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ARTICLE

Benthic Foraminifera Biostratigraphy and Sedimentation Fiatures of the Western Sakhalin Upper Eocene

Sergey I. Bordunov[1,2], **Dmitry M. Olshanetsky[1*], Andrey Yu. Gladenkov[1], Arseniy I. Tarasov[2]**

1. Geological Institute of the Russian Academy of Sciences, Moscow 119017, Russia
2. Geological Department, Lomonosov Moscow State University, Moscow 119991, Russia

Abstract: New data on micropaleontological and lithological characteristics of Eocene deposits exposed along the Avgustovka River near the village of Boshnyakovo, Western Sakhalin are presented. For the first time, benthic foraminifera were found in these deposits and it was concluded that they are of middle-late Eocene age. Analysis of the taxonomic composition of the foraminifera assemblage, as well as the material composition of the rocks, allowed us to assume that these strata were formed within a relatively deep-water marine basin, which periodically supplied volcanic material in the form of tuffs.

Keywords: Western sakhalin; Eocene; Foraminifera; Lithology; Paleoenvironments

*Corresponding Author:
Dmitry M. Olshanetsky,
Geological Institute of the Russian Academy of Sciences, Moscow 119017, Russia
Email: o.mitia@gmail.com

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1. Introduction

The Cenozoic different facies, represented by terrigenous and volcanogenic-sedimentary rocks, are widely developed within Sakhalin Island and its shelf. Sakhalin is the main gas and oil producing region of the Russia Far East. It, as a geologic structure, is part of the Sea of Okhotsk geoblock, the largest element of the transition zone from the western Pacific Ocean to the Asian continent [1]. Tectonically, the study area belongs to the central part of the Hokkaido-Sakhalin fold system, including the Tatar Strait of the Sea of Japan, located on the western wing of the West Sakhalin anticlinorium, the core of which contains Cretaceous deposits [2].The results of geological survey and thematic geological works carried out in this region in the 1950s–1990s made it possible to identify the main features of the geological structure of the island and the stratigraphic subdivision of the Cenozoic formations represented in its various areas. As a result of generalization of the available materials, in 1994 the Interdepartmental Stratigraphic Committee of Russia adopted stratigraphic schemes of the Cenozoic of Sakhalin [3]. In addition, in the 1990s and early 2000s, a number of generalizing works were published on the geological structure, stratigraphy and oil and gas content of Cenozoic deposits of Sakhalin [1, 4–7]. Despite this, some problems of stratigraphy, such as the exact age of Paleogene strata in some regions, remain unsolved. This is due, in particular, to the fact that these deposits in many cases have rather weak paleontological characteristics, especially fossil remains of planktonic organisms are rarely found [1, 8, 9]. In this regard, the new materials obtained during the study of Paleogene strata in the area of the village of Boshnyakovo (Western Sakhalin), which previously remained practically uncharacterized paleontologically, are of interest. This area is interesting because it contains a complete section of Paleogene sediments, starting from the K–Pg boundary, consisting of both continental and marine strata [7, 9]. The Eocene section is represented in the lower part by alternating siltstones and mudstones with sandstone interlayers, and in the upper part by siliceous mudstones occurring in the core of a large synclinal fold.

Problems of Dating the Paleogene Strata of Western Sakhalin

In the western part of the island, which belongs to the structural-formational zone of Southwest Sakhalin, in the West Sakhalin sedimentation basin [1, 3, 6], Paleogene deposits are widely distributed [6, 7, 10, 11]. However, the precise determination of the age of the formations developed here directly overlying the Cretaceous formations, as well as their correlations based primarily on rare finds of benthic fauna and flora, remain often rather tentative. One of the reference sections of the Paleogene is located near the village of Boshnyakovo—along the Avgustovka River (49°40’27.00”north, 142°13’29.00”east) (**Figure 1**). It is here that the section of the marine Lower Paleogene is located, lying with erosion on the Cretaceous sediments.

A great contribution to the study of the formations developed here was made by Savitsky and Margulis, who proposed the partitioning of the Paleogene strata of this and adjacent areas into a number of formations (stratigraphically from bottom to top: snowzhinka, Krasnopolyev, Takaradai, Aral formations with a total thickness of more than 1500 m [2, 7, 9, 12]. At the same time, the age of individual formations was determined rather conditionally due to their poor paleontological characterization. Therefore, the new materials that the authors obtained during the study of the Boshnyakovsky section can supplement the data on the age of the Paleogene deposits developed here and on the conditions of their formation.

2. Material and methods

Sampling in the Augustovka River section was carried out at 10–20 m intervals from clayish rock constituents. A total of 18 samples were collected. Shells of benthic agglutinated and secreted foraminifera were found in 8 of them.

Analytical studies were carried out at GIN RAS and at the Faculty of Geology, Lomonosov Moscow State University.

The material composition of rocks was studied in petrographic sections of all 18 samples using a Polam-213 M optical microscope. As a result, 4 lithologic types

ples, only one sample 7/2 contained nannofossil remains, which were determined by M.A. Ustinova (GIN RAS). Preparations for the study of nannofossils under a light polarizing microscope were made according to the standard technology and examined using a BiOptic 210 microscope at a magnification of 1000x. The remains of coccoliths were partially dissolved and corroded, although the main diagnostic features were preserved. Their occurrence is low.

3. Research results

3.1 Description of the section

In 2021, the expedition of the Geological Institute of the Russian Academy of Sciences (GIN RAS) conducted a layer-by-layer study of the above-mentioned Paleogene section along the right side of the Augustovka River, with sampling for micropaleontological, lithological and paleomagnetic analyses. Special attention was also paid to the thickness of "dumb" siliceous mudstones exposed on the left side of the river in a separate block and conventionally attributed to the Takaradai Formation.

The Takaradai Formation is underlain by the rocks of the Krasnopolyevskaya Formation , traditionally attributed to the Middle Eocene, represented by the interbedded sandstones, siltstones, and rarely mudstones, and is overlain by the Arakai Formation (Lower Oligocene), consisting of conglomerates, tuffs, siltstones, and mudstones. The middle part of the section (most of Member 2) is sodden. The apparent thickness of the Takaradai Formation in the section of the Avgustovka River is about 550 meters. Stratigraphically from bottom to top, the following strata are identified.

Member 1: Sandstones and siltstones alternate (**Figures 2** and **3**). Sandstones (10–100 cm) are light gray from fine- to coarse-grained, often coarsely laminated, with horizontal layering, overlain by carbonaceous and coarse plant detritus, with ripple marks on the surface, with clay flattened pellets of red-brown color. There are mechanoglyphs and traces of ichnofossils at the bottom. Siltstones (3–30 cm) are gray with thin horizontal layering, sometimes convolute, with plant detritus in the stratum. Mudstones are brownish, thinly rippled, and siltstones are gray. There are subordinate interlayers of sandstones (3–10 cm) with traces of wave ripples. In the basement there are two horizons of oyster shells. In the middle part there are 2 coal layers of 5 and 15 cm. In the upper part of the pack, mudstones are dark gray, with purple manganese bracts and textures of ring compaction. Separate interlayers of 2–3 cm of rusty-brown siliceous mudstones were noted. At 20 m from the pack roof there are two horizons of 15–20 cm thick oyster shells. Between the horizons is about 2 m. Pelletized black pebbles (2–5 cm) also occur in the roof. The thickness of the pack is about 150 m.

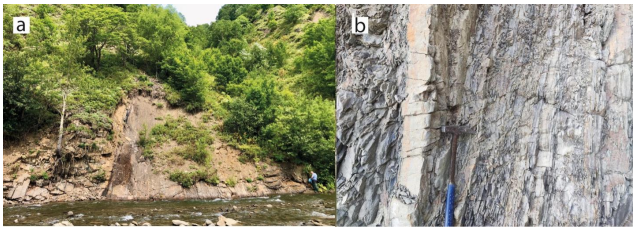

Figure 2. Rocks of Member 1 in the section presented on the right side of the Avgustovka River valley: (**a**) interbedded mudstones and siltstones with sparse sandstone interlayers; (**b**) interbedded siltstones and mudstones with a light sandstone interbed (middle part of the pack).

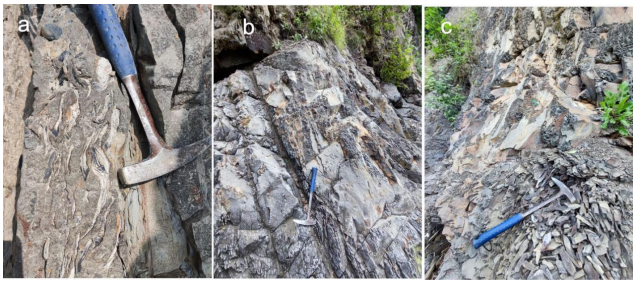

Figure 3. Rocks of Members 1 and 3: (**a**) oyster in sandstone interbed (Package No. 1) on the right side of the Avgustovka River valley; (**b**,**c**) siliceous mudstones (Package No. 3) on the left side of the river.

Member 2: Siltstones are gray, with vaguely pronounced horizontal layering, with rusty-brown smears along fractures and overlaying, finely splintered, broken by fractures. Pebbles of mudstone composition from the underlying layers were noted. The thickness of the pack is more than 200 m.

Member 3: Mudstones are dark gray, black, siliceous, with cherry-brown bracts, and there are bracts of bright yellow jarosite (**Figure 4**). Oval siliceous-carbonate nodules up to 10 cm in diameter occur. The rocks are broken by fractures and low-amplitude drops. The thickness of the Member is more than 200 m.

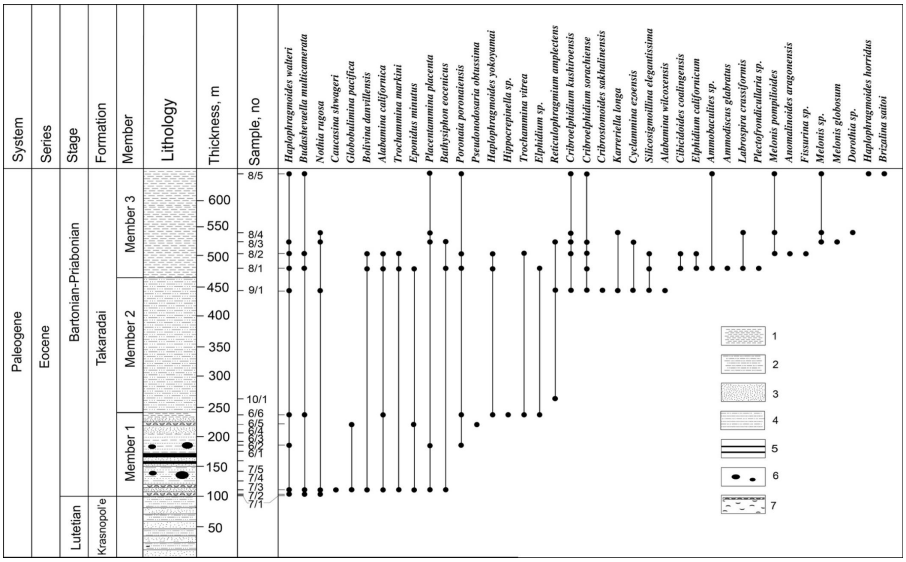

Figure 4. Stratigraphic distribution of foraminifera in the Takaradai Formation in the Augustovka River section.

Note: Legend: 1—mudstone; 2—siltstone; 3—sandstone; 4—interbedded sandstone and siltstone; 5—coal layer; 6—nodules; 7—oyster deposits.

3.2 Paleontological characterization of deposits represented in the section

As a result of laboratory processing, fossil foraminifera (**Figure 5** and **6**) were found in 12 samples (in particular, from the so-called "dumb" dark mudstones presented on the left side and previously in some cases conventionally attributed to the Takaradai Formation), data on which were previously unavailable. Foraminifera are represented by secreted and agglutinating benthic species, planktonic forms were not found.

Based on the analysis of the systematic composition and quantitative ratio of foraminifera, a foraminifer complex with *Poronaia poronaiensis* (Asano) em Uji and Watanabe, 1960, was isolated. The complex is dominated by agglutinating foraminifera. Typical forms belong to the deepwater agglutinating foraminifera (DWAF fauna). Characteristic species belonging to this group are *Haplophragmoides yokoyamai* (Kaiho, 1984); *Haplophragmoides umbilicatus* (Kaiho, 1984); *Reticulophragmium amplectens* (Grzybowski, 1898); *Haplophragmoides walteri* (Grzybowski, 1898); *Budashevaella multicamerata* (Voloshinova & Budasheva, 1961); *Poronaia poronaiensis* (Asano), em. (Ujiie & Watanabe, 1960); *Placentammina placenta* (Grzybowski, 1898); *Elphidium californicum* (Cook M.S., 1950); *Cribroelphidium sorachiense* (Asano, 1954); *Cibicidoides coalingensis* (Cushman & Hanna, 1927); *Alabamina californica* Mallory, 1959, et al.

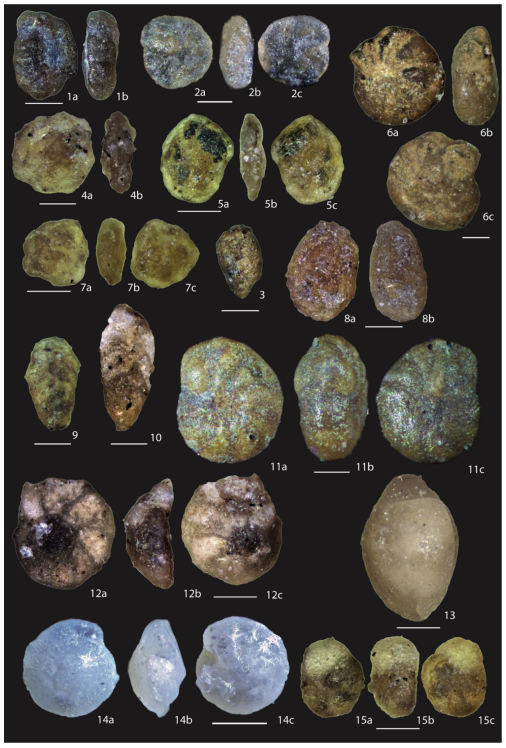

Figure 5. Eocene foraminifera, Avgustovka river, Western Sakhalin.

Note: 1—*Budashevaella multicamerata* (Voloshinova et Budasheva, 1961); 2—*Haplophragmoides yokoyama*i (Kaiho, 1984); 3—*Poronaia poronaiensis* (Asano) em. Ujiie & Watanabe, 1960); 4—*Haplophragmoides umbilicatus* (Kaiho, 1984); 5—*Haplophragmoides walteri* (Grzybowski, 1898); 6—*Elphidium californicum* (Cook M.S., 1950); 7—*Trochammina markini* (Budasheva, 1961); 8—*Placentammina placenta* (Grzybowski, 1898); 9—*Bolivina danvillensis* (Howe et Wallace, 1932); 10—*Brizalina saitoi* (Kaiho 1984); 11—*Cribroelphidium sorachiense* (Asano, 1954); Brizalina saitoi (Kaiho, 1984); 12—*Cibicidoides coalingensis* (Cushman & Hanna, 1927); 13—*Fissurina sp.*; 14—*Alabamina californica* (Mallory, 1959); 15—*Anomalinoides aragonensis* (Nuttall, 1930).

Scale is equal to 100 μm.It should also be noted that in one sample (No. 7/2) from the lower part of the Formation section (Formation 1), single remains of calcareous nannofossils were found. According to M.A. Ustinova (GIN RAS), the sample contains only one species of nannofossils: *Cyclicargolithus luminis* (Sullivan, 1965) Bukry, 1971, distributed from the lower part of the Lower Eocene Igrian Stage (zone NP12) to the upper part of the Middle Eocene Lutetian Stage (subzone NP15b) [13].

4. Discussion of Results

4.1 Conditions of sediment formation

The composition of rocks in Members 1–3 indicates the conditions of sedimentation in a relatively deep-water basin of the open sea with clayey, silt-clayey, rarely sandy fine-grained deposits. The studied rocks are individual representatives of the "Bouma" cycle and genetically represent relatively deep-sea turbidites [14]. Volcanic events in the form of tuff material accumulation are recorded at two levels of the section (in the lower and upper parts of the studied interval: the rocks of the lower part (the upper part of Member 2, sample 10/1) are characterized by acidic composition, and the upper part (Member 3, sample 8/1) by the basic as the main composition (**Figure 6**).

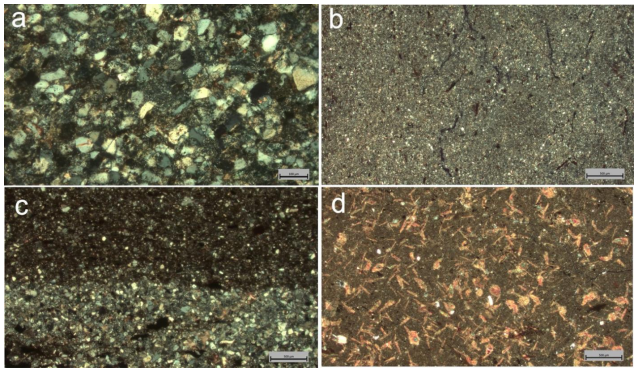

Figure 6. Photo of petrographic slits of lithotypes of rocks of the Takaradai Formation: (**a**) LT1 (fine-grained sandstones, member No. 1, sample 6/1); (**b**) LT2 (mudstones, Member No. 1, sample 6/6); (**c**) LT3 intercalation of siltstones and mudstones, Member No. 1, sample 7/1); (**d**) LT4 (siliceous mudstones with tuffs material, Member No. 3, sample 8/2).

The results of studying the rocks and their material composition may indicate that the deposits accumulated in a relatively deep-water marine basin with a terrigenous type of sedimentation. In the middle and late Eocene—when there was extensive transgression throughout the Hokkaido-Sakhalin fold zone—the margin of the East Sikhote-Alin volcanic belt was captured, where effusions, tuffs and volcanomictic conglomerates accumulated [1]. In the terrigenous mica-feldspar-quartz material, fragments of volcanic rocks in the form of acidic lithoclasts and basic effusions composing the areas of eroded land played a significant role.

4.2 Age of foraminifera complexes

The complexes include taxa of foraminifera characteristic for Paleogene deposits represented in sections of various regions of the Russian Far East [11], North America [15], and Japan [16–18].

The index species Poronaia poronaiensis (Asano) em. assemblage (Ujiie &Watanabe, 1960) is known from deposits of the Snatol and Kovachinsky stratigraphic horizons (middle-upper Eocene) of western Kamchatka [4, 12]. Haplophragmoides yokoyamai (Kaiho, 1984) and Haplophragmoides umbilicatus (Kaiho, 1984) are widely represented in the Takaradai Formation of South Sakhalin, as well as in the foraminifera complex of the Takaradai Formation at the Augustovka River, Western Sakhalin [11]. Some of the secreted foraminifera (Cribroelphidium sorachiense (Asano, 1940); Brizalina saitoi Kaiho, 1984, etc.) and agglutinated forms (Poronaia poronaiensis (Asano) em. Ujiie & Watanabe, 1960; Haplophragmoides umbilicatus Kaiho, 1984; Haplophragmoides yokoyamai Kaiho, 1984, etc.), found as part of the selected complex of foraminifera, are found in deposits of the middle-upper Eocene and Oligocene sections of the Japanese Islands, especially they are characteristic of the sections of the island of Hokkaido [16–18]. Such species as Cibicidoides coalingensis (Cushman et Hanna, 1927) Alabamina californica (Mallory, 1959); Anomalinoides aragonensis (Nuttall, 1930); Elphidium californicum (Cook Ms, 1950) are known from Eocene depositsof the Sea of Okhotsk (Magadan well 1 [19], East Kamchatka [4], and the west coast of North America [15].

Benthic foraminifera are known to respond to changes in bottom environmental parameters and can

be used to obtain paleoenvironmental information [20]. DWAF (Deep Water Agglutinated Foraminifera) biofacies are based on the occurrence of characteristic species, these biofacies are related to the depth of species from the upper to middle bathyal and are known as "slope fauna" [19]. These biofacies are often confined to relatively warm-water conditions [20] that existed in the Eocene [1].

The mixed taxonomic composition of foraminifera is characteristic of the Eocene deposits of the Russian Far East [21]. During the extensive Eocene transgression, open sea conditions with normal salinity were established throughout the North Pacific Ocean [1, 5, 6, 8]. The sea depth in the study area reached the first hundred meters, i.e., the conditions were quite deep. In the middle Eocene, shallow-marine conditions alternating with coastal-continental conditions periodically appeared in the Far East region, which contributed to the accumulation of coal layers [2, 6, 7]. The predominance of agglutinated forms also indicates unfavorable habitat conditions and possibly reflects stagnant, nearly oxygen-free conditions in the bottom water column [21, 22]. Thus, the biostratigraphic data confirm the results of lithogenetic typification.

It should be noted that earlier in the Paleogene section along the Tamarinka River, located 200 km south of the studied section, a nannoplankton complex was established in the mudstones and siltstones of the lower part of the Takaradai Formation, represented by species of rather wide stratigraphic distribution [5]. The combined presence of representatives of *Reticulofenestra dictyoda* (Deflanre) Stradner and *Dictyococcites bisectus* (Hay, Mohler & Wide), Bukry et Percival, allowed us to date the host deposits to the Middle Eocene zone SR 14 *Reticulofenestra umbilicus*, although the possibility of the lower part of the Upper Eocene zone SR 15 *Discoaster barbadiensis* was not excluded [5].

Probably, the stratigraphic level in the Augustovka River section, where sample No. 7/2 containing nannoplankton was collected, is more ancient than the one where samples from the Tamarinka River section were collected. Apparently, the first of the mentioned levels can be attributed to the Lutetian Stage (its middle part), while the second to the upper Lutetian—lower Bartonian Stage.

Finds of foraminifer shells and nannoplankton in the Takaradai Formation of Western Sakhalin make it possible to refine the dating of certain levels of the Paleogene intervals in the region. In particular, this allows us to confirm the presence of Middle Eocene deposits in the lower parts of the Takaradai Formation. Correlation with these complexes of benthic associations makes it possible to use these associations more confidently to determine the age of the host strata. The presence of nannoplankton in the deposits indicates that the Southern Sakhalin basin had connections with the open ocean during the Takaradai time. The nannoplankton present in the Tamarinka River section of the Takaradai Formation are typical species for high latitudes of the northern hemisphere [5, 6].

The foraminifera complex and nannoplankton finds in the deposits of the Takaradai Formation apparently indicate a higher sea level rise in the middle-late Eocene. This confirms the assumption made earlier by Shcherbinina about the significant coverage of the Far Eastern areas by the Bartonian transgression [23].

5. Conclusions

Fossil benthic foraminifera were found for the first time in the Avgustovka River section of Western Sakhalin.

The results of the study of the isolated foraminifera complex allowed us to conclude about the middle-late Eocene age of the host sediments.

Findings of foraminifera supplement the paleontological characterization of the host strata and clarify their age.

The age conclusions contribute to improving the correlations of the Paleogene strata developed in Western Sakhalin.

Analysis of the taxonomic composition of the foraminifera complex made it possible to draw conclusions about the paleoenvironments of its formation under such condition, -i.e., depth, type of sea basin, temperature, and salinity, etc.

New data obtained during the study of the lithological composition of rocks (sediments) in which

foraminifera were found allowed for their lithogenetic typification (to distinguish 4 groups of lithotypes) and to draw conclusions about the conditions of sedimentation in the sea basin, which were influenced by eustatic fluctuations of the sea level, as well as at two levels the introduction of volcanic material, mainly in the form of tuffs, is characteristic.

The results of the study of fossil foraminifera and the peculiarities of the material composition of the surrounding deposits make it possible to conclude that the process of sedimentation in the middle-late Eocene time took place within a relatively deep-water (open shelf) sea basin with a terrigenous type of sedimentation - in slope turbidite paleoenvironments, under the conditions of the middle-late Eocene regional marine transgression [24].

Author Contributions

S.I.B.: Writing Original Draft, Investigation; D.M.O.: Investigation, Writing editing, Translation, Illustrations; A.Y.G.: Resourses, Organisation of Field Works, Writing editing, Investigation; A.I.T.: Investigation.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Data Availability Statement

All data is publicly available.

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