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New Findings and Stratigraphic Distribution of Foraminifera from Permian–Triassic Boundary Deposits in the Southern Verkhoyansk Region

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Abstract—The first study results on foraminifera from the Permian–Triassic boundary deposits in the southern Verkhoyansk region (the lower part of the Nekuchan Formation, Suol section located in the basin of Setorym River, a tributary of the East Khandyga River) are presented. The studied foraminifera constitute a novel group for this section and have not been used in paleontological-stratigraphic studies. The foraminiferal assemblage is represented exclusively by ammodiscids (*Ammodiscus*, *Glomospira*, and *Glomospirella* genera), among which *Ammodiscus septentrionalis* Gerke dominates. The distribution of foraminifera in the Suol section is compared to the previously constructed carbon isotope curve, which reflects global environmental changes. Three intervals are identified in the stratigraphic distribution of foraminifera. In the lower interval, foraminifera are relatively numerous and diverse. In the middle interval, foraminifera are not detected; the maximum negative values of $\delta^{13}C_{org}$ isotope is also recorded here. This interval obviously corresponds to the main extinction episode in the Tethyan basins. In the upper interval, a gradual restoration of the abundance and structure of the foraminiferal complex occurs. A comparative analysis of the distribution and dynamics of taxonomic reorganization of the foraminiferal assemblages from the Permian–Triassic deposits within the Suol section and the assemblages from the Tethyan and Boreal sections has been carried out; as a result of this analysis, the common features and regularities are established. Brief descriptions of four foraminiferal species and a plate with their images are given.

Keywords: foraminifera, Permian–Triassic boundary, southern Verkhoyansk region, Russian Northeast

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INTRODUCTION

The end of the Permian period was marked by the most significant mass extinction event during the Phanerozoic. Numerous publications in the last 2 decades have been devoted to this problem and were aimed at revealing of its possible cause-and-effect relationships, and determination of various physical and geochemical characteristics and exact dates of this event (see, for example, [42, 49, 50, 52, 53, 68, 71, 74, 80] and others). A considerable amount of paleontological–stratigraphic, geochemical, and mineralogical investigations has been conducted for a number of the world's most stratigraphically complete sections from this time. The most important indicators of the environmental changes are the $\delta^{13}C_{org}$ and $\delta^{18}O$ isotopes; the variation curves for the respective parameters have been constructed for many sections (see [82, 84] and others). Carbon isotope curves are successfully applied as one of the instruments for global correlation of deposits in the interval of the Permian–Triassic boundary (PTB) (see [28, 56, 57, 61] and others).

The global stratotype point for the PTB has been established to be the Meishan section in South China, as is shown, for example, in [83] and other works. During validation of the boundary between the Permian and Triassic systems in the global stratotype, Chi-

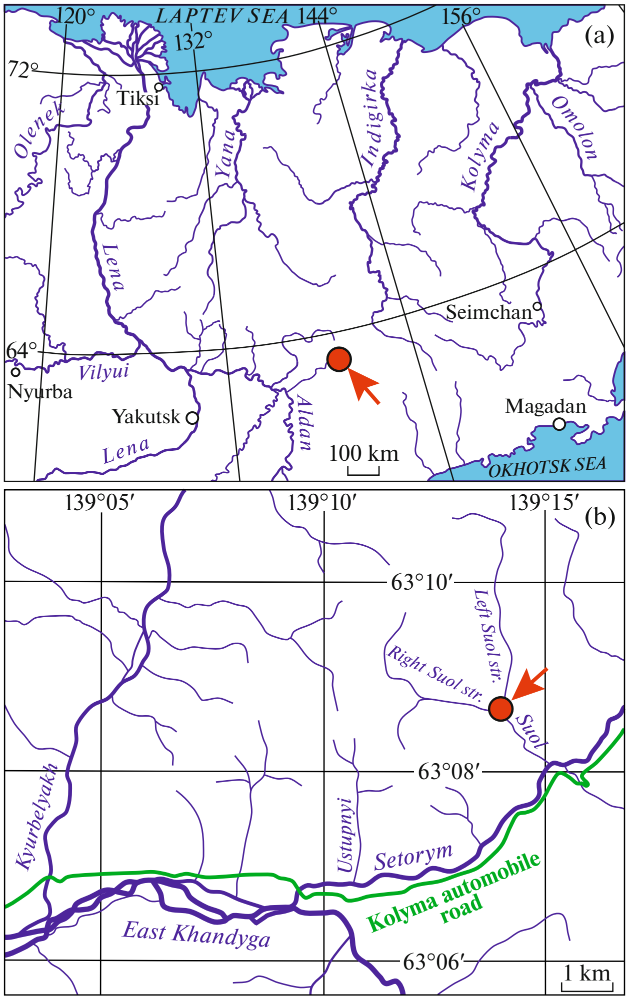


Fig. 1. The location of the Suol section (a) in the Russian Northeast and (b) within the Setorym River basin.

nese geologists had to use a conodont-based chart due to an unsatisfactory degree of preservation or even absence of ammonoids at this level. The new conodont-based boundary is not consistent with that drawn earlier on the basis of ammonoids [79]; however, is well correlated to the isotope data reflecting the global environmental changes. The reasonability of PTB determination based on conodont species *Hindeodus parvus* (Kozur et Pjatakova) is argued by many Russian researchers, because the vertical distribution range of this taxon is considerably broader than particular ammonoid species, whereas the first occurrence of *H. parvus* can be not isochronous in different sections [23, 34, 47]. The selection of the Meishan section as the PTB global stratotype is also criticized because no index taxon (species) of ammonoids has been found in it [40, 45, 46, 54].

The section in the Suol stream area (hereinafter, Suol section), located in the basin of Setorym River (right tributary of East Khandyga River, which flows into Aldan River), is the most suitable section in Northeast Asia in terms of PTB investigation (Fig. 1). The South Verkhoyansk region is the only one in Northeast Asia where the Triassic section is represented by its basal part that is characterized by index faunal fossils and where the lowermost biostratigraphic unit otoceras-bearing layers—*Otoceras concavum* Zone—has been identified (see [1, 17, 19, 55] and others). Earlier, the boundary between the Permian and Triassic systems in the South Verkhoyansk region was drawn at the contact between Imtachan Formation sandstones and Nekuchan Formation argillites [18, 21, 22, 55] (right part of Fig. 2). Sandstones in the upper Imtachan Formation refer to the Permian system [20], whereas the age of Nekuchan Formation argillites has become disputable [64] due to the selection of a global stratotype point in South China as the lower boundary of the Induan stage [83]. In the late 20th century, researchers considered the PTB to be connected to the first occurrence of the *Otoceras* genus, which was preceded by a global geological event that led to a large-scale stratigraphic hiatus [78]. In this respect, the Setorym River basin is of large interest because it is one of the few regions of the world where the oldest representative of the *Otoceras* genus, namely, *O. concavum* Tozer, has been found [55]; this species is an index species for the biostratigraphic zone reported in the boreal regions, and the PTB has been earlier drawn at the base of this zone [77].

In recent years, comprehensive studies of particular sections of the PTB interval and their detailed lithological–sedimentological studies have been conducted in the Setorym River basin; large collections of many macrofossil groups have been collected and the taxonomic compositions of fossil complexes and their stratigraphic distributions have been substantially supplemented and specified. As a result, the presence of the terminal part of the “boreal” Permian, namely, the *Intomodesma costatum* Zone, has been validated [4] (Fig. 2), the completeness of the PTB section has been verified, and the conclusion has been made that a sharp lithologic contact between the Imtachan and Nekuchan formations reflects a change in sedimentation environments (from the upper deltaic parts to the deep shelf zone, under the conditions of rapidly developing transgression) rather than a regional sedimentation hiatus [6]. The most recent studies of the lowermost Nekuchan Formation have revealed bivalves from the uppermost Permian [8]; we note that earlier a single bivalve species was described from this stratigraphic interval, *Palaeonucula aldanensis* Kurushin, which was believed to be Lower Triassic [38]. At the base of the Nekuchan Formation (lowermost 3.2 m) from the Suol section, such ammonoids as *Otoceras concavum* Tozer and *O.* aff. *gracile* Tozer; bivalves *Palaeonucula aldanensis* Kurushin, *Dacryomya* sp. (predominant), *Malletia*? sp. 1 and 2, Sarepta? sp., *Myalina* aff. *putiatinensis* (Kiparisova), *Pteria* cf. *ussurica* (Kiparisova), *Maitaia* cf. *errabunda* (Popow),

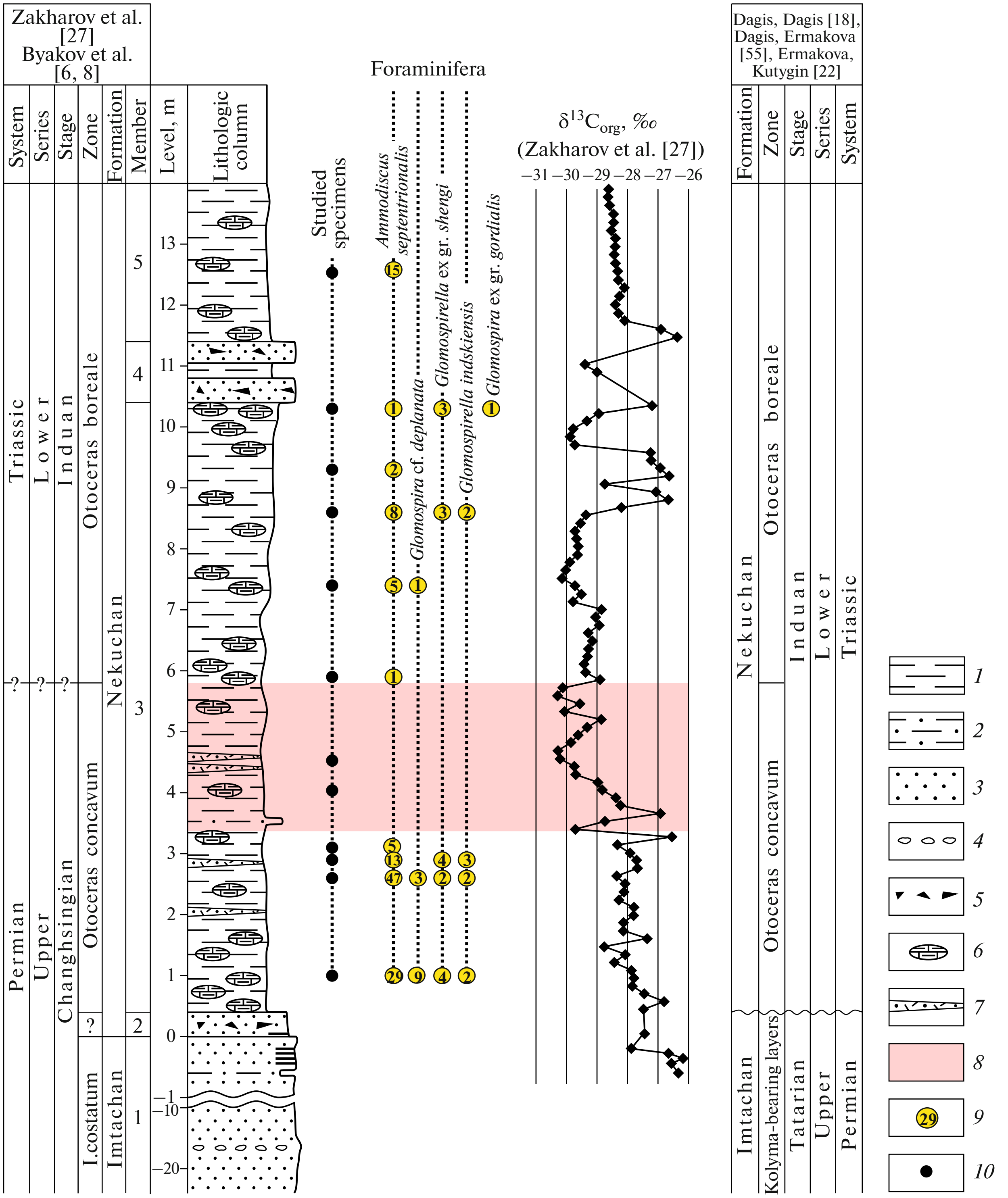


Fig. 2. The distribution of foraminifera in the PTB deposits of the Suol section. (*1*) argillites; (*2*) siltstones; (*3*) sandstones; (*4*) conglomerates; (*5*) argillite intraclasts; (*6*) clayey-carbonate nodules; (*7*) tuffs; (*8*) level of the last Permian extinction event; (*9*) foraminifera and their number; (*10*) samples examined for microfossils.

and *Unionites* cf. *canalensis* (Catullo); gastropods *Bellerophon*? sp.; and conchostraca with a bad degree of preservation have been collected. The macrofaunal fossils found in the interval of 3.3–5.9 m above the Nekuchan Formation base included only single bellerofontids, whereas multiple *Otoceras boreale* Spath ammonoids, as well as such bivalves as *Palaeonucula aldanensis* Kurushin, *Dacryomya* sp., *Myalina* aff.

putiatinensis (Kiparisova), and *Claraia* sp. were defined in the interval of 5.9–13 m [18].

Along with new biostratigraphic investigations of recent years, detailed geochemical studies of the PTB interval in terms of $\delta^{13}C_{org}$ isotopy has been conducted, and the respective carbon isotope curve has been constructed and interpreted. The carbon isotope intervals distinguished in the PTB deposits of the Verkhoyansk region have been also traced in a number of reference sections of the world. As a result of the entire research, a new position of the PTB has been proposed, approximately 6 m above the base of the Nekuchan Formation, i.e., immediately above the interval of the established carbon isotope minimum [27, 28] (Fig. 2).

Foraminifera from deposits of the PTB interval have been quite well studied in the Tethyan regions of Southern Alps, West Slovenia, Caucasus, Pamirs, Turkey, North Iran, South China, etc. (see [24, 25, 37, 41, 58, 67, 72] and others). The data on the terminal Permian and Lower Triassic foraminifera are extremely scarce regarding the boreal paleobasins; moreover, findings of these forams have not been reported in the integrated section. Thus, our study results on foraminifera from the PTB deposits of the South Verkhoyansk region are novel and are of high importance for understanding the nature of biotic events at the PTB. In addition, benthic foraminifera represent a very sensitive indicator of changes in facies conditions; hence the data on this group are important for providing the complete characteristics of the most significant extinction event in the Earth's history. The first data on foraminifera from this section were generally presented at the Micropaleontological Meeting that was held in 2018 in Kazan [48].

The aim of our studies were to determine of the compositions and structures of foraminiferal complexes, to study the dynamics of taxonomic diversity in the PTB deposits of boreal paleobasins, to reveal regularities and to explain them based on a comparison with the published data on other regions.

MATERIALS AND METHODS

The materials for the present study were the personal foraminifera collections of T.V. Klets and A.V. Kopylova (together with the collections of 2002 and 2003 by A.S. Biakov) from the Nekuchan Formation from the Suol section (Setorym River basin). The collections were compiled during a targeted search for conodonts in the section, with foraminiferal findings being reported in ten samples from the lower Nekuchan Formation. Due to silicification of the host rocks, samples for laboratory studies were subjected to disintegration using 5% hydrofluoric acid. The standard amount (mass) of rock for dissolution was 1.0 kg at an exposure time in acid of 8–12 h. The dissolved samples were then sieved (sieve cell sizes were 2.0 and 0.056 mm): the size fraction larger than 2 mm was subjected to further dissolution, while the finer one was examined to find and sample macrofaunal specimens. All foraminifera extracted this way had an agglutinated test.

Assuming that the species with calcareous shells could have been dissolved in acid during disintegration, we made 20 thin sections out of the samples that contained the largest number of foraminifera. The examination of thin sections did not reveal the presence of calcareous forms. Additionally we estimated the degree of the direct effect of 5% hydrofluoric acid solution on calcareous shells of foraminifera; for this purpose we used shells from other locations (Kotelny Island, from deposits of the Middle Norian). No visible decay was detected in shells at the used dissolution exposure time and at the given hydrofluoric acid concentration. Thus, it can be reliably stated that there are no foraminifera with calcareous shells in the samples, as they could not be dissolved during acid treatment. The method of using hydrofluoric acid during disintegration of argillites and clay siltstones from the lower Nekuchan Formation in order to extract foraminifera appeared to be more effective than manufacturing of multiple thin sections because of the scarcity of foraminifera.

In this respect, the study of foraminifera from the Setorym River basin was conducted on the extracted entire shells; to some degree this complicates the comparison of the extracted foraminifera with the taxa from the Tethyan sections, which were studied exclusively in thin sections.

Determination and monographic description of the foraminifera was made using a Zeiss Stemi 2000 microscope; imaging was performed with a Zeiss Discovery V 12 Stereo optical system with AxioVision 4.6.3 software. The internal structures and coiling character of the shells (which are the diagnostic features of these taxa, namely, *Glomospira* and *Glomospirella* genera) were studied by analyzing images of shells in immersion liquid.

RESULTS AND DISCUSSION

All studied foraminifera were collected from the lowermost (13 m) Nekuchan Formation of the Suol section located at the confluence of the Right and Left Suol streams (Fig. 2). The foraminiferal complex of the lower Nekuchan Formation is represented by exclusively benthic forms. The complex is taxonomically depleted, represented exclusively by ammodiscids of the *Ammodiscus*, *Glomospira*, and *Glomospirella* genera, which include both Permian and Triassic species that have quite a broad stratigraphic distribution range (Fig. 2). Among them, the *Ammodiscus septentrionalis* Gerke species, which is widespread in the Permian deposits [11] but is also found in the Lower–Middle Triassic ones of Middle Siberia [16, 35] is predominant. Such species as *Glomospira deplanata* Kasatkina and *Glomospirella indskiensis* Kasatkina were described by E.A. Kasatkina [32]; their holotypes originate from the lower Induan stage (*Otoceras boreale* Zone) of the Vardebukta Formation, western Spitsbergen Island. These species were also reported in the Pryamorechenskaya sequence of conditionally Induan age on Kotelny Island [31, 35]. *Glomospirella* ex gr. *shengi* Ho is a form that is morphologically similar to the *Glomospirella shengi* Ho species, which is described in the Lower Triassic deposits of China [60] and is quite widespread in the Lower and Middle Triassic deposits of both China and Europe [63, 70].

Analysis of the foraminifera distribution in the lower 13 m of the Nekuchan Formation has shown that they are relatively abundant in the lowermost beds, whereas they are absent in the middle of this interval, with a gradually increasing level up the section. The comparison of the data on foraminifera distribution with the carbon isotope data available for this part of the section [8, 28] allowed us to distinguish three intervals in the foraminifera distribution within the Suol section, namely, the lower, middle, and upper ones (Fig. 2).

The lower interval includes the lowermost Nekuchan Formation (from its base to 3.3 m), where foraminifera are relatively abundant (up to 50 specimens per sample). Among them, the dominating species is *Ammodiscus septentrionalis* Gerke, while rare findings of the rest (*Glomospira* cf. *deplanata* Kasatkina, *Glomospirella indskiensis* Kasatkina, and *G.* ex gr. *shengi* Ho) are reported: from two and, less frequently, up to nine specimens per sample.

The middle interval is characterized by the maximal negative excursions of the $\delta^{13}C_{org}$ isotope (3.3–5.8 m from the formation base). Two samples collected here did not reveal any foraminifera (Fig. 2). This interval is also characteristic of a strong manifestation of authigenic pyrite, which indicates euxinic environments [8]. This interval most likely corresponds to the Late Permian (Tethyan) biotic extinction event at the PTB, which is supported by the absence of macrofaunal remains here [8, 49]; this event might have also been reflected in the distribution of microbenthic organisms.

The upper interval is located above the section part with negative $\delta^{13}C_{org}$ excursions. Foraminifera reappear here and are represented by singular *Ammodiscus septentrionalis* Gerke) and rare glomospirellas. Thus, we can state that the microbenthic fauna recovered almost immediately (in terms of the geological timescale) after the extinction event, and both the quantity and taxonomic diversity of foraminifera increased with time, generally corresponding to the complex from the lower distinguished interval (Fig. 2).

In order to understand the correlation of our results with the general timeline of taxonomic reorganization during the PTB extinction event, we compared our data with the published data on the terminal Permian and Lower Triassic foraminifera from the other regions of the world. This allowed us to establish the common features and to explain the causes of the revealed regularities.

Tethyan Paleobasins

The foraminifera from the PTB deposits have been quite well studied in the Tethyan paleobasins (see [36, 37, 41, 58, 59, 67] and others). The evolution of Permian foraminifera is marked by the two main mass extinction episodes [37]. The first occurred at the Guadalupian–Lopingian boundary (the so-called Midian crisis), when 40% of all foraminiferal genera went extinct, chiefly fusulinids (more than 70%). In the late (terminal) Permian, fine foraminifera (mainly lagenids (=nodozariids) and ammodiscids) had become dominating in many regions of the world [37]. The latter episode occurred in the end of the Changhsingian age, when fusulinids, as well as a considerable part of fine foraminifera (lagenids and others), went completely extinct, while the remaining taxa abruptly decreased. As an example, as was revealed in the sections of northern Italy (South Alps), 96% of 27 lagenid species that belong to 15 genera went extinct at the PTB, whereas at the Paleozoic–Mesozoic boundary it was as few as 4 genera out of 36 [59]. Similar results on formainifers have been documented in the other sections of South Alps [69].

O.A. Korchagin conducted detailed studies of how the taxonomic diversity of foraminifera changes in the transitional layers of the Meishan section [37]. Interestingly, the PTB extinction event is characterized in a number of sections by the presence of an interval called the "dead zone," where foraminifera are absent [37, 41]. A similar pattern is also observed in the Suol section: in the interval 3.3–5.8 m from the Nekuchan Formation base the signatures of fatal hydrogen-sulfide concentrations are revealed; as well, the absence of macroscopic benthic organisms and foraminifera is documented and both these features can be correlated to the global biotic crisis (Fig. 2).

The lowermost Triassic deposits in a number of European and Asian sections are characteristic of taxonomically uniform depleted complexes represented by Ammodiscidae and Fischerenidae [85]. Analysis of Lower Triassic foraminiferal assemblages in the South China sections has demonstrated that these foraminifera were highly adapted to stressed environments: more precisely, foraminifera demonstrated a high population density at a low taxonomic diversity, with a simple morphology and a small size of their shells [75]. Some authors described the so-called "Lilliput effect" (a multiple reduction in shell size) in early Triassic foraminifera, namely, in the taxa that survived the PTB crisis. The "Lilliput effect" has been noted in foraminifera from the Meishan section, where the reduction of all specimens was reported to have decreased by more

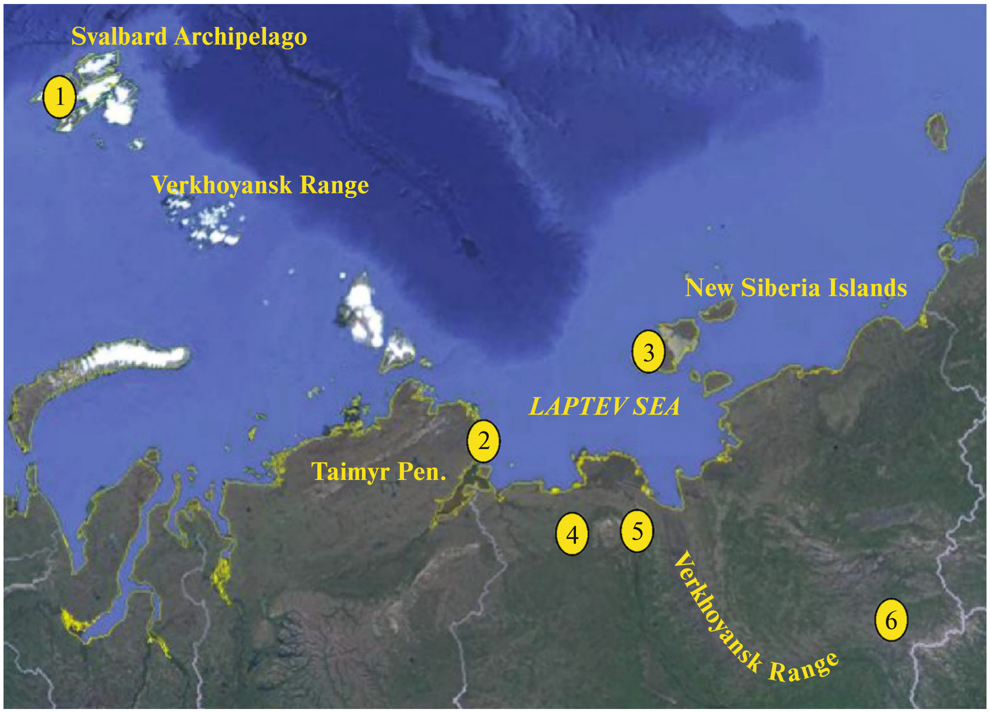


Fig. 3. The known localities of foraminifera in the Induan deposits of the Boreal realm. 1, Western Spitsbergen Island [32]; 2, Cape Tsvetkov, eastern Taimyr Pen. [2]; 3, Kotelny Island, New Siberia Islands [14, 30]; 4, Bur River, tributary of Olenek River [3]; 5, Eyekit River, tributary of Lena River (Yadrenkin, collection of 2017); 6, Setorym River (South Verkhoyansk region, authors' data).

than 2–3 times, to less than 0.5 mm (approximately 0.2 mm on average), in the interval between the two extinction episodes of the PTB [73].

Boreal Paleobasins

The weak degree of knowledge of foraminifera from the PTB deposits of the boreal regions is determined primarily by the small number of continuous sections of this age. The interval usually corresponds to a sedimentation hiatus or to beds with no fossil fauna; this is caused by facies peculiarities. The findings of Upper Permian and Lower Triassic foraminifera have been documented in the northern Middle Siberia [2, 9, 11], on the Kotelny Island [14, 30, 31, 35], on Svalbard [31, 32], in the Omolon massif [13, 62], and in the South Verkhoyansk region [8, 48].

In the sections of the Omolon massif, the Upper Permian deposits are represented by only the uppermost part (Khivach horizon) and are characterized on the basis of abundant foraminiferal complexes [33]. The first description of the foraminiferal complex (consisting almost exclusively of nodozariids) from the Khivach horizon was provided by A.A. Gerke and G.P. Sosipatrova [13]. Later, N.N. Karavaeva developed a foraminifera-based biostratigraphic chart for the Permian [32], with seven foraminifera layers being distinguished (we note that the complex of the Khivach horizon included 50 species). Karavaeva and G.P. Nestell later continued to study this complex; at present, its uppermost unit (*Hovchinella maxima* Zone) includes 80 species, all of which are calcareous representatives of such genera as *Nodosaria*, *Lingulonodosaria*, *Dentalina*, *Rectoglandulina*, *Hovchinella*, *Tristix*, *Pseudoammodiscus*, *Lingulina*, and *Astacolus* [62]. However, the recent data on the PTB stratigraphy of the Omolon massif suggest that the uppermost Permian layers, as well as the lowermost Induan ones, are absent here [7, 44].

In the north of Middle Siberia, Permian marine sediments included in the terrigenous complex of the Anabar–Lena and Pre-Verkhoyansk troughs of the Siberian Platform are well characterized by foraminifera [9–12]. These foraminifera complexes became the basis of the first regional biostratigraphic chart where the Permian was subdivided into four horizons. Regarding the completeness of the Permian section, it has been proved that a hiatus is observed in the upper series, with the absence of the upper Dulgalakh horizon and the entire Khal'pirka one, within this region [39, 51]; the more superior horizons of the Permian–lowermost bivalve-based *I. costatum* Zone were revealed only in the area of the Pronchishchev Range [5].

Findings of Induan foraminifera in the boreal regions (Fig. 3) are reported in northern Middle Siberia, namely, in the Cape Tsvetkov (Tsvetkovomysskaya

Table 1. Foraminiferal complexes from the Induan deposits of boreal regions

Western Spitsbergen Is. [31, 32]	Cape Tsvetkov (eastern Taimyr) [2]	Bur River (tributary of Olenek River) [3]	Eyekit River (tributary of Lena River), Yadrenkin's collection of 2017	Kotelny Is. (New Siberia Islands) [14, 15, 31, 32]	Setorym River (South Verkhoyansk region, authors' data)
Hyperammina sp.* *Ammodiscus korchinskajae* Kasatkina** *Glomospira deplanata* Kasatkina** *G.* ex gr. *gordialis* (Parker et Jones)* *Glomospirella indskiensis* Kasatkina** *Verneuilina* (?) *foliacea* Kasatkina** *Involutina liassica sibirica* Gerke** *Cornuspira* sp.*	*Saccammina bulla* (Voronov)* *Hyperammina proneptis* Schleifer** *Ammodiscus septentrionalis* Gerke* *Glomospira* sp.* *Haplophragmoides* sp.* *Trochammina* sp.*	*Reophax* sp.* *Haplophragmoides* sp.* *Trochammina* sp.* *Gaudryina* sp.** *Nodosaria* sp.*	*Saccammina bulla* (Voronov)* *Hyperammina proneptis* Schleifer** *Ammodiscus septentrionalis* Gerke* *Reophax* sp.* *Haplophragmoides* sp.* *Trochammina* sp.* *Ammobaculites* ex gr. *longus* Gerke**	*Psammosphaera* sp.* *Ammodiscus korchinskajae* Kasatkina** *Hyperammina proneptis* Schleifer** *Trochammina* aff. *alpina* Kristan-Tollmann** *Trochammina buliminoides* Gerke** *Gaudryina* sp.** *Glomospirella* sp.* *Ammobaculites* ex gr. *longus* Gerke** *Digitina* sp.*	*Ammodiscus septentrionalis* Gerke* *Glomospira* cf. *deplanata* Kasatkina** *Glomospira* ex gr. *gordialis* (Parker et Jones)* *Glomospirella indskiensis* Kasatkina** *Glomospirella* ex gr. *shengi* Ho**

* Species and genera know in Permian, ** species and genera know in Triassic.

Formation) of eastern Taimyr [2] and from the Ulakhan-Yuryakh Formation of the Bur-Olenek facial district (Bur River, tributary of the Olenek River, [3], Eyekit River, collected by A.V. Yadrenkin in 2017). On the Kotelny Island, foraminifera were established in the Pryamorechenskaya member [14, 15, 30, 31, 35]. According to the accepted stratigraphic charts, the age of deposits from these localities is believed to be Induan [29, 43]; due to the absence of orthostratigraphic fauna (ammonoids or conodonts), a more detailed stratigraphic position (at least a substage) of these units cannot be determined.

The foraminiferal complex that is closest in age to the Setorym one is the complex described by Kasatkina [32] in the Vardebukta Formation from the sections of the Dickson Land, Sassenfjorden, and Van Keulenfjorden (Spitsbergen Island). The age of these deposits is dated by the *O. boreale* Zone of the Lower Induan; unfortunately, the part of this formation from which these foraminifera were collected was not given [32]. The modern PTB position in the western Spitsbergen Island is founded on palynological data [66] and by the position of the negative excursion of $\delta^{13}C_{org}$ isotope 7 m above the Vardebukta Formation base [81].

There are no monographs dedicated to Induan foraminifera, excluding the species from western Spitsbergen Island [32], whereas other publications provide taxonomic lists (often in terms of open nomenclature). In general, the complexes incorporate genera common for the Permian and Triassic, and the Triassic species are present among the Permian ones (Table 1). Certain Triassic forms given in Table 1 have been reported in the Olenekian deposits of the Olenek River basin [11].

Thus, the lower Triassic horizons of the northern Middle Siberia, Kotelny Island, and Svalbard are characteristic of taxonomically poor foraminifera assemblages where morphologically simple agglutinating forms of the Saccamminidae, Hyperamminidae, and Ammodiscidae families dominate (Table 1).

The cores of these complexes are constituted by ammodiscids of the *Ammodiscus*, *Glomospira*, and *Glomospirella* genera, making these complexes close to the Setorym complex in terms of taxonomic composition.

CONCLUSIONS

(1) New data have been obtained on foraminifera from the PTB deposits of the section in the Setorym River area. The foraminiferal complex includes exclusively benthic agglutinating species of the Ammodiscidae family, namely, those of the *Ammodiscus*, *Glomospira*, and *Glomospirella* genera. In total, five species have been identified; the Permian species *Ammodiscus septentrionalis* Gerke dominates among them.

(2) In terms of taxonomic composition and morphological peculiarities, these complexes are characteristic of the post-crisis restoration period and of the initial evolutionary stages. In particular, they are characterized by relatively high population density, low taxonomic diversity, and simple shell morphologies; hence, they have a high adaptation capacity and are eurybiontic.

(3) As a result of the analysis of the vertical distribution range of foraminifera in the lower Nekuchan Formation, three intervals have been distinguished: the lower one, where foraminifera are relatively abundant, the middle one characterized by the absence of foraminifera, and the upper one, where the abundance and taxonomic composition of foraminifera gradually recovers. The comparison between the foraminifera distribution range in the section and isotope data has revealed that the middle interval devoid of foraminifera is characterized by low values of the $\delta^{13}C_{org}$ isotope and, most likely, corresponds to the PTB extinction episode in the Tethyan sections (the end-Permian extinction event) [8, 49]. However, in the case under discussion it is not quite correct to state that it was an extinction, because the taxonomic composition of the complex before and after the extinction did not change and only an abrupt reduction (up to complete?) in number is observed, with the subsequent gradual restoration of both the number and taxonomic composition.

(4) Comparison between foraminiferal complexes from the PTB deposits of the Tethyan and Boreal realms has revealed common features, namely: foraminiferal complexes of the terminal Permian demonstrate taxonomic diversity with the domination of nodozariids; at the end of the Permian, most taxa of the specific and generic levels went extinct, while the most primitive, morphologically simple taxa survived; an interval devoid of foraminifera that corresponds to the PTB is constantly present in continuous sections, the so-called "dead zone" (after Leven and Korchagin [41]); Early Triassic complexes are characterized by low taxonomic diversity, and ammodiscids become dominant in them.

A BRIEF PALEONTOLOGICAL DESCRIPTION OF FORAMINIFERA

As mentioned above, foraminifera from the PTB deposits of the Boreal realm have not been properly studied in monographs. In this respect, we have decided to provide images and brief descriptions (synonimics, comparison, stratigraphic and geographic ranges) of the found species.

We followed the foraminiferal systematics of A. Loeblich and H. Tappan [65]. The main morphological criterion for distinguishing generic taxa of ammodiscids is the shell structure type, which is determined by the main coiling style of the second tubular chamber. The studied collection of foraminifera is stored at the Laboratory of Micropaleontology, Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of the Russian Academy of Sciences (Novosibirsk) and has no. SET-2003.

Order Foraminifera Eichwald, 1830

Suborder Textulariina Delage et Herouard, 1896

Superfamily Ammodiscacea Reuss, 1862

Family Ammodiscidae Reuss, 1862

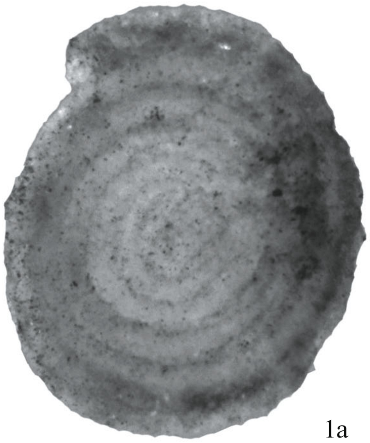
Subfamily Ammodiscinae Reuss, 1862

Genus *Ammodiscus* Reuss, 1862

Ammodiscus septentrionalis Gerke, 1961

Plate 1. The collection of foraminifera is stored at the Laboratory of Micropaleontology, Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of the Russian Academy of Sciences (Novosibirsk) and has no. SET-2003. All shown specimens were recovered from the lower Nekuchan Formation at the Suol 1 section (Left Suol stream, tributary of Setorym River, East Khandyga River basin, South Verkhoyansk region). *1–4*, *Ammodiscus septentrionalis* Gerke, sample 1-2-2.2p: 1, specimen SET-2003/1, ×118, (a) side view of immersed specimen in translucent light, (b) view from left side, (c) view from right side; 2, specimen SET-2003/2, ×93, side view; 3, specimen SET-2003/3, ×115, side view; 4, specimen SET-2003/4, ×95, partially broken test, side view, sample 1-2-2.2p; 5, 6, *Glomospira* cf. *deplanata* Kasatkina: 5, specimen SET-2003/5, ×143, side view of immersed specimen in translucent light, sample 2-2-2.2p; 6, specimen SET-2003/6, ×146, side view of immersed specimen in translucent light, sample 15A-1; 7–10, *Glomospirella indskiensis* Kasatkina: 7, specimen SET-2003/7, ×138, side view of immersed specimen in translucent light; sample 2-2-2.2p; 8, specimen SET-2003/8, ×135, side view of immersed specimen in translucent light, sample 15A-1; 9, specimen SET-2003/9, ×136, side view of immersed specimen in translucent light, sample 1-2-2.2p; 10, specimen SET-2003/10, ×135, side view of immersed specimen in translucent light, sample 1-2-2.2p.; 11, 12, *Glomospirella* ex gr. *shengi* Ho: 11, specimen SET-2003/11, ×117, (a) left side view of immersed specimen in translucent light; (b) right side view of immersed specimen in translucent light, sample 1-2-2.2p; 12, specimen SET-2003/1 2, ×130, side view, sample 15A-1.

Plate 1


1a

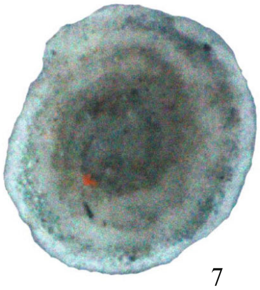

1b

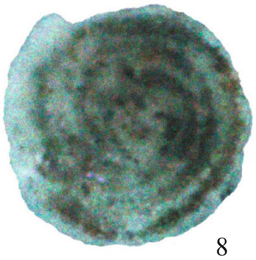

1c

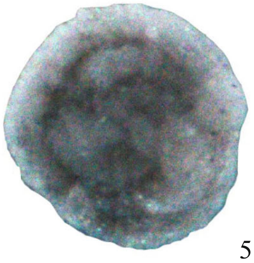

2


3


4


7


8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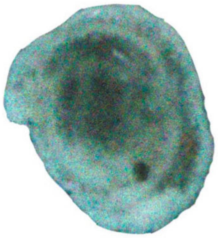
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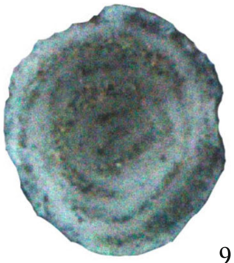
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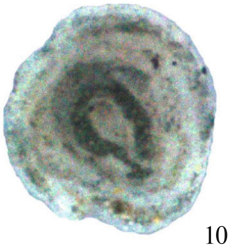
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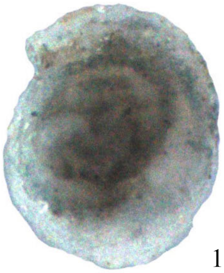
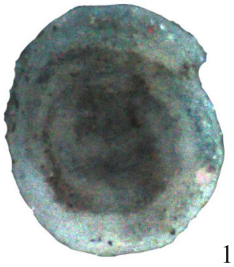
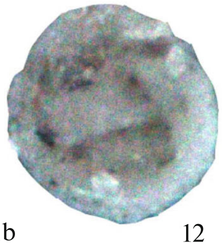

11a


11b


12

(Pl. 1, figs. 1–4)

Ammodiscus ex gr. *semiconstrictus* Waters, [9] Gerke, 1952, pp. 67–70, Pl. IV, fig. 4.

Ammodiscus septentrionalis Gerke, [11] Gerke, 1961, pp. 122–124, Pl. XII, fig. 1, Pl. XII, fig. 14.

Comparison. This species is distinguished from morphologically similar Triassic species *A. inaecuabilis* Styk of the Lower Anisian of Poland and western Carpathians ([76], p. 507, pl. XXXV, figs. 3, 4; [70], pl. CXLI, fig. 7), *A. septentrionalis* is larger (1.5 times) size and lower number of coils; from *A. korchinskajae* Kasatkina, ([32], Pl. 1, figs. 1a, 1b) from the Induan deposits of Svalbard, in the larger size, a larger number of coils, and a more coarseness test wall. This species is differentiated from *A. parapriscus* Ho, ([60], p. 408, Pl. II, figs. 3–6; [85], Pl. 2. figs. 1, 2) and *A.*? *parapriscus* Ho from the Olenekian deposits of the eastern Alps, Slovenia ([61], p. 219, figs. 5a–5d) in the larger size, larger number of coils, narrower last coil, and the cross-section shape which is weakly biconcave, contrary to biconcave one in the Tethyan forms. It is also distinguished from *A. minutus* Efimova ([24], Pl. 1, fig. 16) from the Induan (Lower Triassic) limestones of western Caucasus in the considerably larger size and larger number of coils (seven to eight versus two to three).

Geologic range. Permian, Lower Triassic.

Locality. Nordvik area of Eastern Taimyr (Cape Tsvetkov), Olenek area, Bur-Olenek area, Eyekit River, South Verkhoyansk region, Setorym River area, Suol section.

Subfamily Ammovertellininae Saidova, 1981

Genus *Glomospira* Rzehak, 1885

Glomospira cf. *deplanata* Kasatkina, 1991

(Pl. 1, figs. 5, 6)

Bad degree of preservation and deformation of tests has not allowed us to completely identify the found forms as *Glomospira deplanata* Kasatkina, 1991

Comparison. The species is differentiated from *Glomospira gordialis* (Parker et Jones) in more flattened form, smaller size, a lower number of coils, and more ordered character of coiling.

Note. In the first description, the author provided very low-quality images that give almost no idea about the shell structure.

Geologic range. Lower Triassic, *Otoceras boreale* Zone, Vardebukta Formation [32]; uppermost Upper Permian–Lower Triassic, Nekuchan Formation.

Locality. Western Spitsbergen Island, Dickson Land, Lower Triassic [32]; South Verkhoyansk region, Setorym River area, Suol section.

Genus *Glomospirella* Plummer, 1945

Glomospirella indskiensis Kasatkina, 1991

(Pl. 1, figs. 7–10)

Glomospirella indskiensis Kasatkina, 1991. Kasatkina, 1991 [32], Pl. I, figs. 6a, 6b, p. 14.

Comparison. The species is distinguished from *Glomospirella shengi* Ho ([60], pl. 5, fig. 20–25; [82], pl. 2, fig. 14–16) in the more flattened form, less developed glomerate part, and less number of coils (one to two versus two to three) in the spiral part. It is also differentiated from *Glomospirella irregulareformis* Efimova ([24], pp. 66, 67, Pl. 2, fig. 9) from the lower? Induan deposits of the eastern Cis-Caucasus region, in lower number of coils (one to two versus three to four) in the spiral part.

Note. In the first description, the author provided very low-quality images that give almost no idea about the internal shell structure.

Geologic range. Lower Triassic, *Otoceras boreale* Zone, Vardebukta Formation [32]; uppermost Upper Permian–Lower Triassic, Nekuchan Formation.

Locality. Western Spitsbergen Island, Dickson Land [32]; South Verkhoyansk region, Setorym River area, Suol section.

Glomospirella ex gr. *shengi* Ho, 1959

(Plate 1, figs. 11, 12)

Comparison. The species is distinguished from the Lower Triassic *Glomospirella shengi* Ho, 1959 ([60], pl. 5, fig. 20–25; [70], pl. 3, fig. 6–13; [63], pl. 5, figs. G and H) in slightly less developed spiral part that consists of 1–2 coils. It is also differentiated from *Glomospirella indskiensis* Kasatkina, 1991 ([32], Pl. I, figs. 6a, 6b) by the more developed glomerate part.

Geologic range. Uppermost Upper Permian–Lower Triassic, Nekuchan Formation.

Locality. South Verkhoyansk region, Setorym River area, Suol section.

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