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Calcareous Nannoplankton from the Upper Cretaceous and Paleogene Deposits of the Kamchatsky Mys Peninsula (Eastern Kamchatka)

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Abstract—The results of a study of calcareous nannofossils found for the first time in the lower part of the Stolbovaya Group of the Kamchatsky Mys Peninsula in eastern Kamchatka are presented. Two assemblages of different ages are identified, with one assigned to the Upper Cretaceous and the other to the Paleogene (not older than the Lutetian Stage of the Middle Eocene). These data make it possible to refine the age of terrigenous–tuffaceous sequences in the lower part of the Stolbovaya Group, which are poor in organic remains.

Keywords: Paleogene, Cretaceous, calcareous nannofossils, eastern Kamchatka

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INTRODUCTION

Paleogene marine terrigenous, tuffaceous–sedimentary, and volcanogenic sequences are widespread in the eastern Kamchatka region. This region is ascribed to the tectonically active zone. For this reason, the sequences of this age are highly deformed, have significant thickness, and show facies diversity, which complicates their stratigraphic relations. Accurate dating and correlation of formations developed here are based on the scarce finds of benthic fauna and frequently remain arbitrary. In addition, up to now, data on the remains of calcareous microplankton organisms allowing dating of old sequence based on biostratigraphic zonation have been scarce and even absent for most regions. In particular, the presence of fossil nannoplankton is now established only at separate stratigraphic levels in the Paleogene sections of the Govena, Il'pinsky, Kronotsky, and Kamchatsky Mys peninsulas and the Karaginsky and Bering islands [3–5, 12]. All these facts, in spite of the previous geological studies, make it impossible to determine the exact age of the lower part of the Paleogene sequences. This hampers the compilation of reliable regional stratigraphic schemes and the determination of the Cretaceous–Paleogene boundary in the region.

One of the best Paleogene sections of eastern Kamchatka is the section located on the Kamchatsky Mys Peninsula (Fig. 1). We attempted to study one of its parts with more detailed sampling than previously in order to obtain new micropaleontological data.

THE PROBLEM OF THE STRATIGRAPHY AND DATING OF PALEOGENE SEQUENCES OF THE KAMCHATSKY MYS PENINSULA

The Kamchatsky Mys Peninsula as a subzone is assigned to the structural–facies zone of the eastern peninsulas of the Eastern Kamchatka lithotectonic zone [7]. Tertiary deposits developed in this area have been studied for many years by V.G. Valov, B.K. Dolmatov, and M.Yu. Khotin, M.N. Shapiro, M.E. Boyarinova, B.I. Slyadnev, Yu.B. Gladenkov, and others. The detailed stratigraphic scheme of Paleogene sequences, which are widely exposed in the eastern part of the peninsula, was proposed for the first time by M.Yu. Khotin in 1970s [9–11]. These sequences are represented by terrigenous, tuffaceous–sedimentary, and volcanogenic rocks united into the Stolbovaya Group, which is subdivided into four formations (from bottom upward): Tarkhovskii, Vereshchaginskii, Rifovyi, and Baklanovskii ones. Each formation is additionally subdivided into the lower and upper subformations. The age of the group in general is estimated as Paleocene–Oligocene.

An important contribution to study and generalization of geological and stratigraphic data on this area

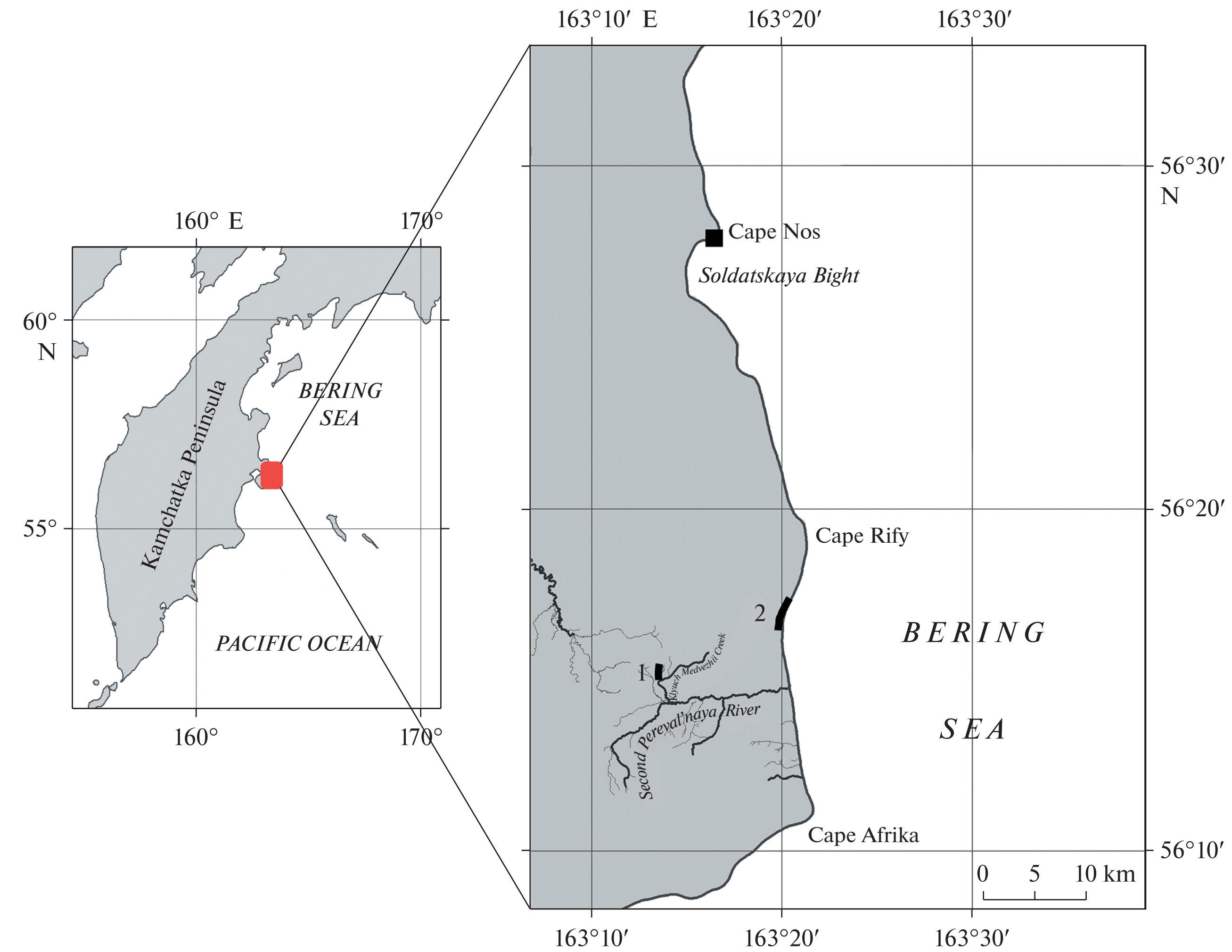

Fig. 1. The geographic position of the Kamchatsky Mys peninsula and position of the studied stratigraphic sections. (1) Section along the Klyuch Medvezhii Creek, (2) section along the Bering Sea shore; black boxes show the position of section of the Baklanovskii Formation, which yielded Paleogene nannoplankton [12].

was made in the 1980–2000s by M.E. Boyarinova, who supervised prospecting and topical works. Owing to these works, the volume and age of units of the Stolbovaya Group was revised and the new Kamennogorskii Formation (previously ascribed to the upper part of the Rifovskii Formation) was distinguished. The study of the reference sections of the group (a total thickness up to 6000 m) made it possible to distinguish regional stratigraphic stages (and their stratotypes), as well as to determine their paleontological characteristics and age [1, 2, 7]. Thus, the following regional (stratigraphic) stages were distinguished (from bottom upward): Tarkhovskii regional stage corresponding to the Danian stage of the Paleocene (corresponds to the Upper Tarkhovskii Subformation), Vereshchaginskii regional stage assigned to the Selandian–Thanetian stages of the Paleocene (corresponds to the Vereshchagin Formation), Rifovskii regional stage correlating with the Ypresian stage of the Eocene (corresponds to the Rifovskii and Kamennogorskii formations), Baklanovskii regional stage corresponding to the Bartonian–lower Priabonian stages of the Eocene (the near-roof parts of the Kamennogorskii Formation and most of the Baklanovskii Formation), and Chaikinskii regional stage ascribing to the Priabonian stage of the Eocene (upper portions of the Baklanovskii Formation) (Fig. 2). The age of the stratigraphic units was determined based on the analysis of stratigraphic distribution of scarce finds of benthic foraminifers and mollusks. The radiolarian finds indicate the Maastrichtian (Upper Cretaceous) age of the Lower Tarkhovskii subformation. Thus, based on foraminiferal, mollusk, and radiolarian assemblages, the age of the Stolbovaya Group was arbitrarily constrained to the Late Maastrichthian–Late Eocene [1, 2, 6, 7]. Data on the calcareous nannoplankton in Tertiary sequences developed on Kamchatsky Mys are now limited by the nannofossil finds in sediments, which

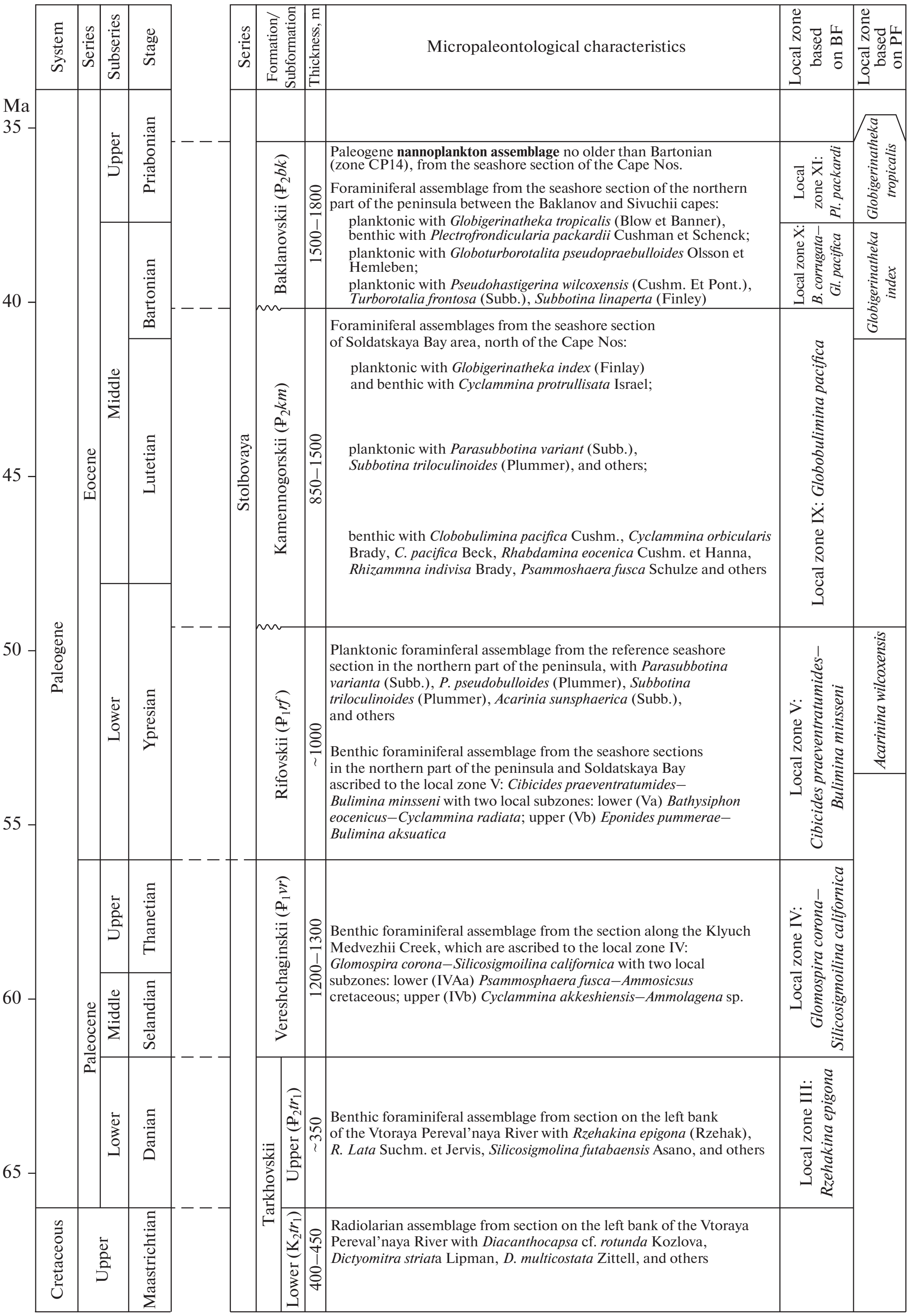

Fig. 2. The stratigraphic scheme of the deposits of the Stolbovaya Group and main microfaunal characteristics of distinguished formations in sections of different parts of the Kamchatsky Mys Peninsula after [1, 2, 6, 7], involving the available data on nannoplankton [12]. (BF) Benthic foraminifers, (PF) planktonic foraminifers, (*Pl.*) *Plectofrondicularia*, (*B.*) *Bulimina*, (*Gl.*) Globobulimina.

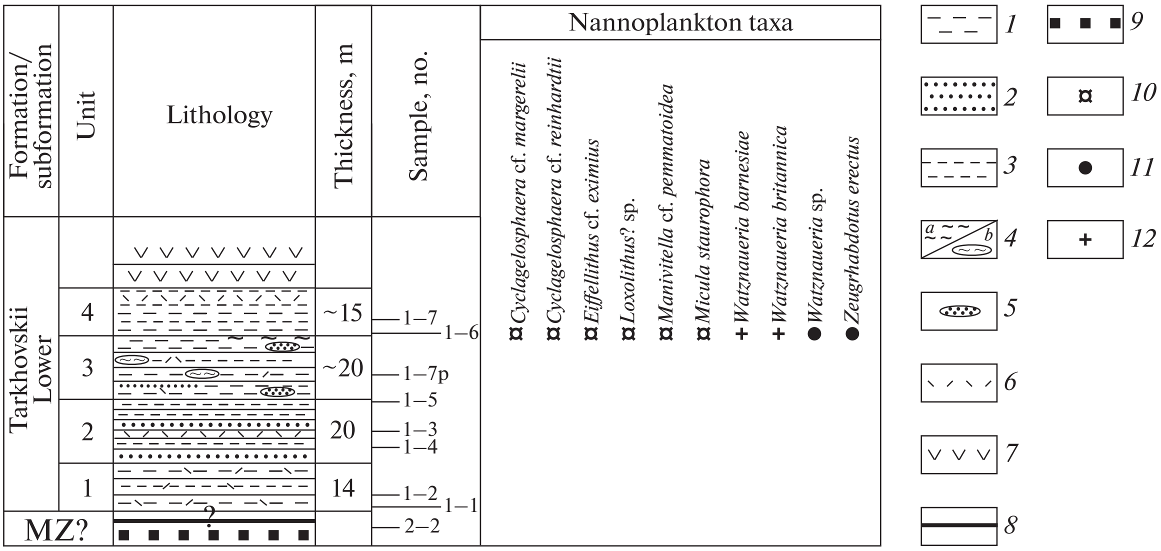

Fig. 3. The level at which nannofossils were found in the rocks of the Lower Tarkhovskii Subformation in section along the Klyuch Medvezhii Creek. (*1–7*) Lithology: (*1*) mudstones and tuffaceous mudstones; (*2*) sandstones and tuffstones; (*3*) siltstones and tuffaceous siltstones; (*4*) cherts (a) and lenses of cherts (b), (*5*) lenses of sandstones; (*6*) tuffs, (*7*) basaltic rocks; (*8*) faults; (*9*) fault zones; (*10–12*) occurrence of nannoplankton: (*10*) one species per the entire specimen, (*11*) 1–2 species per ten fields of view, (*12)* one species per 100 fields of view; (MZ) Mesozoic rocks.

are ascribed to the lower part of the Baklanovskii Formation and represented in the section in the northeastern part of the peninsula, in particular, on the Cape Nos, north of Soldatskaya Bay [12] (Fig. 1, 2). The age of the distinguished assemblage with *Cyclicargolithus floridanus* (Roth et Hay) Bukry, *Coccolithus formosus* (Kamptner) Wise, *C. pelagicus* (Wallich) Schiller, *Discoaster deflandrei* Bramlette et Riedel, *D. nodifer* (Bramlette et Riedel) Bukry, *Dictyococcites bisectus* (Hay, Mohler et Wade) Bukry et Percival, *D. daviesii* (Haq) Perch- Nielsen, *D. scrippsae* Bukry et Percival, *Reticulofenestra umbilicus* (Levin) Martini et Ritzkowski, *R. coenura* (Reinhardt) Roth was determined by Shcherbinina [12] within the range from the upper Middle Eocene (Bartonian stage) to the lower Oligocene (zones CP14 *Reticulofenestra umbilicus*–CP16 *Helicosphaera reticulate*) according to Okada and Bukry [18]).

This paper reports data on the first finds of nanoplankton in the lower part of the Stolbovaya Group.

MATERIAL AND METHODS

In 2019, scientists from the Geological Institute of the Russian Academy of Sciences, including A.Yu. Gladenkov, S.I. Bordunov, D.M. Olshanetsky, A.P. Zhernosenko, and G.K. Nazarov, carried out field works in the eastern part of the Kamchatsky Mys Peninsula. These works involved a complex study of the Tarkhovskii and Vereshchaginskii formations of the Stolbovaya Group. We examined two sections along the Klyuch Medvezhii Creek and the seashore, north of the Vtoraya Pereval'naya mouth (Fig. 1), and collected samples for micropaleontological and paleomagnetic analyses. The applied techniques did not allow us to extract foraminiferal shells from rocks for their comprehensive study, although separate shells were observed in polished thin sections. Forty samples were collected to search for nanoplankton remains (Figs. 3, 4). After laboratory treatment, some of these samples yielded nanofossils, which were determined by M.A. Ustinova.

In spite of the fact that the mentioned sections of the Tarkhovskii and Vereshchaginskii formations were described and studied previously [2, 7], nannofossil finds have not been reported. In addition, our subdivision of sequences into units (with determination of their thickness and contact) slightly differed from previous ones [2, 7].

Specimens for study of nanofossils under light polarization microscope were prepared using standard technique [14] and studied with a BiOptik 210 microscope at 1000 x. Photos were taken by Canon 550 camera equipped with a Canon camera adapter. The remains of coccoliths are partially dissolved and corroded, although their main diagnostic features have been preserved. They rarely occur: from one species per 2 fields of view to one species per 50 fields of view.

The subgroups of Paleocene and Eocene are given according to the General Stratigraphic Chart following the Russian Stratigraphic Code [8].

THE BRIEF CHARACTERISTICS OF THE SECTIONS

The Section along the Klyuch Medvezhii Creek

In the section along the Medvezhii Creek (its first right tributary (Fig. 1), we studied sequences ascribed to the Lower Tarkhovskii Subformation (Fig. 3). The contact with underlying rocks is tectonic via fault zone consisting of highly deformed and altered likely Mesozoic rhyolites and rhyodacites.

The studied deposits of the Lower Tarkhovskii Subformation have a visible thickness of more than 1000 m. Stratigraphically, from the bottom upward, it is subdivided into the following units (Fig. 3).

Unit 1. Alternation of greenish-gray fine-grained tuffstones and greenish dense silicified tuffaceous mudstones intercalated with yellowish weakly lithified tuffs. The thickness is 14 m.

Unit 2. Rhythmic alternation of greenish and gray fine-grained sandstones, tuffstones, green silicified mudstones, and brownish gray mudstones with tuff intercalations. The thickness is 20 m.

Unit 3. Alternation of greenish gray and green siliceous siltstones and tuffaceous siltstones with thin intercalations of tuffs (2–5 cm), lenses and intercalations of dark gray fine-grained sandstones and lenses of dark gray and green cherts. The thickness is ca. 20 m.

Unit 4. Alternation of greenish-gray tuffaceous mudstones and tuffaceous siltstones, with thin interlayers (1–3 cm) of yellowish weakly lithified tuffs. The visible thickness is 15 m.

These are conformably overlain by dark gray and gray basaltic rocks. Their visible thickness is over 50 m.

The Section along the Bering Sea Shore

The section of sediments of the Tarkhovskii Formation and the lower part of the Vereshchaginskii Formation was studied on the seashore, north of the Vtoraya Pereval'naya River (Fig. 1). From the bottom upward, it consists of the following units (Fig. 4) (with indications of faults):

Tarkhovskii Formation

Lower Tarkhovskii Subformation

Unit 1. Alternation of greenish-gray tuffstones, tuffaceous mudstones, and tuffaceous siltstones inter-

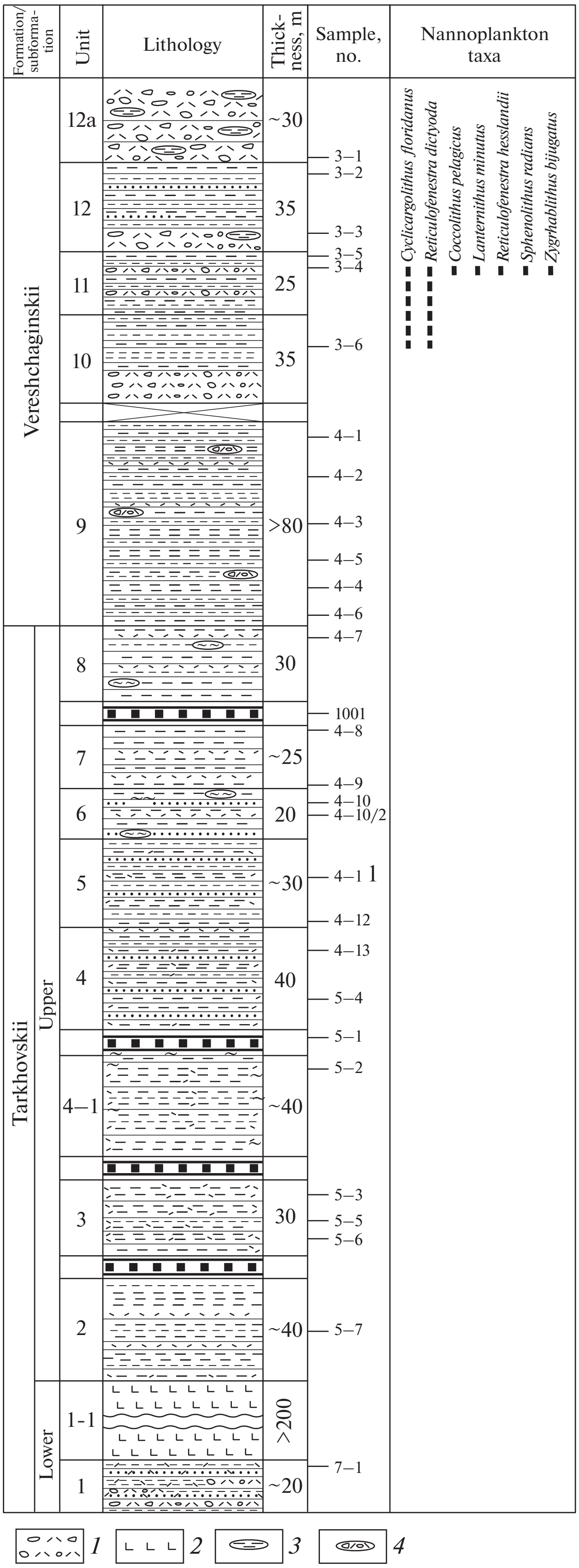

Fig. 4. The levels at which nannofossils were found in rocks of the Vereshchaginskii Formation in seashore section to the north of the Vtoraya Pereval'naya River mouth. (1–4) lithology: (1) tuff breccia and tuff conglomerates; (2) gabbroanorthosites, (3) lenses of mudstones, (4) lenses of tuff breccias; discontinuous line shows the distribution of nannofossils throughout the section. For other symbols, see Fig. 3.

Fig. 5. Rocks of unit 4 in a section along the Klyuch Medvezhii Creek (photo by S.I. Bordunov).

calated with tuff breccia. The visible thickness is ca. 20 m.

Unit 1-1. Light gray gabbroanorthosites. The visible thickness is over 200 m.

Upper Tarkhovskii Subformation

Several fault zones observed in the Upper Tarkhovskii Subformation caused strong deformation of its rocks. The beds dip subhorizontally to subvertically to the north and northwest.

Unit 2. Alternation of greenish, dark green, and gray tuffaceous mudstones, with intercalations of tuffaceous siltstones and reddish weakly lithified tuffs. The visible thickness is ca. 40 m.

Fault zone.

Unit 3. Alternation of greenish brown, green, and dark gray thin-bedded tuffaceous mudstones and tuffaceous siltstones, with reddish interlayers. Visible thickness about 30 m.

Fault zone.

Unit 4-1. Lithologically, this unit is similar to rocks of unit 3. The roof is marked by an interlayer of green silicified tuffaceous mudstones (1.5). The rocks of the unit are highly deformed. This thickness is ca. 40 m.

Fault zone.

Unit 4. Alternation of greenish, dark gray, gray, and brownish tuffaceous mudstones and tuffaceous siltstones, with interlayers of gray, fine-grained sandstones and tuffs. The thickness is 40 m.

Unit 5 is lithologically close to rocks of unit 4, but tuff interlayers are less common. The thickness is ca. 30 m.

Unit 6 is lithologically similar to rocks of units 4 and 5, but contains chert lenses and tuff interlayers. The thickness is 20 m.

Unit 7. Rhythmic alternation of dark gray, brownish gray, and greenish tuffaceous mudstones intercalated with reddish and greenish tuffs. The visible thickness is near 25 m.

Fault zone.

Unit 8. Rhythmic alternation of greenish brown fine- to medium-grained tuffstones, tuffaceous mudstones, and tuffaceous siltstones with nodules of cherts, lenses of greenish and gray cherts, and interlayers of reddish brown, red, and greenish tuffs. The visible thickness is 30 m.

The Tarkhovskii Formation is conformably overlain by the Vereshchaginskii Formation.

The Vereshchagin Formation

Unit 9. Rhythmic alternation of fine- to medium-grained tuffstones, tuffaceous mudstones, and tuffaceous siltstones, with lenses of tuff breccia and scarce tuff interlayers. The visible thickness is more than 80 m.

The sequence is interrupted by over 100-m grass-covered areas with talus.

Unit 10. The lower part of the unit (ca. 10 m) is composed of tuff breccia and tuff conglomerates (similar to those of unit 12a), and the upper part is made up of alternating gray and dark gray mudstones, tuffaceous mudstones, and tuffaceous siltstones. The visible thickness is 35 m.

Unit 11. Alternation of fine to medium-grained tuffstones, tuffaceous mudstones, tuffaceous siltstones, tuff breccia, and fine- to medium-pebble tuff conglomerates. The thickness is 25 m.

Unit 12. Alternation of greenish gray and gray fine to medium-grained tuffstones, tuffaceous mudstones, and tuffaceous siltstones. The lower part of the unit (ca. 8 m) is made up of tuff breccia and tuff conglomerates with lenses of tuffaceous mudstones. The thickness is 35 m.

Unit 12 a. Tuff breccia and fine- to medium-pebble tuff conglomerates, with lenses of greenish-gray fine to medium-grained tuffstones and tuffaceous mudstones. The visible thickness is 30 m.

FINDS OF NANOFOSSILS AND RESULTS OF THEIR STUDY

The Section along the Klyuch Medvezhii Creek

From eight samples collected in the rocks of the Lower Tarkhovskii Subformation along the Klyuch Medvezhii Creek, poorly preserved nannoplankton were found at one stratigraphic level, in sample no. 1-6 taken from tuffaceous siltstones at the base of Unit 4. (Figs. 3, 5). The age of the subformation was justified only by radiolarians found in its rocks (in the section on the left bank of the Vtoraya Pereval'naya River). Their assemblage consisting of *Diacanthocapsa* cf.

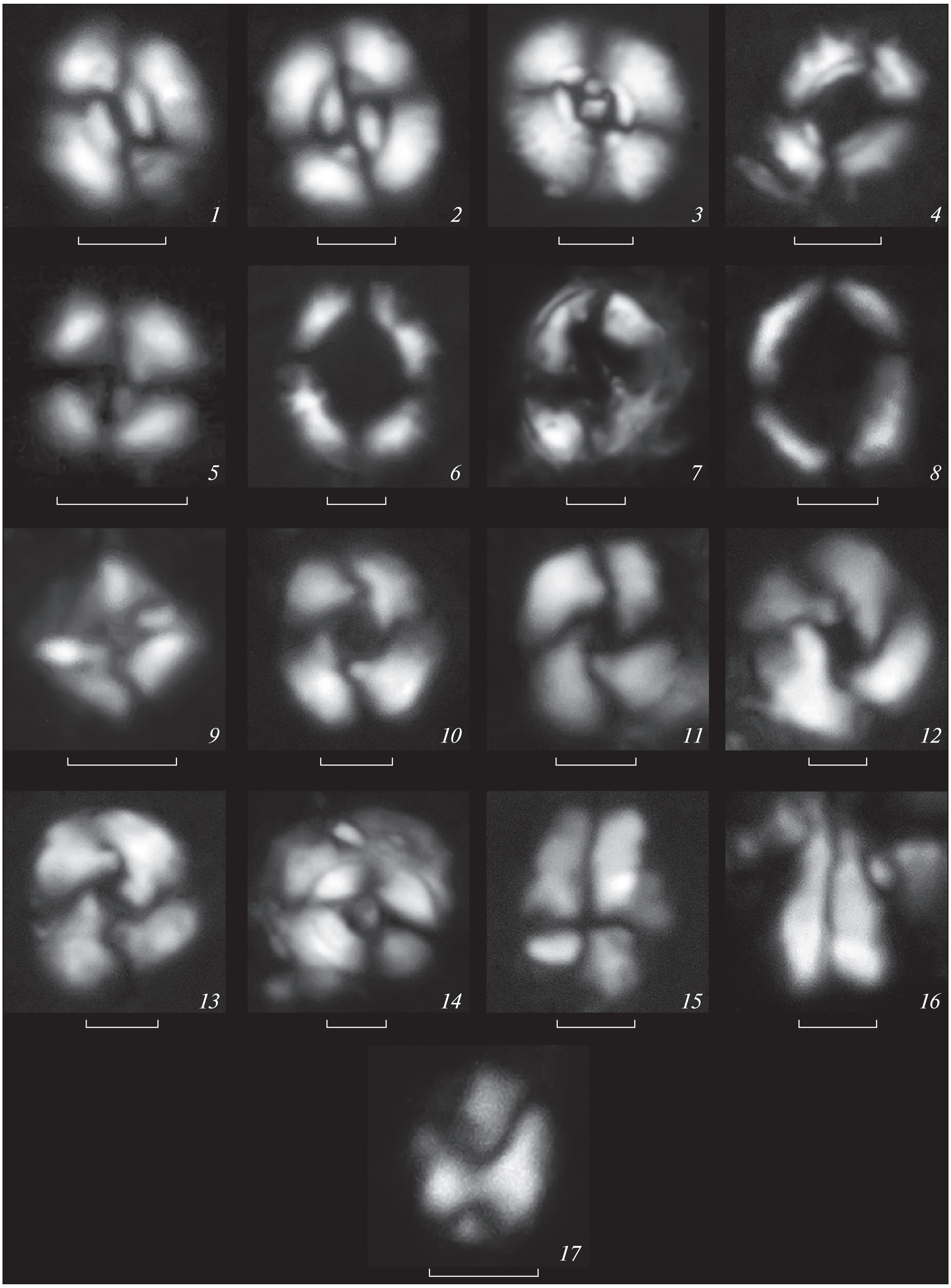

Fig. 6. Representatives of the nannoplankton assemblages extracted from the studied sections of the Kamchatsky Mys Peninsula. (*1–9*) Nannoplankton taxa found in section of the Lower Tarkhovskii subformation along the Klyuch Medvezhii Creek (sample no. 1–6), (*10–17*) taxa found in the section of the Vereshchagin Formation on the seashore, north of the Vtoraya Pereval'naya River mouth (sample no. 3–4). Images were made in the light microscope (cross–polarization). The length of scale bar is 2 μm. (*1–2*) *Watznaueria barnesiae*; (*3*) *Watznaueria britannica*; (*4*) *Watznaueria* sp.; (*5*) *Cyclagelosphaera* cf. *reinhardtii*; (*6*) *Manivitella* cf. *pemmatoidea*; (*7*) *Eiffellithus* cf. *eximius*; (*8*) *Loxolithus?* sp.; (*9*) *Micula staurophora*; (*10–12*) *Reticulofenestra dictyoda*; (*13*) *Reticulofenestra hesslandii*; (*14*) *Coccolithus pelagicus*; (*15*) *Sphenolithus radians*; (*16*) *Zygrhablithus bijugatus*; (*17*) *Lanternithus minutus*.

Fig. 7. Rocks of unit 11 in a section along the Bering Sea shore (photo by S.I. Bordunov).

rotunda Kozlova, *Dictyomitra striata* Lipman, *D. multicostata* Zittell and others is dated by Late Maastrichtian [2].

The distinguished nannoplankton assemblage includes mainly taxa of wide stratigraphic abundance. In particular, the species of genera *Watznaueria*, such as the *Watznaueria barnesiae* (Black) Perch-Nielsen, have been known from the Bajocian (Middle Jurassic) to the Maastrichtian (Upper Cretaceous), except for *Watznaueria britannica* (Stradner) Reinhardt existing from Bajocian to Cenomanian (Upper Cretaceous) (Figs. 3, 6). At the same time, the latter species likely has the wider stratigraphic distribution. *Zeugrhabdotus erectus* (Deflandre) Reinhardt existed from the Pliensbachian (lower Jurassic) to Maastrichtian (Upper Cretaceous). *Cyclagelosphaera* also gained wide distribution: *Cyclagelosphaera margerelii* has existed from the end of the Bajocian (Middle Jurassic) to Thanetian (Paleocene), while *Cyclagelosphaera reinhardtii* (Perch-Nielsen) Romein, from the Albian (Lower Cretaceous) to the Ypresian (Eocene). The late Cretaceous species are *Eiffellithus* cf. *eximius* (Stover) Perch-Nielsen, which are developed from the Turonian to Campanian (Upper Cretaceous) (zones UC8–UC15 according to the Barnett scale [15]) and *Micula staurophora* (Gardet) Stradner (Conjacian stage, zone C10-Maastrichtian [15]). In spite of the fact that the reliably determined taxa spanned sufficiently wide stratigraphic interval, the presence of *Micula staurophora* in the discovered assemblage points to the Late Cretaceous age (within Conjacian–Maastrichtian stages) of host rocks. These results supplement data on the distribution of Cretaceous nannoplankton in the high latitudes of North Pacific [16] (Fig. 6).

The Section along the Bering Sea Shore

In section along seashore, nannoplankton was found at two stratigraphic levels of the Vereshchaginskii Formation: in sample no. 3-4 (mudstone) from the upper part of unit 11 and in sample no. 3-6 (mudstone) from the upper part of unit 10 (Figs. 4, 7). Since nannoplankton species in the studied samples are extremely scarce and poorly preserved, four specimens were made from each sample to obtain a relatively objective information. Both samples contain *Cyclicargolithus floridanus* (Roth et Hay) Bukry and *Reticulofenestra dictyoda* (Deflandre) Stradner. Sample no. 3–4 contains *Coccolithus pelagicus* (Wallich) Schiller, *Lanternithus minutus* Stradner, *Reticulofenestra hesslandii* (Haq) Roth, *Sphenolithus radians* Deflandre, and *Zygrhablithus bijugatus* (Deflandre) Deflandre. The degree of preservation is poor: coccoliths are corroded and slightly recrystallized; and only few taxa retained the main diagnostic features (Fig. 6). Their abundance in specimen is insignificant: ca. 1–2 species per five fields of view at 1000x. The analysis of taxonomic composition of the distinguished assemblage showed that its exact age is difficult to determine. *Sphenolithus radians* is known from the Ypresian to Rupelian (zones NP 11–NP 23 according to E. Martini [17]). *Cyclicargolithus floridanus* occurred in the Lutetian (Middle Eocene) and reached peak in the Oligocene–Miocene; *Reticulofenestra dictyoda* has existed from Ypresian (Lower Eocene) to the end of Chattian (Oligocene) (zones NP 10–NP 25 according to the Martini scale [17]), whereas *Reticulofenestra hesslandii* is known from the Lutetian and existed up to the end of Oligocene. *Lanternithus minutus* occurred from the Lutetian to Rupelian (lower Oligocene) (zones NP 15–NP 23 [*17]). The widest stratigraphic interval is occupied by @Zygrhablithus bijugatus*, which occurred from the Thanetian (Upper Paleocene, zone NP 9) to Aquitanian (Neogene, zone NN 1). According to the new Cenozoic biostratigraphic chart based on calcareous nannoplankton, these zones are correlated with zones CNE 11–CNO 4 [13, 19, 20] (Fig. 8). Thus, we may conclude that the host deposits are no older than Middle Eocene (Lutetian) and could be arbitrarily dated within the Middle Eocene–Early Oligocene.

It should be noted that the foraminiferal assemblage correlated to the assemblage of the local biostratigraphic zone (local zone) III based on benthic foraminifers *Rzehakina epigona* was distinguished previously in the bottom layers of the upper Tarkhovskii subformation on the left bank of the Vtoraya Pereval'naya River. (Fig. 2). The age of this local zone was dated by the Early Paleocene (Danian) [1, 2, 7]. Sediments of the Vereshchaginskii Formation in the section along the Klyuch Medvezhii Creek yielded benthic foraminifers are ascribed to local zone IV: *Glomospira corona–Silicosigmoilina californica* [1, 2, 7] (Fig. 2). The age of this local zone was determined

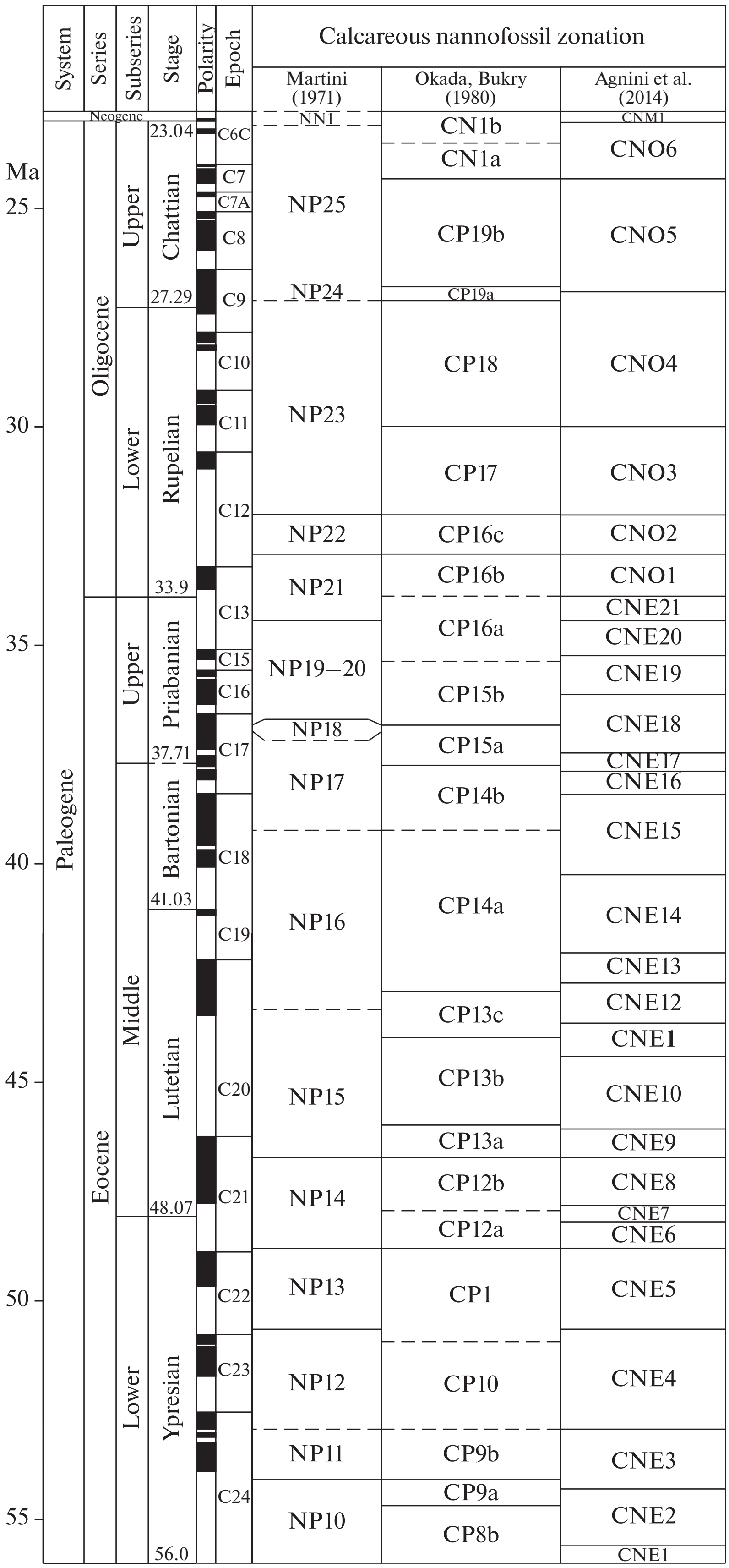

Fig. 8. Comparison of zones based on the Eocene–Oligocene calcareous nannoplakton and their correlation with the geochronological and geomagnetic polarity time scales [13, 19, 20].

within the Middle–Late Paleocene (Selandian and Thanetian). Thus, nannoplankton finds could indicate that sediments ascribed in the studied seashore section to the lower part of the Vereshchagin Formation likely have the younger age (no older than Lutetian, Middle Eocene). This is inconsistent with the Middle–Late Paleocene age of the formation based on the benthic foraminifers in section from other areas of the peninsula.

CONCLUSIONS

Two assemblages of calcareous nannoplankton were found for the first time in the lower part of the Stolbovaya Group (Upper Cretaceous–Lower Paleocene) in the Kamchatsky Mys Peninsula of eastern Kamchatka. The first assemblage, which is restricted to the Lower Tarkhovskii subformation, may indicate its Late Cretaceous age. The second assemblage, which is distinguished in the lower part of the Vereshchagin Formation, suggests the Paleogene age (no older than Lutetian, Middle Eocene) of host deposits. However, these dates are not consistent with the inferred Middle–Late Paleocene age of the Vereshchagin Formation determined using benthic foraminifers in other section, thus demonstrating the controversies of this issue. It should be noted that the nannoplankton assemblage revealed in the studied section of the Vereshchaginskii Formation is close in age to the previously established assemblage from sediments of the Baklanovskii Formation in a section in the more northerly part of the peninsula [12], i.e., from sequences ascribed to the younger stratigraphic interval (Fig. 2). Such results obtained on nannofossils, in particular, highlight the difficulties in the interpretation of accurate stratigraphic position and correlation of lithological units distinguished in the Stolbovaya Group in different sections of the Kamchatsky Mys Peninsula due to the differences in their thickness, facies composition, and paleontological characteristics.

New finds of nannofossils in the Cretaceous–Paleogene sections of eastern Kamchatka supplement data on the fossil nannoplankton of the Kamchatka district and make it possible, in particular, to revise regional stratigraphic schemes. In spite of the fact that nannoplankton assemblages revealed in the studied section are rather poor, their discovery and noted compositional features supplement the paleontological characteristics of Cretaceous and Paleogene formations of the region. Further studies in this direction can expand the scale of the application of nannoplankton to biostratigraphic and paleoclimatic considerations.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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