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Calcareous Nannoplankton of Cretaceous Rocks of the Bakhchisarai Region of Southwest Crimea

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Abstract—Cretaceous calcareous nannoplankton was studied in the Lower Cretaceous Rezanaya and Biasala and Upper Cretaceous Belogorsk, Prokhladnoe, and Kudrino formations of the Bakhchisarai region of the southwest Crimea. The age of the host rocks was refined according to calcareous nannoplankton. No nannoplankton zone was identified in the Rezanaya Formation; the Biasala Formation probably contains part of the NC5 Zone. The Belogorsk and Kudrino formations host the (partly) UC3 Zone (Subzone b) and the UC20 Zone (Subzone UC20b), respectively. No upper and lower boundaries of zones were traced.

Keywords: Lower Cretaceous, Upper Cretaceous, Crimea, Rezanaya Formation, Biasala Formation, Belogorsk Formation, Prokhladnoe Formation, Kudrino Formation, calcareous nannoplankton

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INTRODUCTION

The fossil remains in Cretaceous rocks that are abundant throughout almost the entire territory of Crimea have been studied more than 100 years. The first significant studies of the Crimean macrofauna, including cephalopods, brachiopods, echinoderms, gastropods and bivalves, were made by Eichwald (1850) and Karakash (1907). In the 20th century, these studies were continued by Drushchits (1956), Gustomesov (1967, 1968), Arkadiev (2007), and Arkadiev et al., (2012) (cephalopods), Veber (1934) (echinoderms), Golovinova et al. (1970, 1986) (gastropods), and Smirnova (1972), and Smirnova and Baraboshkin (2004) (brachiopods).

The Cretaceous foraminifers were studied by Voloshina (1966, 1967), Kuznetsova and Gorbachik (1985), and Beniamovsky and Kopaevich (2016) and radiolarians were studied by Bragin and Bragina (1999, 2007) and Vishnevskaya (2007).

The study of the taxonomic diversity of coccolithoforids was started relatively later than that of other microfauna groups. Their studies were significantly advanced by Shumenko (1978, 1991), who distinguished the Upper Cretaceous zones according to nannoplankton and linked them with zones by foraminifers, mollusks, and echinoderms (Shumenko, 1987), as well as by Lyul'eva (1967) and Lyul'eva and Permyakov (1980).

The first standard biostratigraphic division of the Cretaceous rocks by calcareous nannoplankton was proposed by Sissingh (1977) and was later characterized and refined by Perch-Nielsen (1985). In 1998, Bown et al. presented the biostratigraphic division according to nannoplankton of the Lower Cretaceous of Boreal and Tethyan areas and related it with ammonite zones (Bown et al., 1998). For the Upper Cretaceous, Burnett (1998) elaborated three parallel scales: Boreal for Europe and Tethyan and Australian linked to ammonite zones.

Because of the diachronous onset of index species and correlation between the degree of preservation and habitat paleoconditions of calcareous nannoplankton, these scales cannot necessarily be applied to certain sections (Ovechkina, 2007; Shumenko, 1987). Thus, the study of calcareous nannoplankton of Crimea should be continued for both biostratigraphic and practical reasons: the identification of the age of host rocks, the boundaries of the occurrence of index species, and paleoecological interpretations.

The schemes of biostratigraphic division of Cretaceous formations of the Bakhchisarai region by ammonites and calcareous nannoplankton are shown in Figs. 1 and 2.

MATERIAL AND METHODS

Samples for nannoflora study were taken from the Lower Cretaceous Rezanaya, Biasala, and Mangush and Upper Cretaceous Kudrino, Prokhladnoe, and Belogorsk formations. The material was sampled by

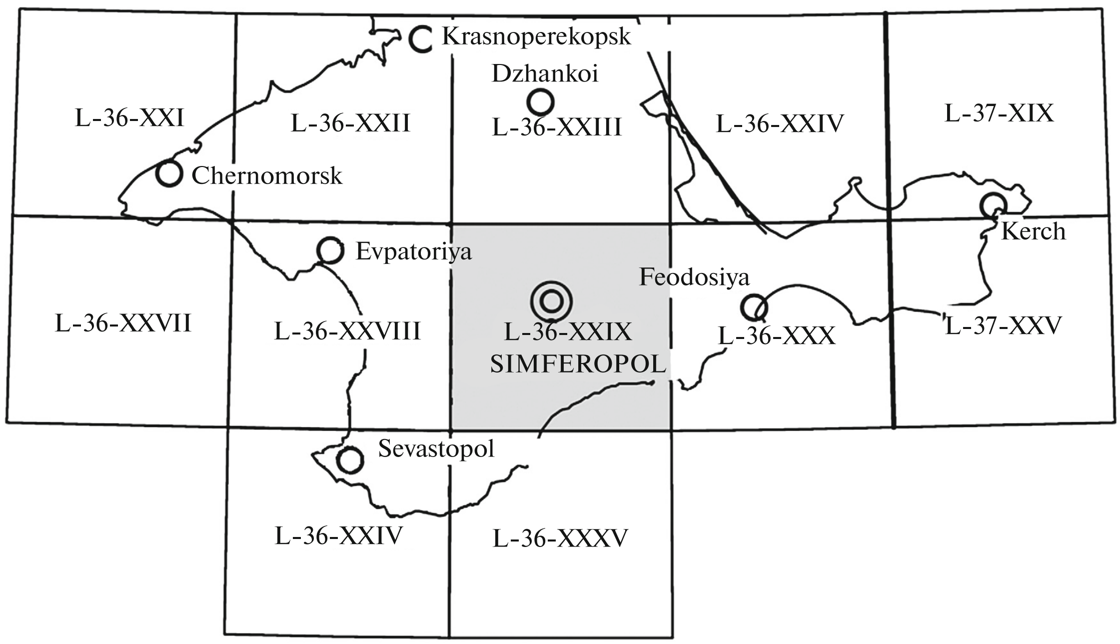

Fig. 1. The position of sheet L-36-XXIX in the Crimean series of sheets on a 1 : 200000 scale.

R.R. Gabdullin in the Bakhchisarai and Simferopol regions of Crimea within the area of sheet L-36-XXIX (Fig. 1) and adjacent territories (in the area of the Crimean Education Research Center of Moscow State University and its vicinities). All samples contain nannoflora of good (unaltered coccoliths) to moderate (coccoliths with minor secondary alteration) preservation. Specimens were prepared following the standard procedure, including preparation of a rock suspension in distilled water and further decantation. After precipitation of heavy and dense particles, the residual solution was mounted on a slide, dried, inserted into canada balsam, and covered by glass with an area of 4 cm^2. The species composition was studied on a BiOptik polarized optical microscope in crossed nicols under a magnification of 1000×. The typical species are shown in Figs. 4 and 5.

CHARACTERISTIC OF THE SECTION

Lower Cretaceous

The Rezanaya Formation (K_1*rz*) traced in the valley of the Alma River is composed of limestones, clays, sandstones, and conglomerates. The stratotypical section is located near the settlement of Verkhorech'e (sheet L-36-XXVIII), on the southeastern slope of Mt. Rezanaya.

The formation occurs with a hiatus on rocks of the Middle Jurassic or Tavrida Group and is unconformably overlapped by the Koyasdzhilda Formation or Albian and younger rocks. The composition of the formation is facially variegated: the carbonate rocks gradually replace terrigenous rocks to the north. The thickness of the formation reaches 120 m, decreasing to the northeast. Locally, one can observe intercalation of limestones and sandstones.

The formation hosts an abundant faunal assemblage, including the ammonites *Leopoldia leopoldiana* Orb. and *Crioceratites duvali* Lev. of Early Hauterivian *Crioceratites nolani* (Kilian) Zone, which supports ascribing these rocks to the same age. The rocks also contain Valanginian–Hauterivian corals *Cyclolites* sp. and Valanginian–Early Hauterivian *Stylina elegans* Eichwald and Hauterivian nautilus *Cymatoceras pseudoelegans* Orb. Thus, the age of the formation is accepted as Valanginian–Early Hauterivian.

The nannoplankton assemblage is inconsistent within the area of the formation. It is absent or includes cosmopolitan species of broad occurrence: *Cyclagelosphaera margerelii* Noël, *Rhagodiscus asper* (Stradner) Reinhardt, *Watznaueria barnesae* (Black) Perch-Nielsen, and *Watznaueria fossacincta* (Black) Bown in Bown and Cooper. The nannoplankton assemblage of the Rezanaya Formation with high taxonomic diversity includes *Biscutum constans* (Górka) Black in Black and Barnes, *Biscutum ellipticum* (Górka) Grün in Grün and Allemann, *Broinsonia? sp.*, *Cretarhabdus conicus* Bramlette and Martini, *Cyclagelosphaera margerelii* Noël, *Diadorhombus rectus* Worsley, *Diazomatolithus lehmanii* Noël, *Helenea chiastia* Worsley, *Manivitella pemmatoidea* (Deflandre in Manivit) Thierstein, *Retecapsa angustiforata* Black, *Rhagodiscus asper* (Stradner) Reinhardt, *Rhagodiscus dekaenelii* Bergen, *Rhagodiscus robustus* Bown, *Staurolithites crux* (Deflandre and Fert) Caratini, *Staurolithites mutterlosei* Crux, *Zeugrhabdotus scutula* (Bergen) Rutledge and Bown, *Zeugrhabdotus elegans* (Gartner) Burnett

Stage	Substage	Zonal standard of Western Mediterranean (Baraboshkin, 2004)		Crimean Mountains (Baraboshkin, 2004)		Formation	Nannoplankton Zone (Bown et al., 1998)
Barremian	upper	*Pseudocrioceras*		*Patruhusiceras uhhgi*		Biasala	NC5
		Colchidites sarasini					
		Imerites giraudi					
		Hemihoplites feraudianus					
		Gerardthia sartousiana	*Gerardthia provincialis*	*Lreraratma provincialis*		Koyasdzhilga	No nannoplankton was studied
			Gerardthia sartousiana				
		Ancyloceras vandenheckii					
	lower	*Montonicares moutonianum*		*Holcodiscus caillaudianus*			
		Kotetishvilia compressissima					
		Kotetishvilia nicklesi		*Niclesia pulhella*			
		Avramidiscus hugii		*Taveraediscus hugii*			
Hauterivian	upper	*Pseudothurmannia angulicostata auctori*	*Pseudothurmannia catulloi*	*Pseudothurmannia catulloi*			
			P. angulicostata auct.	*Pseudothurmannia ohmi*			
		Balearites barealis		*Milanowskia speetonensis*			
		Plesiospitidiscus ligatus		*Speetoniceras inversum*			
		Saynella sayni		*Crioceratites duvali*			Not distinguished
	lower	*Lyticoceras nodosoplicatum*		*Lyticoceras nodosoplicatum*			
		Crioceratites loryi	*Olcostephanus jeannoti*	? *Crioceratites loryi*			
			Crioceratites loryi				
		Acanthodiscus radiatus		*Leopoldia desmoceroides*			
Valanginian	upper	*Teshenites callidiscus*		*Eleniceras tauricum*		Rezanaya	?
				Teshenites callidiscus			
		Himantoceras trinodosum	*Criosarasinella furcillata* *Olcostephanus nicklesi*	*Himantoceras trinodosum*			
		Saynoceras verricosum	*Vahrleideites peregrinus*	*Neohoploceras submartini*	? *Vahrleideites peregrinus*		
			Karakasch. pronecostatum		?		
			Saynoceras verricosum				
	lower	*Busnardoites campylotoxus*		*Campylotoxia campylotoxa*			
		Thurmanniceras perttansies		*Thurmanniceras perttansies*			
		Thurmanniceras otopeta		*Kilianella otopeta*			

Fig. 2. Biostratigraphic division of the Lower Cretaceous formations of the Bakhchisarai region according to ammonites and calcareous nannoplankton.

in Gale et al., *Watznaueria barnesae* (Black) Perch-Nielsen, *Watznaueria britannica* (Stradner) Reinhardt, and *Watznaueria fossacincta* (Black) Bown in Bown and Cooper (Fig. 4).

The 2–3 m thick Koyasdzhilda Formation, which is composed of dense limestones, overlaps the Rezanaya Formation with erosion. Its stratotype is distinguished near the settlement of Nauchny, in the Koyas Dzhilda gully (rocky gully in Turkic). The formation hosts the ammonites *Phylloceras infundibulum* Orb., *Phylloceras eichwaldi* Karak., and *Emericeras emerici* Lev. and brachiopods *Lacunosella mountoniana* Orb. and *Monticlarella weberi* Moiss. (*Nizhnii*..., 1985). No nannoplankton has been studied.

The Biasala Formation (K_1*bs*) occurs locally in the basins of the Kacha and Bodrak rivers and is com-

Stage	Substage	Zonal standard of West European (Alekseev et al., 2005, Burnett, 1998, Ogg et al., 2008)		Crimean Mountains (Alekseev et al., 2004, Gale et al., 1999	Formation	Nannoplankton Zone (Burnett, 1998)	Nannoplankton Zone (Sissingh, 1977)
Maastrichtian	upper	*Anapachydiscus terminus*		*Anapachydiscus terminus*	Kudrino	UC20b	CC25c
		Anapachydiscus fresvillensis		*Anapachydiscus fresvillensis*			
	lower	*Pachydiscus epiplectus*		*Pachydiscus epiplectus*			
Campanian	upper	*Hoplitoplacenticeras marroti*		*Hoplitoplacenticeras marroti*			
	lower	*Delawarella campaniensis*		*Delawarella campaniensis*			
		Placenticeras bidorsatum		*Placenticeras bidorsatum*			
Santonian	upper	*Placenticeras polyopsis*		*Placenticeras polyopsis*			
	middle						
	lower						
Coniacian	upper	*Paratexanites serratomarginatus*		*Paratexanites serratomarginatus*			
	lower	*Gauthiericeras margae*		*Gauthiericeras margae*	Prokhlandoe	Not distinguished	Not distinguished
		Peroniceras tridorsatum		*Peroniceras tridorsatum*			
Turonian	upper	*Prionocyclus germari*		*Prionocyclus germari*		?	?
		Subprionocyclus neptuni		*Subprionocyclus neptuni*			
	middle	*Collignonoceras woollgari*	*Romaniceras deverianum*	*Collignonoceras woollgari*			
			Romaniceras omatissimum				
			Romaniceras kallesi				
			Kamerunoceras turoniense				
	lower	*Mammites nodosoides*		*Mammites nodosoides*			
		Watinoceras devonense		*Watinoceras devonense*			
Cenomanian	upper	*Nigericeras scotti*		*Nigericeras scotti*	Belogorsk	?	?
		Neocardioceras juddi		*Neocardioceras juddi*			
		Metoiceras geslinianum		*Metoiceras geslinianum*			
		Calycoceras guerangeri		*Calycoceras guerangeri*		UC3b	CC9
	middle	*Acanthoceras jukesbrownei*		*Acanthoceras jukesbrownei*			

Fig. 3. The biostratigraphic division of the Upper Cretaceous formations of the Bakhchisarai region according to ammonites and calcareous nannoplankton.

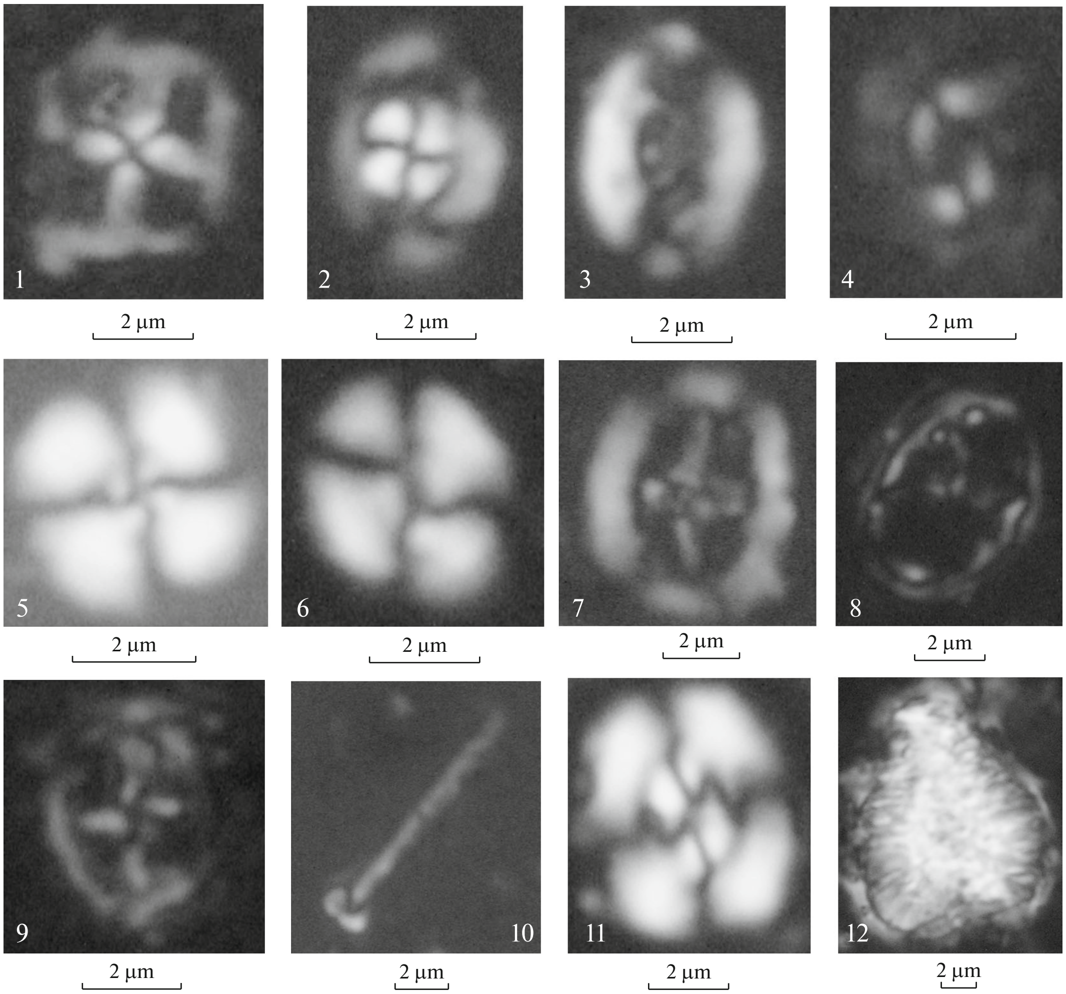

Fig. 4. Lower Cretaceous calcareous nannoplankton of the Bakhchisarai region of southwestern Crimea. Rezanaya Formation: (1) *Diadorhombus rectus* Worsley; (2) *Rhagodiscus dekaenelii* Bergen; (3) *Rhagodiscus robustus* Bown; (4) *Biscutum ellipticum* (Górka) Grün in Grün and Allemann; (5) *Cyclagelosphaera margerelii* Noël; (6) *Watznaueria barnesae* (Black) Perch-Nielsen; (7) *Broinsonia ?* sp. Biasala Formation: (8) *Chiastozygus litterarius* (Górka) Manivit; (9) *Staurolithites crux* (Deflandre and Fert) Caratini; (10) *Rhabdophidites parallelus* (Wind and Cepek) Lambert; (11) *Watznaueria fossacincta* (Black) Bown in Bown and Cooper; (12) *Nannoconus steinmanni* ssp. *steinmanni* Kampter.
Photos (1–3, 5–9, 11), distal side; (10, 12), side view. All photos, crossed nicols.

posed of clays with ankerite nodules and inclusions of carbonaceous plant relics. Its stratotype was distinguished by Vishnevsky and Menyailo in 1963 near the settlement of Verkhorech'e: the former Biya-Sala (two flows in Turkic) founded near the entering place of the Marty River to the Kacha River.

The main rock lithotype is gray, brownish, and yellowish-gray muddy ductile carbonate clays with greenish-brown dense massive or concentrically-zonal vaguely layered ankerite nodules. The thickness of the formation reaches 100–120 m (Fikolina et al., 2008).

The rocks of the Biasala Formation rest with erosion on limestones of the Koyasdzhilda Formation and are transgressively overlain locally by Albian sedimentary rocks (Vysokii Bugor and Mangush formations) or are completely eroded along with rocks of the Koyasdzhilda Formation by Albian or younger rocks.

The lower part of the formation contains a rich assemblage of fossil remains: cephalopods *Barremites strettostoma* Uhl., *Silesites seranonis* Uhl., *Aconeceras nisum* Orb., *Deshayesites deshayesi* Leum. and foraminifers *Globorotalites bartensteini* Bett., *Gaudryinella elongata* Pair., *Dorotia elondata* Tair., and *Patellina subcretacea* Cuschm. et Alex. (Fikolina et al., 2008; *Nizhnii…*, 1985). The Late Barremian age of the formation is identified by ammonites *Barremites strettostoma* and *Silesites seranonis* (*Nizhnii…*, 1985).

The nannoplankton assemblage includes *Chiastozygus litterarius* (Górka) Manivit, *Eprolithus antiquus* Perch-Nielsen, *Helenea chiastia* Worsley, *Nannoconus steinmanni* ssp. *steinmanni* Kampter, *Nannoconus* sp.,

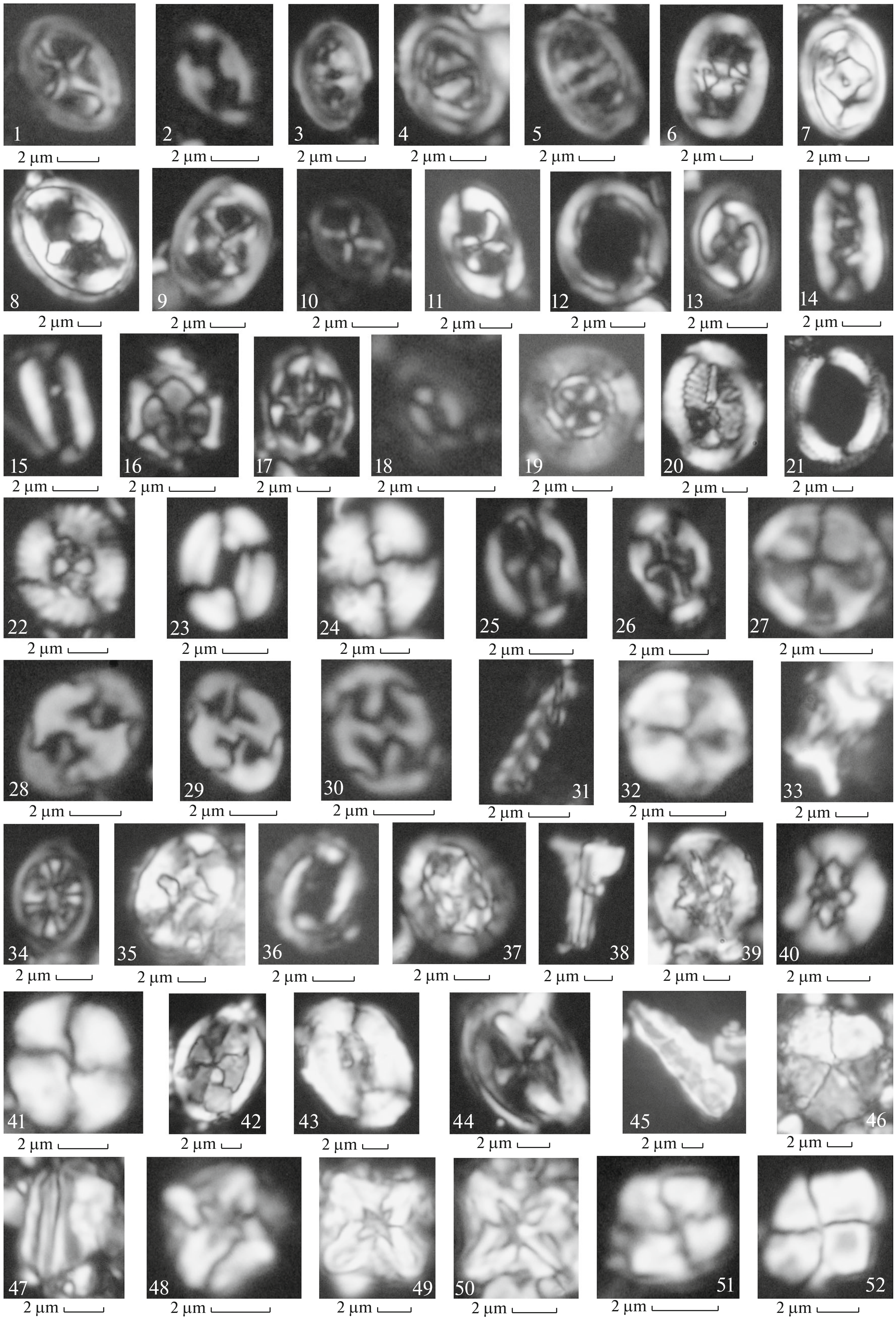
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Fig. 5. The upper Cretaceous calcareous nannoplankton of the Bakhchisarai region of southwestern Crimea. The Belogorsk Formation: (1) *Staurolithites gausorthethium* (Hill) Varol ang Girgis; (2) *Tranolithus gabalus* Stover; (3) *Tranolithus orionatus* (Reinhardt) Reihardt; (4) *Zeugrhabdotus bicrescenticus* (Stover) Burnett in Gale et al.; (5) *Zeugrhabdotus diplogrammus* (Deflandre in Deflandre and Fert) Burnett in Gale et al.; (6) *Zeugrhabdotus noeliae* Rood et al.; (7, 8) *Zeugrhabdotus embergeri* (Noël) Perch-Nielsen; (9) *Chiastozygus bifarius* Bukry; (10) *Chiastozygus synquadriperforatus* Bukry; (11) *Tegumentum stradneri* Thierstein in Roth and Thierstein; (12) *Loxolithus armilla* (Black in Black and Barnes) Noël; (13) *Eiffellithus gorkae* Reinhardt; (14) *Rhagodiscus splendens* (Deflandre) Verbeek; (15) *Rhagodiscus angustus* (Stradner) Reinhardt; (16) *Corollithion kennedyi* Crux; (17) *Axopodorhabdus albianus* (Black) Wind and Wise in Wise and Wind; (18) *Biscutum ellipticum* (Górka) Grün in Grün and Allemann; (19) *Prediscosphaera ponticula* (Bukry) Perch-Nielsen; (20) *Cretarhabdus striatus* (Stradner) Black; (21) *Manivitella pemmatoidea* (Deflandre in Manivit) Thierstein; (22) *Helenea chiastia* Worsley; (23) *Watznaueria fossacincta* (Black) Bown in Bown and Cooper; (24) *Watznaueria biporta* Bukry; (25) *Broinsonia signata* (Noël) Noël; (26) *Acaenolithus cenomanicus* Black; (27) *Radiolithus hollandicus* Varol; (28–30) *Orastrum colligatum* Henderiks and Ziveri; (31) *Microrhabdulus belgicus* Haye and Towe; (32) *Radiolithus planus* Stover; (33) *Eprolithus floralis* (Stradner) Stover.

Kudrino Formation: (34) *Ahmuerella octoradiata* (Górka) Reinhardt; (35) *Eiffellithus turriseiffelii* (Deflandre in Deflandre and Fert); (36) *Biscutum magnum* Wind and Wise in Wise and Wind; (37) *Prediscosphaera cretacea* (Arkhangelsky) Gartner; (38) *Prediscosphaera cretacea* (Arkhangelsky) Gartner; (39) *Cretarhabdus conicus* Bramlette and Martini; (40) *Retecapsa angustioforata* Black; (41) *Watznaueria barnesae* (Black) Perch-Nielsen; (42) *Arkhangelskiella cymbiformis* Vekshina; (43) *Broinsonia parka constricta* (Stradner) Bukry; (44) *Gartnerago segmentatum* (Stover) Thierstein; (45) *Lucianorhabdus cayexii* Deflandre; (46) *Braarudosphaera bigelowii* (Gran and Braarud) Deflandre; (47) *Litharphidites quadratus* Bramlette and Martini; (48, 49) *Micula stauropora* (Gardet) Stradner; (50) *Micula* ex gr. *concava* (Stradner in Martini and Stradner) Verbeek; (51) *Micula murus* (Martini) Bukry; (52) *Uniplanarius gothicus* (Deflandre) Hattner and Wise.

Photos (1–16, 19–26, 34–37, 39–44) distal side; (27–32, 45–47) general view; (33) side view; (37) a fragment of a spine; (48–52) top view. All photos, crossed nicols.

Rhabdophidites parallelus (Wind and Cepek) Lambert, *Rhagodiscus asper* (Stradner) Reinhardt, *Staurolithites crux* (Deflandre and Fert) Caratini, *Watznaueria barnesae* (Black) Perch-Nielsen, and *Watznaueria fossacincta* (Black) Bown in Bown and Cooper.

The Mangush Formation (K_1mn) is composed of clays and sandstones and was distinguished by Chernov and Yanin in 1975 near the settlement of Prokhladnoe (former Mangush, which means cool in Turkic). The stratotypical section occurs in the eponymous gully and is composed of silty fine-layered calcareous clays, which are replaced along the lateral by coarse-grained quartz dense obliquely layered sandstones (Fikolina et al., 2008).

The Mangush Formation (K_1mn) lies transgressively on older rocks to the Tavrida Group inclusively. It is overlapped by Vysokii Bugor Formation in sheet L-36-XXVIII and includes ingression rocks in the paleorelief of the Mangush gully. The rocks of the Mangush Formation are most representative in the vicinities of the settlement of Prokhladnoe. They lie ingressively, filling the ancient pre-Late Albian (so-called Mangush) erosion depression, locally occurring hypsometrically lower in the Jurassic and Hauterivian outcrops (area of mounts Dlinnaya and Sheludivaya), or overlapping the Hauterivian, Barremian, and Aptian rocks (area of Mt. Prisyazhnaya) in territory adjacent to sheet L-36-XXVIII (Alekseev, 1989). The structure and composition of the formation are inconsistent.

The section of the sequence in the area of the settlement of Prokhladnoe is composed of silty thinly laminated calcareous clays, which are replaced along the lateral direction by coarse-grained dense obliquely layered quartz sandstones. The thickness is 25–30 m.

The age of the sequence is substantiated by ammonites *Hysteroceras orbignyi* Spath., *Hysteroceras verricosum* Sow., *Puzosia (Puzosia) mayoriana* (Orb.), *Epihoplites gibbosus* Spath., *Epihoplites inornatus* Spath., etc., which are typical from the beginning of the Late Albain (Fikolina et al., 2008; Komarov and Kutluakhmetov, 2014). The formation also contains foraminifers *Hedbergella infracretacea* (Glaessn.), *Hedbergella globigerinelliolinoides* (Subb.) etc., as well as bivalves *Actinoceramus sulcatus* (Park.), *Nucula albensis* (Orb.), *Grammatodon carinatus* (Sow.), *Inoceramus anglicus* Woods, *Inoceramus concentricus* Park., *Lima gaultina* Woods etc. and brachiopod *Rectithyris banionisi* Komarov et Kutluachmetov (Fikolina et al., 2008; Komarov and Kutluakhmetov, 2014). No nannoplankton has been found in sandstones of the Mangush Formation.

Upper Cretaceous

The Belogorsk Formation (K_2bg) consists of the transgressive series: sandstones and sandy marls in the lower part, which gradually give way to more carbonate rocks (up to limestones) upward the section including silicified rocks in the upper part. The formation encloses siliceous nodules, which occur as numerous marking horizons in its upper part and form placers on uplifts (e.g., Mt. Kremennaya) as a result of weathering. An interlayer of montmorillonite clays can be considered a marking horizon in the uppermost parts of the Middle Cenomanian. The cyclic structure is a distinctive feature of rocks of the formation. Elementary bedded two-element cyclites, which are formed as a result of the astronomic–climatic cycles of Milutin Milankovitch (19–21 ky precession cycles), mostly include intercalated more or less carbonate varieties of marls and/or limestones (Gabdullin, 2002). At the foot of the formation, the cyclicity is identified in members of intercalated sandstones and sandy marls, as well as in limestones close to the top. In the area of study, the rocks crop out as a 200–1800-m wide band (Fikolina et al., 2008) and transgressively occur on

Triassic, Jurassic, and Lower Cretaceous sedimentary rocks. They are overlapped by rocks of the Porkhladnoe Formation with stratigraphic unconformity. Locally, the rocks of the Belogorsk Formation are erosively overlain by Paleogene or Neogene deposits. The thickness is up to 100–120 m.

The stratotype is located in the Belogorsk region (the right bank of the Tonas River) (Fikolina et al., 2008) and the reference sections of the formation are on the southern slope of Mt. Selbukhra and on Mt. Kremennaya near the settlement of Prokhladnoe.

The Cenomanian age of rocks of the formation is proved by findings of bivalves *Inoceramus crippsi* Mant., *Inoceramus tenuis* Mant., and *Inoceramus scalprum* Boehm, ammonites *Neohibolites ultimus* Orb., *Mantelliceras mantelli* (Sow.), and *Schloenbachia varians* (Sow.), foraminifers *Rotalipora appenninica* Renz., *Rotundina stephani* (Gand.), *Anomalina globosa* (Brotz.), *Anomalina baltica* (Brotz.), and *Anomalina cenomanica* (Brotz.) (*Atlas*..., 1959). The Early Turonian age of the formation is substantiated by cephalopods, bivalves, pelecypods, and foraminifers *Inoceramus labiatus* Schloth., *Inoceramus hercynicus* Pert., and *Praeglobotruncana helvetica* (Bolli) (Fikolina et al., 2008). According to these data, the formation is Cenomanian–Early Turonian. The Cenomanian–Turonian boundary is marked by anoxic event-2, as shown by lenticular interlayers of bitumen marls and clays in the Belogorsk Formation.

The nannoplankton includes *Acaenolithus cenomanicus* Black, *Axopodorhabdus albianus* (Black) Wind and Wise in Wise and Wind, *Biscutum coronum* Wind and Wise in Wise and Wind, *Biscutum ellipticum* (Górka) Grün in Grün and Allemann, *Broinsonia matalosa* (Stover) Burnett in Gale et al., *Broinsonia signata* (Noël) Noël, *Chiastozygus amphipons* (Bramlette and Martini) Gartner, *Chiastozygus bifarius* Bukry, *Chiastozygus litterarius* (Górka) Manivit, *Chiastozygus synquadriperforatus* Bukry, *Cretarhabdus crenulatus* Bramlett and Martini, *Cretarhabdus striatus* (Stradner) Black, *Cribrosphaerella ehrenbergii* (Arkhangelsky) Deflandre in Piveteau, *Cyclagelosphaera margerelii* Noël, *Eiffellithus gorkae* Reinhardt, *Eiffellithus monechiae* Crux, *Eiffellithus turriseiffelii* (Deflandre in Deflandre and Fert), *Gartnerago segmentatum* (Stover) Thierstein, *Haqius circumradiatus* (Stover) Roth, *Helenea chiastia* Worsley, *Helicolithus compactus* (Bukry) Varol and Girgis, *Loxolithus armilla* (Black in Black and Barnes) Noël, *Manivitella pemmatoidea* (Deflandre in Manivit) Thierstein, *Microrhabdulus belgicus* Haye and Towe, *Micula concava* (Stradner in Martini and Stradner) Verbeek, *Orastrum colligatum* Henderiks and Ziveri, *Prediscosphaera cretacea* (Arkhangelsky) Gartner, *Prediscosphaera columnata* (Stover) Perch-Nielsen, *Radiolithus hollandicus* Varol, *Radiolithus planus* Stover, *Rhagodiscus angustus* (Stradner) Reinhardt, *Rhagodiscus achlyostaurion* (Hill) Doeven, *Rhagodiscus asper* (Stradner, 1963) Reinhardt, *Rhagodiscus splendens* (Deflandre) Verbeek, *Retecapsa angustioforata* Black, *Tegumentum stradneri* Thierstein in Roth and Thierstein, *Thoracosphaera operculata* Bramlett and Martini, *Tranolithus orionatus* (Reinhardt) Reihardt, *Staurolithites crux* (Deflandre and Fert) Caratini, *Zeugrhabdotus bicrescenticus* (Stover) Burnett in Gale et al., *Zeugrhabdotus diplogrammus* (Deflandre in Deflandre and Fert) Burnett in Gale et al., *Zeugrhabdotus "elegans"* (Gartner) Burnett in Gale et al., *Zeugrhabdotus embergeri* (Noël) Perch-Nielsen, *Watznaueria barnesae* (Black) Perch-Nielsen, *Watznaueria biporta* Bukry, and *Watznaueria britannica* (Stradner) Reihardt.

The Prokhladnoe Formation (K_2pr) made of chalky limestones rests erosively on the Belogorsk Formation and is unconformably overlain by the Kudrino Formation. In area of sheet L-36-XXIX, the rocks are exposed as a band 50–1500 m wide. Locally, the formation is eroded by Paleogene or Neogene sediments. The rocks of the formation are facially consistent and include chalk-like limestones with white or pink stylolites, whose presence is a mapping feature of the formation. The thickness reaches 56 m and is typically ~20 m, varying due to the eroded upper part of the formation by overlapping rocks and the variable thickness of the lower part of the formation. The stratotype is located in the Bakhchisarai region (settlement of Prokhladnoe) (Fikolina et al., 2008).

The formation contains pelecypods *Inoceramus wandereri* Andr., *Inoceramus lamarcki* Part., *Inoceramus deformis* Mant., and *Inoceramus incostans* Woods. and foraminifers *Globotruncana primitiva* Dalb., *Globotruncana lapparenti* Brotz., *Gavelinella ammonoides* (Rss.), and *Stensioeina emscherica* Barysh. of Late Turonian–Coniacian age (Fikolina et al., 2008), indicating the same age of the formation.

The calcareous nannoplankton includes *Ahmuerella octoradiata* (Górka) Reinhardt, *Biscutum magnum* Wind and Wise in Wise and Wind, *Cretarhabdus crenulatus* Bramlett and Martini, *Cyclagelosphaera margerelii* Noël, *Eiffellithus turriseiffelii* (Deflandre in Deflandre and Fert), *Micula concava* (Stradner in Martini and Stradner) Verbeek, *Micula stauropora* (=*Micula decussata*) (Gardet) Stradner, *Prediscosphaera cretacea* (Arkhangelsky) Gartner, *Rhagodiscus splendens* (Deflandre) Verbeek, *Watznaueria barnesae* (Black) Perch-Nielsen, *Watznaueria biporta* Bukry, *Watznaueria fossacincta* (Black) Bown in Bown and Cooper, and *Watznaueria manivitae* Bukry.

The Kudrino Formation (K_2kd) is widespread throughout the sheet L-36-XXIX and is composed of sandy marls transiting to a sequence of cyclic intercalation of marls and green bentonite clays (or clayey marls) in the lower part, members of clayey, calcareous, silicified marls with sponge layers (marking horizons) in the middle part, and sandy marls and sandstones in the upper part. The rocks of the formation are facially consistent. The formation occurs with erosion on the Prokhladnoe Formation and is unconformably crowned by the Starosel'e Formation or is completely eroded by Paleogene or Neogene sediments (area of settlements of Rusakovka and Dolinovka of the Belogorsk region). In the present-day erosion section, the rocks of the formation are exposed in the foot of the Internal Ridge of the Crimean Piedmont striking from west to east as a 200—1000-m wide bend.

The presence of numerous fossil cups of sponges *Ventriculites* sp. and horizons of green bentonite clays are the mapping features of the formation. Its thickness reaches 250 m (typically, 150–200 m) and varies due to erosion of overlying rocks. The stratotype is located in the Bakhchisarai region (settlement of Kudrino, sheet L-36-XXVIII) (Fikolina et al., 2008).

The formation contains a diverse assemblage of numerous fossil remains: bivalves, cephalopods, brachiopods, echinoderms, and foraminifers including *Cibicidoides temirensis* (Vass.), *Globotruncanita elevate* Brotz., *Inoceramus azerbaydjanensis* Aliev., *Bolivina incrasata* (Rlu.), *Cibicides bembix* Marson., *Reusella minuta* Marson, etc., which are evident of Santonian–Campanian age (Fikolina et al., 2008).

The nannoplankton assemblage contains *Ahmuerella octoradiata* (Górka) Reinhardt, *Arkhangelskiella confusa* Burnett, *Arkhangelskiella cymbiformis* Vekshina, *Biscutum ellipticum* (Górka) Grün in Grün and Allemann, *Braarudosphaera bigelowii* (Gran and Braarud) Deflandre, *Broinsonia parka constricta* (Stradner) Bukry, *Cretarhabdus crenulatus* Bramlett and Martini, *Cretarhabdus conicus* Bramlette and Martini, *Cribrosphaerella ehrenbergii* (Arkhangelsky) Deflandre in Piveteau, *Cyclagelosphaera margerelii* Noël, *Eiffellithus gorkae* Reinhardt, *Eiffellithus turriseiffelii* (Deflandre in Deflandre and Fert), *Gartnerago segmentatum* (Stover) Thierstein, *Lithraphidites quadratus* Bramlette and Martini, *Lucianorhabdus cayexii* Deflandre, *Microrhabdulus decoratus* Deflandre, *Micula ex gr. concava* (Stradner in Martini and Stradner) Verbeek, *Micula stauropora* (Gardet) Stradner (*Micula decussata* Vekshina), *Micula murus* (Martini) Bukry, *Prediscosphaera cretacea* (Arkhangelsky) Gartner, *Reinhardtites levis* Prins and Sissingh in Sissingh, *Retecapsa angustioforata* Black, *Thoracosphaera operculata* Bramlett and Martini, *Tranolithus orionatus* (Reinhardt) Reihardt, *Zeugrhabdotus bicrescenticus* (Stover) Burnett in Gale et al., *Zeugrhabdotus praesigmoides* Burnett, *Uniplanarius gothicus* (Deflandre) Hattner and Wise, *Watznaueria barnesae* (Black) Perch-Nielsen, *Watznaueria biporta* Bukry, and *Watznaueria manivitae* Bukry.

The temporal volume of the Kudrino and overlapping Starosel'e formations is a matter of debate. Their boundary can correspond either to the Campanian–Maastrichtian (Fikolina et al., 2008) or to the Early–Late Maastrichtian, which is consistent with the geological data: variations in paleodepths, paleotemperatures, and salinity of Tethyan waters, as well as transgressive–regressive cycles according to the geochemical data. In this case, the Kudrino Formation is accepted in the volume of members XIII–XXI according to (Alekseev et al., 1989). According to another viewpoint, the boundary is the top of member XXII inside the Late Maastrichtian, because the marls of members XXI–XXII are similar visually and lithologically, whereas rocks of member XXIII can be considered as transgressive sediments of a new geological stage. However, some geologists of Moscow State University do not support the presence of the Starosel'e Formation because of the above issues and the difficult biostratigraphic substantiation of the boundaries between the Kudrino and Starosel'e formations.

Assuming all of the data, we accept the Santonian–Lower Maastrichtian age of the Kudrino Formation (in the volume of members XIII–XXIII after Alekseev, 1989) and do not recommend to distinguish the Starosel'e Formation as the independent unit.

The Starosel'e Formation is abundant everywhere within the sheet of the geological map and includes siltstones, limestones, and sandstones (typically, glauconite in the lower part) (member XXIII (Alekseev, 1989) 20–30 m thick) and less abundant silty glauconite marls with numerous guards and pectenid shells in the upper part (member XXIV (Alekseev, 1989) up to 0–5 m thick). The formation occurs with erosion on Kudrino Formation (there are different interpretations of the volume of the Kudrino and overlapping Starosel'e formations) and is unconformably overlain by the Bely Kamen Formation or is completely eroded by Paleogene or Neogene sediments (the area of the settlements of Rusakovka and Dolinovka of the Belogorsk region). In this territory, it is extended as a narrow band 50–75 m wide from the valley of the Burul'cha River in the west to Mt. Bor-Kaya in the east. The stratotype is located in the Bakhchisarai region (the settlement of Starosel'e). From west to east, the level of sandy marls increases; thus, the clay and glauconite contents decrease (Fikolina et al., 2008). The thickness of the rocks varies from 20 to 35 m.

The formation contains a diverse assemblage of abundant fossil remains: *Inoceramus impressus* Orb., *Spondylus dutempleanus* Orb., *Chlamys acuteplicatus* Alth., and *Pachydiscus neubergicus* (Hauer) and *Echinocoris vulgaris* Leshe., *Chlamys trisulea* (Hag.), *Cibicidoides bembix* (Marss.), *Belemnnella arkhangelskii* Najd., etc. in the upper parts (Fikolina et al., 2008). This faunal assemblage indicates the Maastrichtian age of the formation. No nannoplankton was studied.

THE BIOSTRATIGRAPHY ACCORDING TO CALCAREOUS NANNOPLANKTON

Lower Cretaceous

The data on the Lower Cretaceous rocks are limited, making it difficult to trace nannoplankton assemblages along the area and the vertical section. Shumenko (1976) indicated the poor species composition of calcareous nannoplankton of the Valanginian–Hauterivian rocks of Crimea. The absence of index species of the nannoplankton assemblage of the Rezanaya Formation prevents identification of zones.

However, the presence of *Rhagodiscus robustus*, which was abundant from the Hauterivian to the Albian and *Rhagodiscus dekaenelii*, which was abundant from the Early Valanginian to the Early Hauterivian, can refine the age of the formation to Early Hauterivian (Bown, 2005; Bown et al., 1998). In the Biasala Formation, we can probably distinguish the uppermost part of the NC5 Zone (Upper Barremian, the ammonite zones of Tethyan chart giraudi and sarasini) according to the presence of *Chiastozygus litterarius* (Górka) and *Nannoconus steinmanni ssp. steinmanni* (Bown et al., 1998). The boundary between the Upper Barremian NC5 Zone and Lower Aptian NC6 Zone corresponds to the onset of *Hayesites irregularis* (Thierstein in Roth and Thierstein) Applegate et al. in Covington and Wise (Bown et al., 1998). Because of its absence in our material, however, we can suggest that this part of the Biasala Formation is Late Barremian. This is consistent with the above data on ammonites and foraminifers.

Upper Cretaceous

The Late Cretaceous calcareous nannoplankton is better studied in comparison with that of the Early Cretaceous (Alekseev et al., 2007; Lyul'eva and Permyakov, 1980; Shumenko, 1976, 1987). Shumenko (1987) proposed a regional scale for the Upper Cretaceous of Mountainous Crimea. The scales of Sissingh (1977) and Burnett (1998) are also widespread. The latter is especially detailed.

The studied part of the Belogorsk Formation is Middle Cenomanian on the basis of the presence of *Acaenolithus cenomanicus*, which occurs above Subzone b of the UC3 Zone spanning the middle and lower parts of the Upper Cenomanian (Burnett, 1998). No upper and lower boundaries of the subzone have been traced. The Cenomanian age is also supported by the presence of *Axopodorhabdus albianus*, *Corollithion kennedyi*, *Helenea chiastia*, *Orastrum colligatum*, and *Radiolithus hollandicus*, which are not found in the overlying Turonian rocks, as well as by the absence of *Quadrum gartneri* (Burnett, 1998). The latter species appears in the Early Turonian (Burnett, 1998).

The calcareous nannoplankton assemblage of the Prokhladnoe Formation contains no index species that are indicative of zones, but can refine the age by the appearance of representatives of the Coniacian–Maastrichtian Micula genus (Burnett, 1998).

The nannoplankton of the Kudrino Formation has been studied locally. The available material has provided a rich species assemblage, although most taxa have broad vertical occurrence in the Upper Cretaceous. The presence of *Lithraphidites quadratus* and *Micula murus* substantiates the Late Maastrichtian age of the sample. These species are typical of the Sissingh scale (Subzone CC25 of Zone CC25) (Sissingh, 1977) and the Burnett scale (Subzone UC20B of Zone UC20) (Burnett, 1998) correlated with the first scale. We should note the presence of *oroinatus* (=Tranolithus phacelosus Stover) species in the Upper Maastrichtian of Crimea, whose upper boundary in many sections worldwide does not intersect the Upper Maastrichtian. It is considered that this species is present below Zone CC23 (Burnett, 1997; Ovechkina, 2007); however, it is described from the Upper Maastrichtian rocks of the southwestern part of Tunisia (El Kef section) (Verbeek, 1977).

Paleoecology and Paleogeography

The Cretaceous period in the evolution of Mountainous Crimea was characterized by transgressions and regressions due to eustatic oscillations of sea level and tectonic events (Kopaevich, 1997; Millev et al., 1997; Naidin et al., 1980; Nikishin et al., 2006). The marine basin of Mountainous Crimea was part of the Tethys Ocean. The Valanginian–Huaterivian (the period of sedimentation of the Rezanaya Formation) was high-temperature (~22–24°C) (Baraboshkin, 2003; Vishnevskaya et al., 2006). The temperature of the surface waters was also high, which is evident from the presence of Biscutum constans and Rhagodiscus asper (Pauly, 2012). The depth of the basin gradually increased from 30–40 m in the north to 100–300 m in the south (Nikishin et al., 2006). The rocks of the Biasala Formation were formed in a relatively deep (up to 500–600 m) cold basin (Nikishin et al., 2006). The temperature of the surface waters was probably higher than that of the bottom waters. Although the species composition of the calcareous nannoplankton is poor and the nannoplankton occurs locally, it has warm-water nannoconids typical of deeper zones of the photic area (Pauly, 2012): *Chiastozygus litterarius* and *Staurolithites crux* (Matveev, 2015).

In the Cenomanian–Coniacian (the period of sedimentation of the Belogorsk and Prokhladnoe formations), the depth of the basin reached 400–700 m (Nikishin et al., 2006). The water temperature of west Tethys was 27–29°C (Puceat et al., 2003). The Cenomanian was a period of accumulation of the Belogorsk Formation, which was highly bioproductive in coccolithophorids, calcispherulids, and plankton foraminifers, which inhabited pelagic warm waters. This is evident from the nannoplankton species diversity. The species *Axopodorhabdus albianus*, *Broinsonia matalosa*, *Cribrosphaerella ehrenbergii*, *Eiffellithus turriseiffelii*, *Gartnerago segmentatum*, *Micula concava*, *Prediscosphaera cretacea*, and *Tranolithus orionatus* preferred moderately warm or cold waters (Mahanipour and Najafpour, 2016; Matveev, 2015; Ovechkina, 2007). In our material, they are minor. In the Middle Cenomanian, the marine basin deepened (Naidin and Alekseev, 1981).

During the Campanian (the period of sedimentation of the Kudrino Formation), the depth of the basin was 350–450 m and the water temperature was ~14°C (Gabdullin et al., 2015a; Puceat et al., 2003). In the Maastrichtian, the water temperature was moderate (22–24°C). The basin had variable depth and salinity (Gabdullin et al., 2015b). This nannoplankton assemblage also supports the high-temperature surface waters in the Maastrichtian by both high diversity and the presence of *Micula murus* and *Lithraphidites quadratus* (Matveev, 2015; Ovechkina, 2007).

CONCLUSIONS

A more detailed study of calcareous nannoplankton can help to refine the age of host sedimentary rocks up to identification of boundaries between stages in lithologically monotonous rocks with minor macrofauna relics and other microfossils (foraminifers, ostracods, and radiolarians), e.g., the Biasala Formation. It is also necessary to refine (or elaborate) the biostratigraphic scale of the Cretaceous rocks of Crimea by calcareous nannoplankton related to the regional scales by ammonites and foraminifers, as well as with the Mediterranean ammonite scale.

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