Cenomanian); specimen illustrated by fig. 6 is from Sample 18A (Turonian). Magn. ×200. All specimens are from upper Cenomanian–Turonian sediments of the Mt. Sel'-Bukhra section; radiolarian collection is stored at the Russian micropaleontological reference center.

Plate IV

known from overlying siliceous limestones. Higher in the section, the lower Cenomanian spongolites yield *Alievium sculptus* (Squinabol), *Amphipyndax stocki* var. A Vishnevskaya, and other species of the *Holocryptocanium barbui* assemblage. Similar radiolarian assemblage is also characteristic of the lower Cenomanian *Rotalipora globotruncanoides* Beds (*Mantelliceras mantelli* Zone) of sections exposed along the Baksan River (Vishnevskaya, 2001).

The Turonian *Alievium superbum–Thanarla veneta* Beds are exposed at the base of the carbonate section in the western slope of the Greater Caucasus (Ol'khovaya, and Khosta rivers) and in Ciscaucasia (Urukh River). Radiolarians occur here in association with foraminifers. The radiolarian-bearing beds contain frequent shells of *Inoceramus lamarcki* Parkinson. The characteristic Turonian species are *Halesium sexangulum* Pessagno, *Thanarla veneta* (Squinabol), and *Alievium superbum* (Squinabol); the last species first appears at this level (Vishnevskaya, 2001).

In the western part of North Osetiya, the section exposed along the left tributary of the Urukh River 2.7 km south of the Akhsarisar Village is represented at its base (right wall of the Urukh River canyon) by dark gray to black Albian calcareous clays with *Crolanium*. Clays are overlain by ocherous Cenomanian marls (2.5 m) with pebble of clayey limestones, and Cenomanian strata appear to be partially eroded. Higher in the section, there are Turonian siliceous limestones (11.5 m) with *Inoceramus lamarcki* Park. and abundant pinkish to black concretions of cherts, which yield radiolarians *Praeconocaryomma* aff. *universa* Pessagno, *Crucella irwini* Pessagno, *Cavaspongia contracta* O'Dogherti, *Histiastrum membraniferum* Lipman, *Patellula verteroensis* Pessagno, *Pseudoaulophacus praefloresensis* Pessagno, *Halesium sexangulum* Pessagno, *Lithostrobus turitellus* Lipman, *Dictyomitra pyramidalis* Grigorieva, *D. striata* Lipman, *Amphipyndax stocki* (Campbell et Clark), *Distylocapsa squama* O'Dogherti, and *Spongostichomitra* aff. *elatica* (Aliev). Radiolarians are associated with numerous early Turonian planktonic foraminifers.

The well-preserved early Turonian radiolarian assemblage was extracted from cherts and siliceous limestones of the Ananuri and Kerket formations in the western slope of the Greater Caucasus (sections along the Olkhovaya, Khosta, and Tuapse rivers). Dominant species of the assemblage are *Alievium superbum* (Squinabol), *Pseudoaulophacus praefloresensis* Pessagno, *P.* cf. *parqueraensis* Pessagno, *Halesium sexangu-*

lum Pessagno, *Dictyomitra striata* Lipman, and *Amphipyndax stocki* (Campbell et Clark) var. A (Vishnevskaya, 2001).

The Ananuri Formation exposed near the Lazarevskoe Settlement, the Greater Caucasus western slope, contains the late Cenomanian and early Turonian radiolarians (Bragina and Agarkov, 2005). The upper Cenomanian strata 60 cm above the bituminous member yielded the following radiolarian assemblage: *Acaeniotyle diaphorogona* Foreman, *Acanthocircus impolitus* O'Dogherty, *A. tympanum* O'Dogherty, *Archaeocenosphaera ? mellifera* O'Dogherty, *Cavaspongia antelopensis* Pessagno, *C. californiaensis* Pessagno, *Crucella aster* (Lipman), *C. messinae* Pessagno, *Dactyliodiscus lenticulatus* (Jud), *D. longispinus* (Squinabol), *Halesium quadratum* Pessagno, *H. sexangulum* Pessagno, *Orbiculiforma ovoidea* Bragina, *Paronaella spica* Bragina, *Patilibracchium ingens* (Lipman), *Pessagnobrachia irregularis* (Squinabol), *Phaseliforma inflate* Bragina, *Praeconocaryomma californiaensis* Pessagno, *P. lipmanae* Pessagno, *P. universa* Pessagno, *Pyramispongia glascockensis* Pessagno, *Quinquecapsularia ombonii* (Squinabol), *Stylodictya insignis* Campbell et Clark, *Triactoma cellulose* Foreman, *Amphipyndax stocki* (Campbell et Clark), *Diacanthocapsa euganea* Squinabol, *D. fossilis* Squinabol, *D.* sp. A, *Dictyomitra montisserei* (Squinabol), *Distylocapsa squama* O'Dogherty, *D. veneta* (Squinabol), *Holocryptocanium astiensis* Pessagno, *Phalangites telum* O'Dogherty, *Pseudodictyomitra nakasekoi* Taketani, *P. pseudomacrocephala* (Squinabol), *Pseudoeucyrtis pulchra* (Squinabol), *Spongostichomitra elatica* (Aliev), *Stichomitra communis* Squinabol, and *Xitus spineus* Pessagno. The early Turonian radiolarians are found immediately above the bituminous member corresponding to the OAE-2. They are represented by the following species: *Acanthocircus tympanum* O'Dogherty, *Alievium superbum* (Squinabol), *Archaeocenosphaera ? mellifera* O'Dogherty, *Cavaspongia antelopensis* Pessagno, *C. contracta* O'Dogherty, *Crucella cachensis* Pessagno, *C. messinae* Pessagno, *Dactyliodiscus longispinus* (Squinabol), *Dactyliosphaera silviae* Squinabol, *Halesium quadratum* Pessagno, *Paronaella spica* Bragina, *Patellula verteroensis* (Pessagno), *Patulibracchium ingens* (Lipman), *Pessagnobrachia rara* (Squinabol), *Phaseliforma inflate* Bragina, *P. subcarinata* Pessagno, *Praeconocaryomma universa* Pessagno, *Pseudoaulophacus floresensis* Pessagno, *P. praefloresensis* Pessagno, *Pyramispongia glascockensis* Pessagno, *Quinquecapsularia ombonii* (Squinabol), *Triactoma compressa* (Squinabol), *T. fra-*

Plate IV. Cenomanian and Turonian radiolarians of the Crimean Mountains:

(1) *Alievium sculptus* (Squinabol); (2) *Crucella cachensis* Pessagno; (3) *Holocryptocanium barbui* Dumitrica; (4) *Cavaspongia antelopensis* Pessagno; (5) *Godia* sp.; (6) *Pyramispongia glascockensis* Pessagno; (7) *Patulibrachium* sp.; (8) *Archaeocenosphaera ? melifera* O'Dogherty; (9) *Crucella messinae* Pessagno; (10) *Stichomitra communis* Squinabol; (11) *Pseudodictyomitra pseudomacrocephala* (Squinabol). Specimens in figs. 1–3, 5, 7–11 are from sample 18A (Turonian); specimens in figs. 4, 6 form sample 136 (upper Cenomanian); magnification ×200. All specimens are from upper Cenomanian–Turonian sediments of the Mt. Sel'-Bukhra section; radiolarian collection is stored at the Russian micropaleontological reference center.

gilis Bragina, *T. hexeris* O'Dogherty, *Vitorfus brusto-lensis* (Squinabol), *V. morini* Empson-Morin, Amphipyndax stocki (Campbell et Clark), Archaeodic-tyomitra sliteri (Squinabol), *A.* ex gr. *squinaboli Pessa-gno, Cryptamphorella conara (Foreman), C. sphaerica (White), Diacanthocapsa elongata Bragina, D. euga-nea* (Squinabol), *D. fossilis* Squinabol, *D. ovoidea* Dumitrica, *D. rara* Squinabol, *Dictyomitra montisserei* (Squinabol), *Distylocapsa squama* O'Dogherty, *D. veneta* (Squinabol), *Holocryptocanium barbui* Dumitrica, *Phalangites hastatus* O'Dogherty, *P. telum* O'Dogherty, *Pogonias? hirsutus* (Squinabol), *Pseudodictyomitra nakasekoi* Taketani, *P. pseudomac-rocephala* (Squinabol), *Pseudoeucyrtis pulchra* (Squinabol), *Squinabollum fossile* (Squinabol), *Sti-chomitra communis* Squinabol, *S. insignis* (Squinabol), *S. magna* Squinabol, *Thanarla* ex gr. *conica* (Aliev), *Tibilustrium transmontanum* O'Dogherty, *Xitus spicu-larius* (Aliev), and *X. spineus* Pessagno (Bragina and Agarkov, 2005). The early Turonian assemblage is recorded also in the Zarat Horizon of Kobystan, where R. Kh. Lipman found *Lithostrobus turitellus* (Vish-nevskaya and Agarkov, 1998).

Summing up all the available data on the Upper Cre-taceous radiolarians of the Ciscaucasia region, Crimea, western and eastern slopes of the Greater Caucasus, we propose to define the *Alieviun superbum* radiolarian zone (Turonian–Coniacian) as a single stratigraphic unit, which is well traceable through the entire Ciscau-casia, northern Caucasus, and even in the Transcaucasia (Suram Ridge section).

In addition to index species, the Turonian–Conia-cian radiolarian zone *Alievium superbum* contains the following important taxa: *Praeconocaryomma* aff. *uni-versa*, Crucella irwini, C. membraniferum, Cavaspon-gia antelopensis, C. contracta, *Patellula* cf. *verteroen-sis, Pseudoaulophacus* ex gr. *praefloresensis, Halesium sexangulum, Dictyomitra striata, Distylocapsa squama*, and *Lithostrobus turitellus.*

The radiolarian *A. superbum* zone is well known in the Crimea, Caucasus, Italy, and Spain. It was first established in the Turonian of California and then was proposed to characterize the Turonian–Coniacian sedi-ments in oceans.

Thus, impact of anoxic events on the Albian–Turo-nian radiolarian assemblages of the Crimea (Vish-nevskaya et al., 2005), Greater Caucasus, and Ciscau-casia was less significant as compared with foramin-iferal communities, which entirely changed or renewed their composition. The Albian–Turonian radiolarian assemblages of the Crimea and Caucasus are readily correlative with coeval assemblages of Italy, Spain, and Turkey (O'Dogherty, 1994; Salvini and Marcucci Pas-serini, 1998; Bragina, 2004). Besides the reference stratigraphic value, they are indicative of specific paleogeographic settings.

It is reasonable therefore to elaborate the radiolarian zonation for the Northern Peri-Tethys and to correlate it with zonal scales of foraminifers and macrofauna. Most appropriate for this purpose are the Aksudere, Sel'-Bukhra, Urukh, and other sections, where radiolarians occur in association with planktonic foraminifers. Unfortunately, the northerly mid-Cretaceous sections of the Russian platform are lacking planktonic foramin-ifers, and macrofauna is scarcer here than microfossils. Consequently, radiolarians can be regarded as the orthostratigraphic group.

MORPHOLOGICAL TRANSFORMATIONS OF RADIOLARIAN SKELETONS DURING THE LATE ALBIAN–EARLY TURONIAN

Characteristic and guide species of radiolarian assemblages from the Northern Peri-Tethys, which occur at Albian–Cenomanian and Cenomanian–Turo-nian critical boundaries, are specially mentioned above, because radiolarians form separate localities of Russia have been described in brief only. The Albian–Turonian radiolarian stratigraphy is based on development of phylogenetic and morphological features of radiolarian skeletons, which are most useful for biostratigraphic interpretation. Evolution of radiolarians during the late Albian was marked by development and perfection of skeletal features necessary for floating in pelagic zone, changeable environments in which are evident from tectonic indicators (appearance of tuffs and phosphorite nodules in black clays of the uppermost Albian section) and pertinent morphological innovations of radiolarian skeletons.

The diversity and distinctive features of late Albian assemblages consist in abundance of high-conical tests with triangular and quadrangular distal sections and with lateral costae in the corners grading into terminal *legs.* Tests of this kind belong to the genus *Crolanium* represented by numerous last Albian species *C. cunea-tum* (Smirnova et Aliev), *C. puga* (Schaaf), *C. spineum* Pessagno, *C. triangulare* (Aliev), and *C. triquetrum* (Pessagno). Also abundant were last representatives of dictyomitrid, cyrtocapsid, and stichocapsid with sagit-tate initial chambers and distinct longitudinal rows of pores, e.g., *Dictyomitra tekschaensis* Aliev, *Cyrtocapsa perspicua* Squinabol, and *Stichocapsa euganea* Squin-abol. In the Albian, species of genera *Pantanellium, Podoburs*, and *Tethysetta* became extinct. In additional to changes in genera composition, there were remark-able renovations among species: some spumellarians (discoid *Orbiculiforma multangula* Pessagno and *Porodiscus kavilkinensis* Aliev), nassellarians (*Theo-campe cylindrical* Smirnova et Aliev, *Thanarla conica* Aliev), and almost all the species of the genus *Crola-nium* disappeared in the terminal Albian. Proportion between spumellarians and nassellarians was approxi-mately 1 : 1 to 1 : 2. The same proportion was charac-teristic of the late Albian assemblages from the south-ern Russian platform (Vishnevskaya et al., 2005).

The Cenomanian base is established based on sub-stantial renewal in composition of radiolarian genera:

Guttacapsa and *Lipmanium* represent new genera of nasselarians, which appeared at this boundary, and biconvex spongy pseudoaulophacoid discs with the triangular sections become numerous among spumellarians (genera *Alievium* and *Pseudoaulophacus*). Nevertheless, the Cenomanian radiolarian assemblages were dominated by spherical and discoid forms, and spherical ones represented a half of all not numerous nassellarians. These were cryptocephalic and cryptocephalotaxic genera *Holocryptocanium* (*H. astiensis* Pessagno, *H. barbui* Dumitrica, *H. geysersensis* Pessagno, and *H. tuberculatum* Dumitrica) and *Excentropylomma* (*E. cenomana* Dumitrica). The Cenomanian was marked by mass appearance of subspherical–ellipsoid three-chamber cryptocephalic *Diacanthocapsa* species (*D. antiqua, D. brevithorax, D. euganea, D. matsumotoi,* and *D. ovoidea*) and of pseudocephalic *Dictyomitra maleolla* Aliev, *D. disparlita* Aliev, *Pseudodictyomitra pseudomacrocephala* (Squinabol), and *P. sagitafera* Aliev.

Discussion of Data on Radiolarians

The analyzed morphological features in radiolarian skeletons from the Albian–Cenomanian boundary sediments (sharp prevalence of discoid and spheroid groups over cyrtoid morphotypes) suggest certain ecological changes, i.e., a relative shoaling of the basin at that time. This is also evident from deposition of carbonate sediments with rich assemblages of planktonic foraminifers. Thus, variations in proportion of different morphological radiolarian and foraminiferal groups could be a result of bathymetric rather than climatic changes. From the viewpoint of morphological–functional adaptation, disappearance of multichamber skeletons and abundance of new cryptocephalic forms implies that Cenomanian radiolarians actively colonized pelagic settings changed at that time.

The Cenomanian–Turonian transition was a period of compositional changes among species and higher-rank taxa. The terminal Cenomanian is marked by extinction of the family Rotaformidae that appeared in the Albian and of genera *Obeliscoites* and *Godia* among nassellarians and spumellarians, respectively. Early representatives of the genus *Alievium* (*A. antiguum)* and index species *Triactoma parva* became gradually extinct as well.

The radiolarian assemblage from bituminous marls and clays of the uppermost Cenomanian is characterized by a smaller size of skeletons, increased share of spongy forms among spumellarians and nassellarians, which are of reduced morphological diversity and have smoothed external sculpture and distorted arrangement of pores. Only the conserving properties of host sediments enriched in organic matter favored the retention of specimens with well-preserved apertural tubes. The end of the Cenomanian was marked by appearance of the index species *Patulibracchium ingens* (Lipman).

In the initial Turonian, main changes occurred at the species level. New species, which appeared at that time, are *Alievium superbum* (Squinabol), *Archaeospongoprunum triplum* Pessagno, *Paronaella pseudoaulophacoides* O'Dogherty, *Patella heroica* O'Dogherty, *Vitorfus morini* Empson-Morin, *Dictyomitra densicostata* Pessagno, *D. striata* Lipman, *Ultranapora cretacea* (Squinabol), *U. dendrocanthos* (Squinabol), and others. The only higher-rank taxon of that time was the genus *Afens*.

CONCLUSIONS

The Albian–Cenomanian transition was a time of intense development of rotaliporids, a highly specialized group of planktonic foraminifers, which became extinct in the terminal Cenomanian. Rotapolirids coexisted with other groups of planktonic foraminifers, and this was the polytaxic stage in evolution of foraminifers (Plates I, II). The Cenomanian–Turonian boundary period was associated with development of anoxic environments, which spread almost throughout the entire Peri-Tethys and determined bloom of primitive cosmopolitan taxa. This was a well-manifested oligotaxic stage in evolution of planktonic foraminifers. The next polytaxic stage commenced in the early Turonian and lasted until the Maastrichtian.

Among radiolarians, most of *Crolanium* species and diverse last representatives of dictyomitrids, cyrtocapsids, and stichocapsids with the sagittate initial chamber and distinct longitudinal rows of pores became extinct at the Albian–Cenomanian boundary time. Simultaneously, new genera *Guttacapsa* and *Lipmanium* appeared, being accompanied by mass development of biconvex spongy pseudoaulopacoid disckoid forms (*Alievium, Pseudaulophacus*), three-chamber cryptocephalic cyrtids, and pseudaulophacoid dictyomitrids (Plates III, IV).

The terminal Cenomanian was marked by extinction of the family Rotaformidae that appeared in the Albian and of genera *Obeliscoites* and *Godia* among nassellarians and spumellarians, respectively. Earliest representatives of the genus *Alievium* (*A. antiguum*) and index species *Thanarla parva* also became extinct at that time.

Across the Cenomanian–Turonian boundary, radiolarian assemblages experienced compositional changes at the species and higher-rank levels. Many new species, the index taxon *Alievium superbum* included, and new genus *Afens* appeared at the beginning of the Turonian. The next phase of transgression commenced in the middle or in the second half of the Cenomanian, when all morphological groups of radiolarians and planktonic foraminifers appeared.

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REFERENCES

1. A. S. Alekseev, V. S. Vengertsev, L. F. Kopaevich, et al., "Lithology and Micropaleontology of Cenomanian–Turonian Boundary Sediments in the Southwestern Crimea," in *Essays of Crimean Geology*, Ed. by E.E. Milanovskii (MGU, Moscow, 1997), pp. 54–73 [in Russian].

2. M. A. Arthur, S. O. Schlanger, and H.C. Jenkyns, "The Cenomanian–Turonian Oceanic Anoxic Event. Palaeoceanographic Controls on Organic-Matter Production and Preservation," Geol. Soc. Spec. Publ., *Marine Petroleum Source Rocks*, No 26, pp. 401–420 (1986).

3. A. R. Azizbekova and A. B. Abbasov, "Populations of Planktonic Microorganisms at the Albian–Cenomanian Transition in the Southeastern Crimea," in *Problems of Recent Micropaleontology* (Nauka, Leningrad, 1990), pp. 179–185 [in Russian].

4. E. Ju. Baraboshkin, L. F. Kopaevich, and A.G. Olferiev, "The Mid-Cretaceous Events in Eastern Europe: Development and Paleogeographical Significance. Peri-Tethys Memoir 4: Epicratonic Basins of Peri-Tethyan Platforms," Mem. Mus. Nat. Hist. Natur. **179**, 93–110 (1998).

5. L. G. Bragina, Candidate's Dissertation in Geology–Mineralogy (GIN, Moscow, 2001).

6. L. G. Bragina, "Cenomanian–Turonian Radiolarians of Northern Turkey and Crimean Mountains," Paleontol. J. **38**, Suppl. 4, 325–451 (2004).

7. L. G. Bragina, "Radiolarians in Cenomanian Sediments of the Southwestern Crimea," in *Biostratigraphic Criteria for Stratigraphy and Correlation of Phanerozoic Sections* (IGN NAN Ukrainy, Kiev, 2005), pp. 99–101 [in Russian].

8. L. G. Bragina and Yu. V. Agarkov, "The OAE-2 Event and Radiolarians of the Upper Cenomanian and Lower Turonian Ananuri Formation of the Western Caucasus," in *Paleontological Record of Regional and Global Events* (VSEGEI, St. Petersburg, 2005), p. 22 [in Russian].

9. T. J. Bralower, M. R. Leckie, W. V. Sliter, et al., "An Integrated Cretaceous Microfossil Biostratigraphy," SEPM Spec. Publ., No. 54, pp. 65–79 (1995)

10. P. Bronnimann, "Globigerinidae from the Upper Cretaceous (Cenomanian–Maastrichtian) of Trinidad, B.W.I.," Bull. Am. Paleontol. **34**, 1–70 (1952).

11. T. J. Burnhill and W. V. Ramsay, "Mid-Cretaceous Paleontology and Stratigraphy. Central North Sea," in *Petroleum Geology of the Continental Shelf of North-West Europe* (Institute of Petroleum, London, 1981), pp. 245–254.

12. A. Butt, "Micropalaeontological Bathymetry of the Cretaceous of Western Morocco," Palaeogeogr., Palaeoclimatol., Palaeoecol. **37**, 235–275 (1982).

13. M. Caron, "Cretaceous Planktonic Foraminifera," in *Plankton Stratigraphy* (Cambridge Univ. Press, Cambridge, 1985), pp. 17–86.

14. M. Caron and P. Homewood, "Evolution of Early Planktonic Foraminifera," Marine Micropaleontol. **7**, 453–463 (1983).

15. T. A. Davies, B. P. Luyendyk, K. S. Rodolfo, et al., *Initial Reports of the Deep Sea Drilling Project* (U.S. Government Printing Office, Washington, 1974), Vol. 26.

16. M. R. Dzhalilov, A. A. Atabekyan, O. A. Korchagin, et al., "On the Easternmost Find of Late Cretaceous Belemnitellids in Southern Areas of the USSR," Dokl. Akad. Nauk **29**, 619–621 (1986).

17. D. L. Eicher and P. Worstell, "Cenomanian and Turonian Foraminifera from the Great Plains, United States," Micropalaeontol. **16**, 269–324 (1970).

18. J. Erbacher and J. Thurow, "Influence of Oceanic Anoxic Events on the Evolution of Mid-Cretaceous Radiolaria in the North Atlantic and Western Tethys," Marine Micropalaeontol. **30**, 139–158 (1997).

19. G. Ernst, F. Schmid, and G. Klischies, "Multistratigraphische Untersuchungen inder Oberkreide des Raums Brauschweig-Hannover," Aspeckte der Kreide Europas. Int. Union Geol. Scinces. Series A, No. 6, 230–275 (1979).

20. R.C. Finch, "Mesozoic Stratigraphy of Central Honduras," Bull. Am. Assoc. Petrol. Geol. **65**, 1320–1333 (1981).

21. A. S. Gale, W.J.Kennedy, J.A. Burnett, et al., "The Late Albian to Early Cenomanian Succession at Mont Risou near Rosans (Hautes Alpes, S.E. France); an Integrated Study (Ammonites, Inoceramids, Planktonic Foraminifera, Nannofossils, Oxygen and Carbon Isotopes)," Cretaceous Res. **17**, 515–606 (1996).

22. T. N. Gorbachik, *Jurassic and Early Cretaceous Planktonic Foraminifers of the Southern USSR* (Nauka, Moscow, 1986) [in Russian].

23. T. N. Gorbachik, "Development of the Planktonic Life Mode in Planktonic Foraminifers," in *Biotic Events at main Boundaries of the Phanerozoic. Proceedings of the 12th All-Russian Micropaleontol. Meeting Dedicated to 100th Anniversary of D.M. Rauser-Chernousova* (GEOS, Moscow, 1997), pp. 92–96 [in Russian].

24. T. N. Gorbachik and A. A. Aleksandrova, "Planktonic Foraminifers: Problems of Terminology and New Species from the Upper Albian of the North Caucasus," Paleontol. J. **35** (2), 109–116 (2001).

25. T. N. Gorbachik and L. I. Kazintsova, "Late Albian Radiolarians and Foraminifers from the Mar'ino Section (Outskirts of Simferopol, Crimea)," Stratigr. Geol. Korrelyatsiya **6**, 44–51 (1998) [Stratigr. Geol. Correlation **6**, 576–583 (1998)].

26. T. N. Gorbachik and L. F. Kopaevich, "The Influence of Cretaceous Events on Evolution of Globigerinids," in *Geological History of the Arctic Region in the Mesozoic and Cenozoic* (VNIIOkeangeologiya, St. Petersburg, 1992), pp. 17–29 [in Russian].

27. M. B. Hart, "A Water Depth Model for the Evolution of the Planktonic Foraminifera," Nature, No. 286, 252–254 (1980).

28. M. B. Hart and H.W Bailey, "The Distribution of Planktonic Foraminiferida in the Mid-Cretaceous of NW

Europe," Aspecte der Kreide Europas, IUGS, ser. A, No. 6, 527–542 (1979).

29. H. Hilbrecht and J. Hoefs, "Geochemical and Palaeontological Studies of the ^{13}C Anomaly in Boreal and North Tethyan Cenomanian–Turonian Sediments in Germany and Adjacent Areas," Palaeogeogr. Palaeoclimatol. Palaeoecol. **53**, 169–189 (1986).

30. I. Jarvis, G. A. Carson, M. K. E. Cooper, et al., "Microfossil Assemblages and the Cenomanian–Turonian (Late Cretaceous) Oceanic Anoxic Event," Cretaceous Res. **9**, 3–103 (1988).

31. H. C. Jenkyns, "Cretaceous Anoxic Events: from Continents to Oceans," J. Geol. Soc. London, No.137, 171–188 (1980).

32. L. Kopaevich and T. Kuzmicheva, "The Cenomanian-Turonian Boundary in Southwestern Crimea, Ukraine: Foraminifera and Palaeogeographic Implications," in *Proc. of the 6th International Cretaceous Symposium 2000: Aspects of Cretaceous Stratigraphy and Palaeobiogeography* (Osterreichischen Akademie der Wissenschaften, Vienna, 2002), Vol. 15, pp. 129–149.

33. V. I. Korchagin, "The Section Structure and Foraminifers of Cenomanian–Turonian Boundary Sediments in Eastern Central Asia," Byul. Mosk. O–va Ispyt. Prip., Otd. Geol. **73** (2), 24–33 (1998).

34. W. Kuhnt, J. P. Hewin, J. Thurow, et al., "Distribution of Cenomanian-Turonian Organic Facies in the Western Mediterranean and Along the adjacent Atlantic Margin," Bull. Am. Assoc. Petrol. Geol. **30**, 133–160 (1992).

35. M. R. Leckie, "Paleoecology of Mid-Cretaceous Planktonic Foraminifera: A Comparison of Open Ocean and Epicontinental Sea Assemblages," Micropaleontology **33**, 164–178 (1987).

36. N. I. Maslakova, *Micropaleontology. Manual for Students of Higher Education Institutes* (MGU, Moscow, 1995) [in Russian].

37. D. P. Naidin and A. S. Alekseev, "Significance of Deep-Sea Drilling Data for Interpretation of Cenomanian Sedimentation Settings in the Crimean Mountains," in *Evolution of Organisms and Mid-Cretaceous Biostratigraphy* (DVNTS, Vladivostok, 1981), pp. 7–21 [in Russian].

38. *Practical Manual on Microfauna. Mesozoic Radiolarians* (Nedra, St. Petersburg, 1999) [in Russian].

39. L. O'Dogherty, "Biochronology and Paleontology of Mid-Cretaceous Radiolarians from Northern Apennines (Italy) and Betic Cordillera (Spain)," Mem. Geol., Lausanne, No. 21, 1–443 (1994).

40. D. Peryt, "Planktic Foraminifera Zonation of the Upper Cretaceous in the Middle Vistula River Valley, Poland," Palaeontol. Polonica, No. 41, 1–101 (1980).

41. I. Premoli Silva and W. V. Sliter, "Cretaceous Planktonic Foraminiferal Biostratigraphy and Evolutionary Trends from the Bottaccione Section, Gubbio, Italy," Palaeontol. Italica **82**, 1–89 (1995).

42. P. F. Rawson, A. V. Dhondt, J. M. Hancock, et al., "Proceedings of Second International Symposium on Cretaceous Stages Boundaries, 8-16 September, 1995. Brussels," Bull. Inst. Royal Sci. Natur. Belg. Sci. de la Terre **66**, 1–120 (1996).

43. O. Renz, "Stratigraphische und mikropalaontologische Untersuchungen der Scaglia (Obere Kreide–Tertiar) im zentralen Apennin," Eclog. Geol. Helv. **69**, 1–149 (1981).

44. F. Robaszynski and M. Caron, "Foraminiferes planctoniques du Crétacé: commentaire de la zonation Europe-Mediterranée," Bull. Soc. Geol. France **166**, 681–692 (1995).

45. F. Robaszynski and M. Caron (coord.) and EWGPF, "Atlas de Foraminiferes planctoniques du Cretace moyen (Mer Boreale et Tethys)," Micropaleontol., Parts 1–2, 181–185 (1979).

46. F. Robaszynski, M. Caron, Ch. Dupuis, et al., "A Tentative Integrated Stratigraphy in the Turonian of Central Tunisia: Formations, Zones and Sequential Stratigraphy in the Kalaat Senan Area," Bull. Centres Rech. Explor-Prod. Elf-Aquitaine **14**, 213–384 (1990).

47. F. Robaszynski, M. Caron, F. Amedro, et al., "Le Cenomanian de la Region de Kalaat Senan (Tunisie Central): Litho-Biostratigraphie et Interpretation Sequentaielle," Rev. Paleobiol. **12**, 351–505 (1994).

48. J. Salaj, "Zones planctiques du Crétacé et du Paléogene de Tunisie," in *Proc. I Intern. Conf. Planktonic Microfosils*, Vol. 2, pp. 67–69 (1969).

49. J. Salaj, "Tunisian Upper Cretaceous Hypostratotypes as Possible Candidates of Tethyan Stratotypes Including Stratotype Boundaries," Zemni Plyn Nafta **40**, 245–307 (1996).

50. G. Salvini and M. Marcucci Passerini, "The Radiolarian Assemblages of the Bonarelli Horizon in the Umbria-Marche Apennines and Southern Alps, Italy," Cretaceous Res. **19**, 777–804 (1998).

51. S. O. Schlanger and H. C. Jenkyns, "Cretaceous Oceanic Anoxic Events, Causes and Consequences," Geol. Mijnbouw **55**, 179–184 (1976).

52. S. O. Schlanger, M. A. Arthur, H. C. Jenkyns, et al., "The Cenomanian-Turonian Oceanic Anoxic Events. I. Stratigraphy and Distribution of Organic Carbon-Rich Beds and the Marine δ^{13}C Excursion," Spec. Publ. Geol. Soc. London **26**, 371–399 (1986).

53. P. A. Sholle and M. A. Arthur, "Carbon Isotope Fluctuations in Cretaceous Pelagic Limestones: Potential Stratigraphic and Petroleum Exploration Tool," Bull. Am. Assoc. Petrol. Geol. **64**, 67–87 (1980).

54. J. Sigal, "Notes sur les genres foraminiferes Rotalipora Brotzen et Thalmanninella, famille des Globotruncanidae," Rev. Inst. Franc. Petrol. **3** (4), 95–103 (1948).

55. W. V. Sliter, "Biostratigraphic Zonation of Cretaceous Planktonic Foraminifers Examined in Thin Section," J. Foram. Res. **19** (1), 1–19 (1989).

56. J. Thurow, W. Kuhnt, and J. Wiedmann, "Zeitlicher und paäogeographischer Rahmen der Phthanite- und Black Shale-Sedimentation in Marokko," N. Jahrb. Geol. Palaeont. Abh., No. 165, 147–176 (1982).

57. S. Toshimitsu, T. Matsumoto, M. Noda, et al., "Integrated of Mega-, Micro- and Magnetostratigraphy of the Upper Cretaceous in Japan," in *Proc. 15th Intern. Symp. Kyungpook Nat. Univ.* (1995), pp. 357–370.

58. N. A. Tur, "Planktonic Foraminifera Recovery from the Cenomanian–Turonian Mass Extinction Event, Northeastern Caucasus," Geol. Soc. Spec. Publ. London, No. 102, pp. 259–264 (1996).

59. N. A. Tur, Candidate's Dissertation in Geology and Mineralogy (VSEGEI, St. Petersburg, 1998).

60. R. Venkatachalapathy and V. Ragothaman, "A Foramin-
iferal Zonal Scheme for the Mid-Cretaceous Sediments
of the Cauvery Basin, India," Cretaceous Res. **16**, 415–
433 (1995).

61. V. S. Vishnevskaya, *Jurassic and Cretaceous Radiolar-
ian Biostratigraphy of Russia* (GEOS, Moscow, 2001)
[in Russian].

62. V. S. Vishnevskaya and Yu. V. Agarkov, "Late Ctetaceous
Radiolarians of the North Caucasus as a Missing Link in
Correlation between Tropical and Boreal Scales," Dokl.
Akad. Nauk **310**, 655–659 (1998) [Doklady Earth Sci-
ences **361**, 621–624 (1998)].

63. V. S. Vishnevskaya and L. I. Kazintsova, "Cretaceous
Radiolarians of the USSR," in *Radiolarians in Bios-
tratigraphy* (URO AN SSSR, Sverdlovsk, 1990), pp. 44–
59 [in Russian].

64. V. S. Vishnevskaya and K. K. Sedaeva, "To the Problem
of Biolithostratigraphic Correlation of Mesozoic Polyfa-
cies Sectios of the Southern USSR," in *Radiolarians and
Biostratigraphy* (URO AN SSSR, Sverdlovsk, 1987),
pp. 31–33 [in Russian].

65. V. S. Vishnevskaya, L. G. Bragina, and L. F. Kopaevich,
"Radiolarian Events during Critical Albian–Cenoma-
nian and Cenomanian–Turonian Transition Periods:
Morphological Diversity and Evolution of Skeletal Ele-
ments (Tethyan Province, Crimea, Ukraine)," in *Bios-
tratigraphic Criteria for Stratigraphy and Correlation of
Phanerozoic Sections* (IGN NAN Ukrainy, Kiev, 2005),
pp. 95–99 [in Russian].

66. V. S. Vishnevskaya, L. I. Kazintsova, and L. F. Kopae-
vich, "Radiolarians across the Albian–Cenomanian
Boundary (Examples from the Russian Platform),"
Stratigr. Geol. Korrelyatsiya **13**, 131–145 (2005)
[Stratigr. Geol. Correlation **13**, 438–452 (2005)].

67. J. Wiedmann, W. Kuhnt, J. Thurow, et al., "Oceanic
Anoxic Conditions around the Cenomanian/Turonian
Boundary and the Response of the Biota," Mitt. Geol.
Paläontol. Inst. Univ. Hamburg **60**, 205–246 (1986).