

Article

Microfossil (Diatoms, Tintinnids, and Testate Amoebae) Assemblages in the Holocene Sediments of the Laptev Sea Shelf off the Yana River as a Proxy for Paleoenvironments

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Abstract

The paper presents the results of a microfossil study of Holocene sediments in the Yana River flow zone in the southeastern part of the Laptev Sea. A rich diatom flora (242 species and intraspecific taxa, of which 177 species are freshwater) was revealed; additionally, five species of marine tintinnids (planktonic ciliates) and 15 species of freshwater testate amoebae (testacean) were discovered for the first time in the sea sediments. Three assemblages of microfossils reflecting the phases of environmental changes during the Holocene transgression are distinguished in the studied sediments of core LV83-32. Assemblage 1 was formed under terrestrial conditions (assemblage of diatoms *Eunotia-Pinnularia* and testacean *Diffugia-Cylindridiffugia-Centropixis*), assemblage 2 in the zone of mixing of sea and fresh waters (assemblages of diatoms *Cyclotella striata-Aulacoseira*, *Thalassiosira hyperborea-Chaetoceros* and *T. hyperborea-Aulacoseira*, testacean *Cyclopyxis kahli*, tintinnids *Tintinnopsis fimbriata*), and assemblage 3 reflects modern conditions in the inner shelf of the Laptev Sea under the strong influence of river runoff (assemblage of diatoms *T. hyperborea-Aulacoseira-M. arctica* and tintinnids *Tintinnopsis ventricosoides*). Changes in the natural environment in the coastal part of the Laptev Sea shelf during the Holocene, established by microfossil assemblages, are confirmed by geochemical data.

Keywords: diatoms; tintinnids; testate amoebae; sediments; Holocene; Yana Delta; Laptev Sea



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1. Introduction

The coastal shelf of the southeastern Laptev Sea (LS) is characterized by strong freshening of sea waters, determined by the runoff of the Yana and Lena rivers, the presence of a polynya, an open water area in sea ice [1], and intense ice impact on the bottom [2,3]. This determines the specific habitat conditions for marine microorganisms, the study of which is widely used for paleogeographic and biostratigraphic reconstructions.

The best characterized is the diatom flora, which is used as a source of information on changes in marine environmental conditions and in the river–sea system [4–7]. Diatom assemblages in surface sediments are natural recorders of the physical characteristics of the environment and its changes and have been successfully used to reconstruct paleoenvironments in the geological past [8–18]. The impact of the Lena and Yana River runoffs on the environment in the past was assessed based on a study of diatoms in the LS bottom sediment cores [4,19–22].

The study of testate amoebae (testacean) in the high Arctic began on Spitsbergen Island (Greenland Sea) [23] and continues to the present day on the coasts of the Barents and Kara Seas [24], on the Chukchi Peninsula [25], etc. On the coast of the Laptev Sea, testaceans were studied in Pleistocene–Holocene deposits of the Bykovsky Peninsula [26,27] and Cape Mamontov Klyk (near the Lena River delta) [28]. Reconstructions of the changes in environmental conditions in these areas over the past 53,000 and 44,000 years, respectively, have been presented based on the differences in the testate amoebae assemblages. In addition, a rich fauna of testate amoebae, including 91 taxa, has been identified near the town of Tiksi [29].

Tintinnids are members of planktonic ciliates and have been studied in the Arctic for over 120 years [30]: in the Barents and Kara Seas [30–32], the Baltic Sea [33,34], the Chukchi and Bering Seas, the Beaufort Sea [35–37], the North Sea [38,39], Norwegian Sea [40], and Greenland Sea [41]. In the Laptev Sea, four species were found in plankton samples [33] and six species in surface sediments [42]. The listed works were mainly devoted to the biology of tintinnids and their distribution in the water column.

Analyzing core LV83-32-1, located in the zone of influence of the Yana River runoff, revealed assemblages of microfossils (diatoms, testate amoebae, and tintinnids), reflecting various environmental conditions. The core also contains well-represented sediments and microfossils that have accumulated in the mixing zone of sea and river waters, the study of which in the Arctic seas is associated with certain difficulties. These water areas are covered by fast ice for most of the year, including periods of intensive development of phytoplankton; consequently, the use of large research vessels in shallow water is impossible, and the infrastructure for studying shallow water from land on small vessels is lacking.

The aim of this work is to analyze species composition, typical assemblages of microflora and microfauna, and geochemical data, revealing changes in the natural environment at the land–sea transition zone under the strong influence of river runoff during the Holocene.

2. Physical and Geographical Characteristics of the Region

The LS features a broad continental shelf with an average depth of 53 m. Its seabed slopes gently northward and is intersected by underwater river valleys [43], facilitating significant water exchange between the LS and the Arctic Ocean [44]. For most of the year, the sea is covered by ice. Due to low winter temperatures and northward ice drift, the LS is a major source of sea ice in the Eurasian sector of the Arctic Ocean [45]. In recent decades, Arctic climate warming has led to a sharp decline in ice cover in the LS [46,47]. Fast ice extends over thousands of kilometers in the eastern part of the sea, and polynyas form nearly continuous strips of varying widths along the Eurasian coast, known as the Great Siberian Polynya [1]. These polynyas significantly influence the hydrological regime of the surrounding waters [48] and are crucial for ice formation and biological activity [49].

The water circulation in the LS is notably affected by the discharge of the Lena and Yana rivers, which alters the cyclonic circulation pattern to the northeast, where most of the flow moves along the New Siberian Islands to the north [49,50]. A smaller portion of this

flow, with salinity reduced to 20 psu, spreads along the southeastern part of the sea and passes between the islands into the East Siberian Sea. Surface salinity in the LS's shelf zone is primarily influenced by Siberian River discharge, ice-related processes, and interactions with the Arctic Ocean and adjacent seas [51,52]. Salinity in the LS ranges from 1 to 31 psu, with the surface layer ranging from 20 to 30 psu due to the substantial influx of freshwater.

The Siberian River system controls the supply of clastic material to the shelf and the freshening of seawater [53]. Rivers annually supply approximately 27 million tons of clastic material [54], with the Lena River alone contributing about 21 million tons per year [55].

Large areas of the Laptev Sea shelf floor consist of underwater permafrost, which has undergone intense degradation over the past decades and centuries [56]. In addition, temperature anomalies have been observed in the coastal areas of the Laptev Sea, caused by groundwater, the release of which produces more water than during the spring flood of the Yana River into the sea near the coast [57]. Furrows of varying widths and lengths have been recorded in the coastal part of the sea, formed by the impact of floating ice formations on the bottom [2,3], complicating the bottom relief and disrupting the integrity of sediments.

3. Materials and Methods

Core LV83-32 (LV83-32-1), analyzed in this study, was obtained by the gravity corer during the Russian–Chinese expedition on board the R/V Akademik M.A. Lavrentyev in 2018 from the inner shelf of the LS, in the avandelta of the Yana River ($135^{\circ}19'58.56''$, $72^{\circ}23'40.98''$) (Figure 1), from a depth of 24 m. The core length is 258 cm.

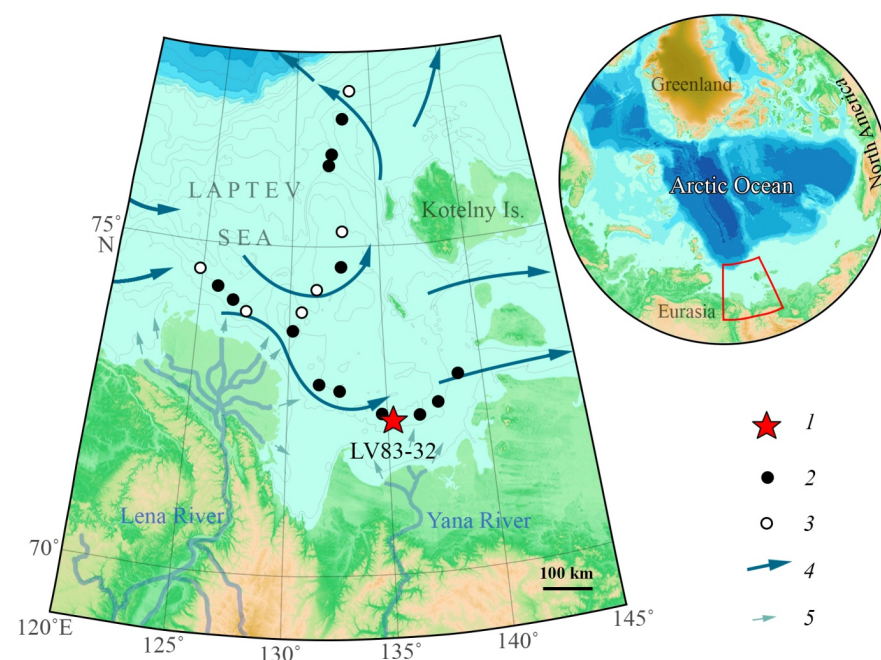


Figure 1. Locations of core LV83-32 and previously studied surface sediment stations [17,42]. Symbols indicate 1—core LV83-32, 2—sediment stations with diatoms and tintinnid loricae, 3—sediment stations with diatoms without tintinnid loricae, 4—surface currents [49], 5—river outflow.

The colors of the sediments were determined onboard immediately after sampling using an original colorimetric setup based on a Canon EOS 6d Mark digital camera (Canon, Tokyo, Japan) using a proven technique [58]. The analysis step used 1 mm of sediment. Color information was recorded in the coordinates of the CIE L*a*b* color model. The particle size distribution of the sediments was determined in a stationary laboratory using a Fritsch Analysette 22 NanoTec laser particle analyzer (Fritsch GmbH, Idar-Oberstein,

Germany). The following particle size fractions were distinguished in the sediment [59]: sand ($>62\ \mu\text{m}$), silt ($4\text{--}62\ \mu\text{m}$), and clay ($<4\ \mu\text{m}$). The analysis step used 1 cm of sediment.

Core LV83-32 was sampled every 4 cm for micropaleontological analysis, and a total of 64 samples were studied. For diatom analysis, the treatment of sediments, preparation of slides, and estimation of the diatom concentration (mln. valves per 1 g of the air-dry sediment) were performed using a standard technique [60]. The heavy potassium–cadmium liquid with a specific gravity of $2.6\ \text{g}/\text{cm}^3$ was used to isolate diatoms from sediments. MOUNTEX synthetic medium (refractive index = 1.67) (Histolab Products AB, Gothenburg, Sweden) was used to prepare permanent slides. The diatoms were identified and enumerated with a LOMO Mikmed 6 light microscope (magnification = $\times 1000$; LOMO, St. Petersburg, Russia) and imaged with an AxioCamMrC digital video camera (Zeiss, München, Germany).

Diatoms were identified mainly from the sources cited in our works [14,16,17,61–64]. Ecological and biogeographic characteristics are primarily sourced from [65–67] and the above-mentioned sources. Taxonomic references and photographs of most of the species mentioned here can be found in [14].

For tintinnid and testate amoebae, each bulk sediment sample was disaggregated by boiling in 0.002 M sodium pyrophosphate solution for 15–20 min. After boiling, the samples were washed using a sieve with a $40\ \mu\text{m}$ mesh. The fraction with a diameter $> 40\ \mu\text{m}$ was dried, and an aliquot of approximately 3–5 mg was separated from this fraction. Canadian Balsam DC (refractive index = 1.520–1.523) was used to prepare permanent mounts. Taxonomic determinations were performed using a LOMO Mikmed 6 Microscope ($300\times$ magnification, LOMO, St. Petersburg, Russia). The fossils were photographed under transmitted light using a Touptek photonics FMA050 digital camera (Hangzhou ToupTek Photonics Co., Ltd., Hangzhou, China). The morphological features of the tintinnid loricae and shells of testate amoebae were studied using a dual-beam scanning electron microscope TESCAN Lyra 3 XMH (TESCAN, Brno, Czech) in the laboratory of micro- and nano-research of the Analytical Center of the Far Eastern Geological Institute FEB RAS (Vladivostok, Russia). For this, tintinnid loricae and shells of testate amoebae were placed on special metal holders ($10\ \text{mm} \times 10\ \text{mm}$) and coated with carbon. The tintinnid species were identified from the following main sources: [32,38,39,68]. The testate amoebae species were identified from the following main sources: [69–71] and an Internet resource: <https://arcella.nl/lobose-testate-amoebae/> (accessed on 5 April 2025).

The chemical composition of the sediments was determined from samples collected with a spacing of 1 cm in the core interval 0–150 cm, and 2 cm in the interval 150–255 cm. An ARL Quant’X energy-dispersive X-ray fluorescence spectrometer (Thermo Fisher Scientific (Ecublens) SARL, Ecublens, Switzerland) was used; it was calibrated using the standard samples SGH5, MAN, and JH-1 (for more details, see [72]). Grain-size analysis was also performed in these samples, and the content of CaCO_3 and total organic carbon (TOC) was determined. These results were used to substantiate various proxy paleoenvironments (Figure 2). Additionally, continuous scanning of the chemical composition of sediments was performed with a 3 mm step using a core scanner based on a Delta Dpo-2000 X-ray fluorescence spectrometer (Olympus Scientific Solutions Americas, Waltham, MA, USA). The results obtained are presented as rubidium-normalized contents (Figure 2) and were used to refine the position of sediment layer boundaries and demonstrate the presence of fine layering (Figure 2 Fe/Rb, As/Rb).

Carbon-stable isotope ($\delta^{13}\text{C}$) analyses were carried out on acidified samples (HCl, 1.5 M) to remove the carbonate fraction [73]. Analyses were performed using the Picarro G2121-i Isotopic Carbon Analyzer. The instrument was calibrated after analysis of every

10 samples using IAEA-601 standards ($-28.81 \delta^{13}\text{C}$) and IAEA-CH-3 ($-24.724 \delta^{13}\text{C}$). Each sample was measured 2–3 times. The analytical error for $\delta^{13}\text{C}$ was lower than $\pm 0.2\text{‰}$.

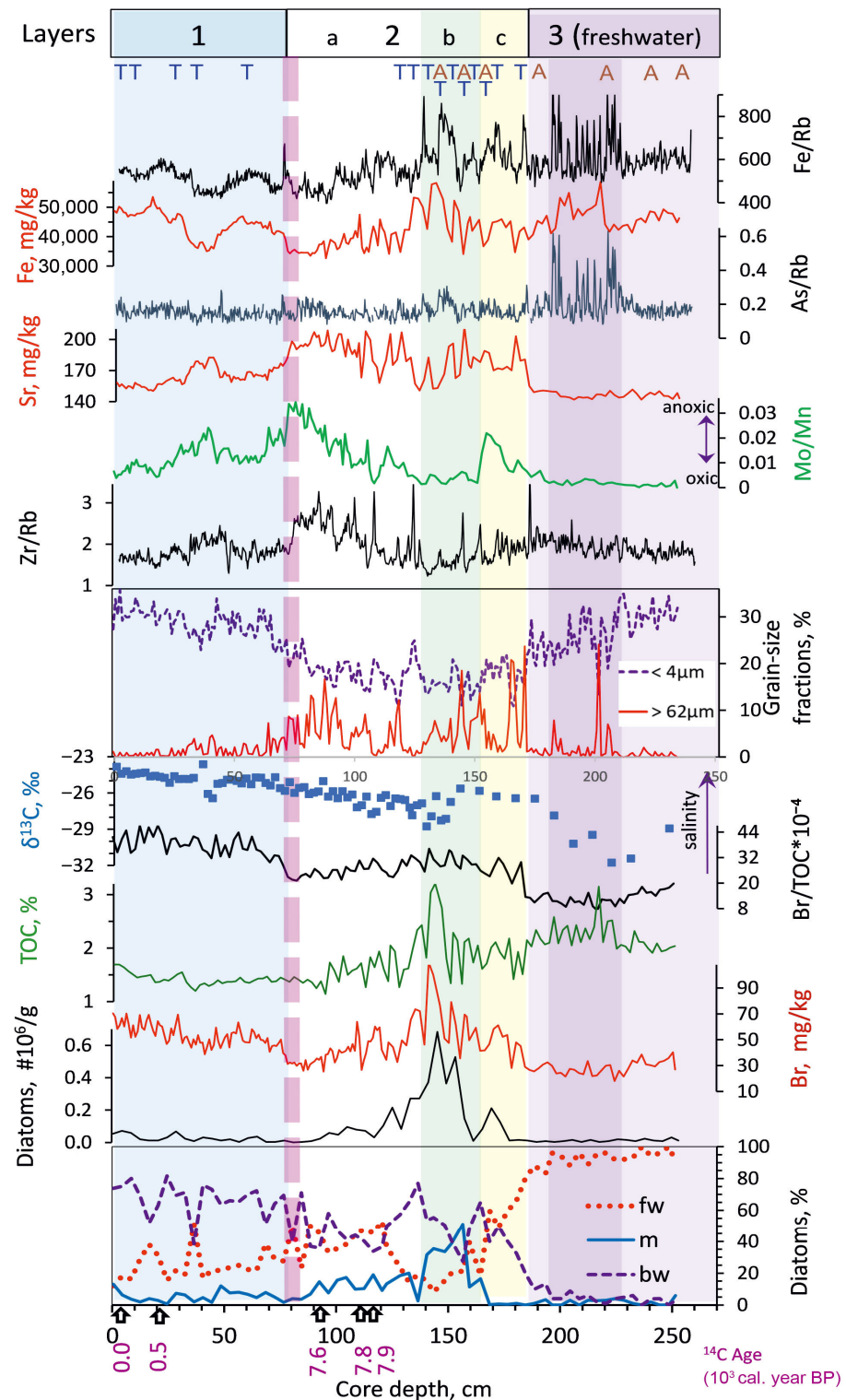


Figure 2. Features of the sediment composition, organic carbon and isotopes content, Br/TOC index, chemical elements content, diatom content (10^6 valves/g), and the ratio of ecological groups in diatom assemblages (fw—freshwater, m—marine, bw—brackish water), presence of tintinnids (T) and amoebas (A) in core LV83-32. The dashed pink line is the location of the sedimentary layer removed by ice erosion of the seafloor. Arrows show the locations of radiocarbon dating. The postglacial sea level position (PSL) is obtained from [74].

AMS ^{14}C radiocarbon dating of mollusk shells was carried out according to standard procedures (Table 1).

Table 1. Radiocarbon (AMS ^{14}C) dating of mollusk shells from core LV83-32.

Core Interval, cm	Lab. ID	Material	Uncorrected AMS ^{14}C Age (y)	Calibrated Age BP (y) Two Sigma Ranges
5	RICH-30576	Mollusk shell, fragments	113 $\pm$ 21	post AD 1950
22	RICH-30577	Mollusk shell, fragments	970 $\pm$ 22	412–645
93–94	Beta-588953	Mollusk shell, fragments	7150 $\pm$ 30	7419–7687
112–113	Beta-522027	Mollusk shell, fragments	7440 $\pm$ 30	7683–7973
116–117	RICH-30578	Mollusk shell, fragments	7510 $\pm$ 32	7740–8048

4. Results

4.1. Chronology

The age–depth model of core LV83-32 (Appendix A, Figure A1) is based on the AMS radiocarbon dates obtained from mollusk shells (Table 1). The radiocarbon date was converted into calendar years before the present (cal. year BP) using the Marine 20 dataset. A mean value of -122 ± 24 years was adopted for the Laptev Sea reservoir age anomaly value (δR), which is based on three points of the Laptev Sea in the CALIB Marine Reservoir Correction Database ([74,75]). The age–depth model was generated in Bacon 2.2 [76,77].

To refine the chronology, data on the age of the surface sediment layer obtained by the multicorer [47] were used. Comparing the data for the density of this core and the one under study showed that when core LV83-32 penetrated the sediment, the upper 2.5 cm of unconsolidated watered sediments, which had accumulated over the past 20 years, had been lost.

Unfortunately, the large core interval (22–93 cm) does not contain shell remains and has not been dated. It is also impossible to date the organic matter in sediments due to the large admixture of ancient terrigenous carbon [50]. When compared with the age model of core LV83-32-3 obtained at the same station [75], large differences in the sedimentation rates for this interval were established in the two cores: 0.1 and 0.5 mm/year, respectively. This suggests the presence of a hiatus in sedimentation in core LV83-32 caused by the removal of a sedimentary layer by ice, which is typical for the East Siberian shelf as a whole [78,79], as well as for this region of the Laptev Sea [3,80]. A detailed analysis of the variations in the material composition of sediments in the 22–93 cm interval of core LV83-32, and high-resolution scanning data for the chemical composition and color characteristics (Appendix A, Figures A2 and A3) showed that the fallen ice gouge layer could have been located in the 78–85 cm interval of the core (Appendix A, Figure A4). Based on the age models of our core (Appendix A, Figure A1) and core LV83-32-3 [75], it can be assumed that it included sediments with an estimated age of 3.2–7.2 thousand years, and the thickness was approximately 50–70 cm.

4.2. Features of the Sediment Composition

The Holocene sediments in core LV83-32 are similar in composition and variations in grain size distribution, geochemical features, carbon isotopes, reconstructed salinity, and other parameters to the postglacial transgression sediment complex, which has been well studied on the Laptev Sea shelf [19,81–83]. Their correlation allows us to conclude that the studied sediments were formed during the post-glacial transgression and accumulated during a gradual rise in sea level near the delta of the Yana River.

The sediment core is divided into different layers based on sediment composition, geochemistry, and diatom distribution (Figure 2).

Layer 1 (258–188 cm) contains clayey silt with a minor admixture of sand (Appendix A, Figure A3). It should be noted that the content of the clay fraction gradually increases from top to bottom along the horizon, while the content of the silt fraction decreases (Appendix A, Figures A2 and A3). The Layer horizon is distinguished most contrastingly by its color characteristics: in comparison with the others, it is the lightest gray, with the presence of reddish and bluish hues that are elusive to the eye (Appendix A, Figures A2 and A3). Layering is noted in the 196–228 cm interval (shown in darker shading in Figure 2), determined by the presence of coarser-grained sandy–silty layers that are 5–15 mm thick and enriched with ferruginous plant detritus. They are clearly distinguished by the distribution of iron (Fe/Rb) and arsenic (As/Rb), obtained by XRF scanning with a step of 3 mm. In general, this horizon is distinguished by increased contents of TOC, Fe, and fraction > 63 μm (Figure 2).

Layer 2 (188–88 cm) is most clearly distinguished by a sharp decrease in the clay fraction against the background of maximum contents of sand and silt (Figure 2, Appendix A, Figure A3). It is composed of dark gray sediments with sharply variable geochemical characteristics, but with consistently high contents of Sr (Figure 2) and Ca (Appendix A, Figure A4).

Layer 3 (88–0 cm) is composed of light gray, unclearly stratified sediments with an increased content of clay fraction. Its content, as well as TOC, Br, Br/TOC, and $\delta^{13}\text{C}_{\text{TOC}}$, gradually increases toward the core surface (SM1). The lower boundary of layer 3, coinciding with the hiatus due to ice erosion (Appendix A, Figures A1 and A4), is distinguished by a sharp gradient in the contents of Fe, Ca, Sr, Zn, Zr, Mo/Mn, clay granulometric fraction, as well as color characteristics (Figure 2, Appendix A, Figure A4).

4.3. Microfossil Data

The microfossils found in core LV83-32 belong to different groups of the protozoa phylum: diatoms, testate amoebae, and tintinnids. The characteristics of these group assemblages are given below.

4.3.1. Diatom Assemblages

Diatoms (Class Bacillariophyceae) are unicellular algae living in any aquatic environment, predominantly inhabiting fresh and salt waters, and playing a key role in the food chain. Diatoms have siliceous valves that are well preserved in the fossil state and are the main suppliers of biogenic silica to bottom sediments. Most diatoms are sensitive to the salt content in water and are used as indicators of the salinity of a basin in the study of bottom sediments [67,84]. Diatoms react very sensitively to the slightest changes in their environment; therefore, changes in their abundances and ratios between freshwater and marine species can be used as a source of information on changes in environmental conditions.

The diatom content in the sediments is quite low (on average about 0.07×10^6 valves/g) throughout almost the entire core, with the exception of the 168–137 cm interval, where the diatom concentration reaches its maximum value (0.68×10^6 valves/g) (Figure 2).

The core sediments contain 242 species and intraspecific taxa in 80 genera (Supplementary Material S2). The following genera contain the most species: *Eunotia* (19 taxa), *Pinnularia* (18), *Gomphonema* (13), *Navicula* (10), *Cymbella* (9), *Diploneis* (9), *Aulacoseira* (8). The ecological structure of the diatom flora is distinguished by a sharp predominance of freshwater species (177 species), with marine diatoms represented by 30 species, and brackish water and euryhaline by 25 species. Also noted are three extinct species and seven species of unknown ecology. Sixty-one species are cosmopolitan. Freshwater and brackish water species are characterized by high abundance.

Five assemblages were identified, named according to the dominant species and genera, based on the taxonomic composition, quantitative ratio of species, ecological structure, and concentration of diatoms in the core from bottom to top.

Assemblage *Eunotia-Pinnularia* (interval 252–188 cm) is characterized by the lowest diatom content ($0.004\text{--}0.032 \times 10^6$ valves/g) in the core (Figure 2), but significant species diversity (125 species and intraspecific taxa). Diatoms are represented by freshwater species (108 taxa), which dominate (83.3–99.1%), and brackish water species (14 species), whose abundance ranges from 0.9 to 16.7% (Figures 2 and 3A). The greatest species richness is characterized by the genus *Eunotia* (16 species), whose species are epiphytes for a wide range of bryophytes and aquatic plants [85,86] and are diverse in sphagnum bogs [87]. The most numerous species are *Eunotia praerupta* (12.1–31.7%) (Figure 3B), *E. bidens* (up to 12.9%), and *E. bilunaris* (up to 6.9%). This assemblage contains a significant amount (2.9–20.8%) of aerophilic and soil species, including *Hantzschia amphioxys*, *Reimeria sinuata*, *Pinnularia borealis*, and *Luticola mutica*, which can live with slight moisture and tolerate temporary drying of the substrate [65,66,88]. The permanent components of the assemblage are *Stauroneis phoenicenteron*, *Staurosirella pinnata*, *Meridion circulare*, *Placoneis amphibola*, *Encyonema elginense*, and *Caloneis silicula*, most of which are typical of low-streaming waters [66]. Among the freshwater species, benthic species are distinguished by their species richness (68 species) and abundance (20–44.6%). In contrast, planktonic–benthic species are less diverse (25 species), but numerically they dominate (40.6–63.3%). Diatoms predominate (43.6–65.3%) in low-streaming waters, the number of species inhabiting standing waters is significant (6.9–21.8%), and species preferring streaming waters make up 3.6–18.6%. The brackish water species *Diploneis smithii*, *Anomoeoneis costata*, and *Thalassiosira hyperborea* occur sporadically, but their content becomes noticeable in the upper part (up to 13.3% in the range of 194–193 cm), which presumably indicates the beginning of an increase in the influence of sea water.

Assemblage *Cyclotella striata-Aulacoseira* (interval 188–168 cm) is characterized by an increase in the concentration of diatoms in sediments ($0.01\text{--}0.2 \times 10^6$ valves/g), a change in the dominant species, and a change in the ecological composition of the diatom assemblage. In the diatom assemblage, which includes 111 species, the number of freshwater species decreases (92 species), there are 10 brackish water species, and 8 single marine species. The brackish water planktonic species *Cyclotella striata* (13–40.3%) and the freshwater planktonic arctic-boreal species *Aulacoseira subarctica* (6.6–32.9%) dominate (Figure 4). Freshwater species still predominate in the assemblage (41.2–81%), including planktonic (15.9–46.5%) and planktonic–benthic (10–36.9%) species, while the proportion of benthic species is sharply decreased (3.2–14.3%). These are mainly species typical of low-streaming waters (38–61%), and the number of species in standing waters is sharply reduced (1.6–4.7%). Brackish water species become a subdominant group (19–49.2%), among them the planktonic *Thalassiosira hyperborea* and *Th. baltica*, which have similar ecological characteristics, are constant. The characteristic of this assemblage is the appearance of single marine species, represented by benthic (*Tryblionella debilis*, *T. littoralis*, *T. levidensis*, etc.) and planktonic (*Porosira glacialis*, *Actinocyclus* sp., *Chaetoceros* spp.) species.

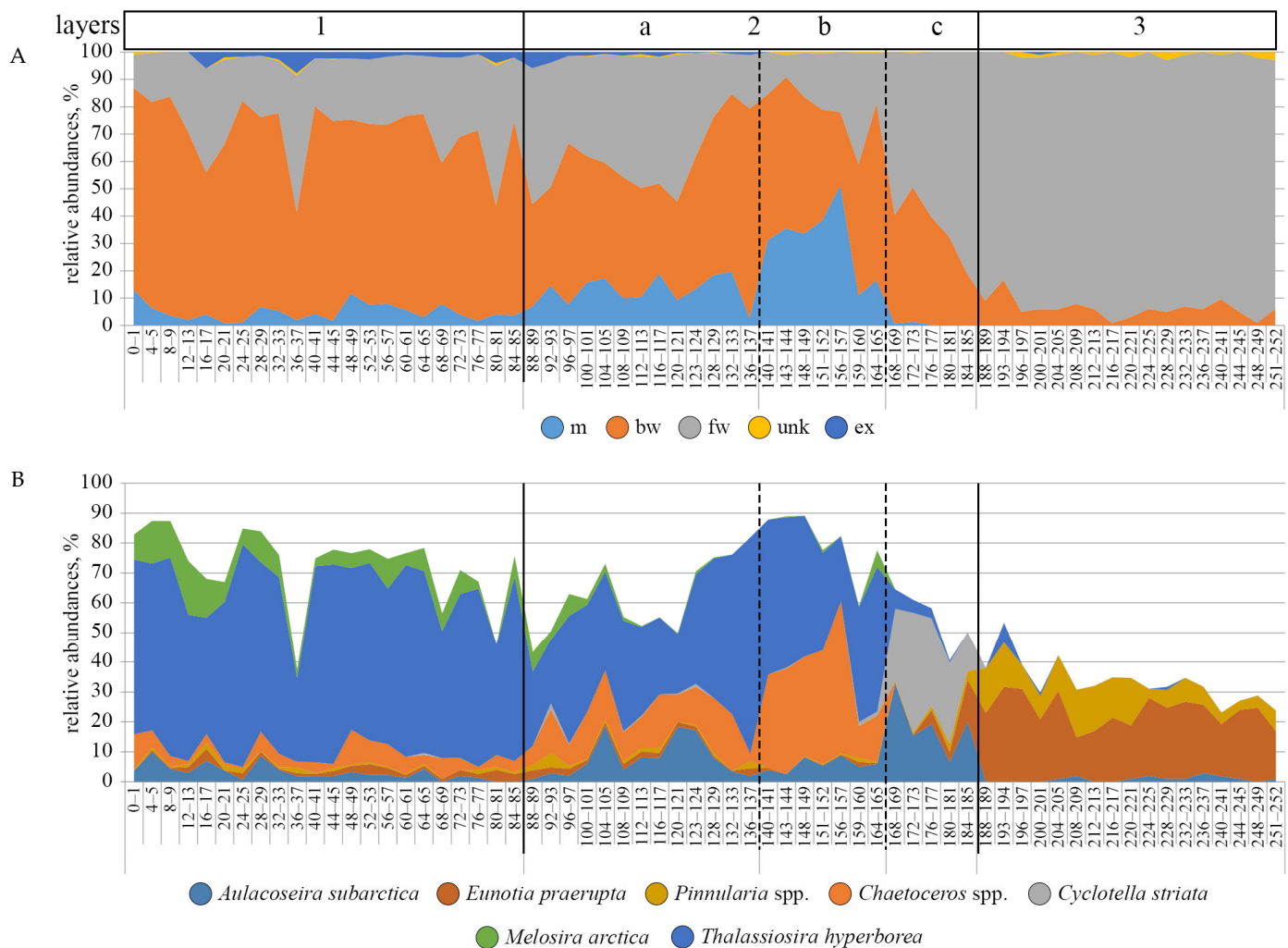


Figure 3. (A) The ecological groups in diatom assemblages. m—marine; bw—brackish water (includes euryhaline, living in both marine and fresh waters); fw—freshwater; unk—unknown ecology and biogeography; ex—extinct. (B) The dominant and subdominant diatom species.

Assemblage *Thalassiosira hyperborea*-*Chaetoceros* (interval 168–140 cm) is characterized by the highest concentration of diatoms in the core ($0.1\text{--}0.68 \times 10^6$ valves/g), an increase in species richness (10 species), and a sharp increase in the abundance (11.3–51.1%) of marine species. The species richness (66 species) and abundance (9.1–22.6%) of freshwater species are significantly decreased (Figure 3A). Brackish water species (11 taxa) become the dominant group (26.9–64%). The dominant species is *Thalassiosira hyperborea* (21.6–52%). The subdominant species are spores of marine planktonic species of the genus *Chaetoceros* (10.7–51.1%), including *Ch. diadema* and *Ch. mitra*, which are indicators of highly productive shelf waters (Figure 3B). These species predominate in modern sediments of the southeastern LS [5,6,17]. Among the marine species, the presence of ice-neritic species *Craspedopleura kryophila*, endemic to the circumpolar Arctic [89], *Pauliella taeniata* and *Porosira glacialis*, a bipolar species inhabiting cold coastal waters adjacent to sea ice [90], and the arcto-boreal species *Bacterosira bathyomphala* should be noted. The brackish water planktonic–benthic species *Thalassiosira baltica*, *Melosira arctica*, and *M. lineata* are also characteristic species of this assemblage (Figure 5). In general, brackish water species predominate in the assemblage (26.9–64%), while marine species are subdominant (11.3–51.1%); the number of freshwater species drops sharply (9.1–22.6%), with the exception of the 160–159 cm interval, where their number remains significant (41.3%). Among freshwater species, planktonic

and planktonic–benthic species are distinguished by high numbers (4.9–25.7%); benthic diatoms, distinguished by species diversity (38 species), make up 1.6–15.7%.

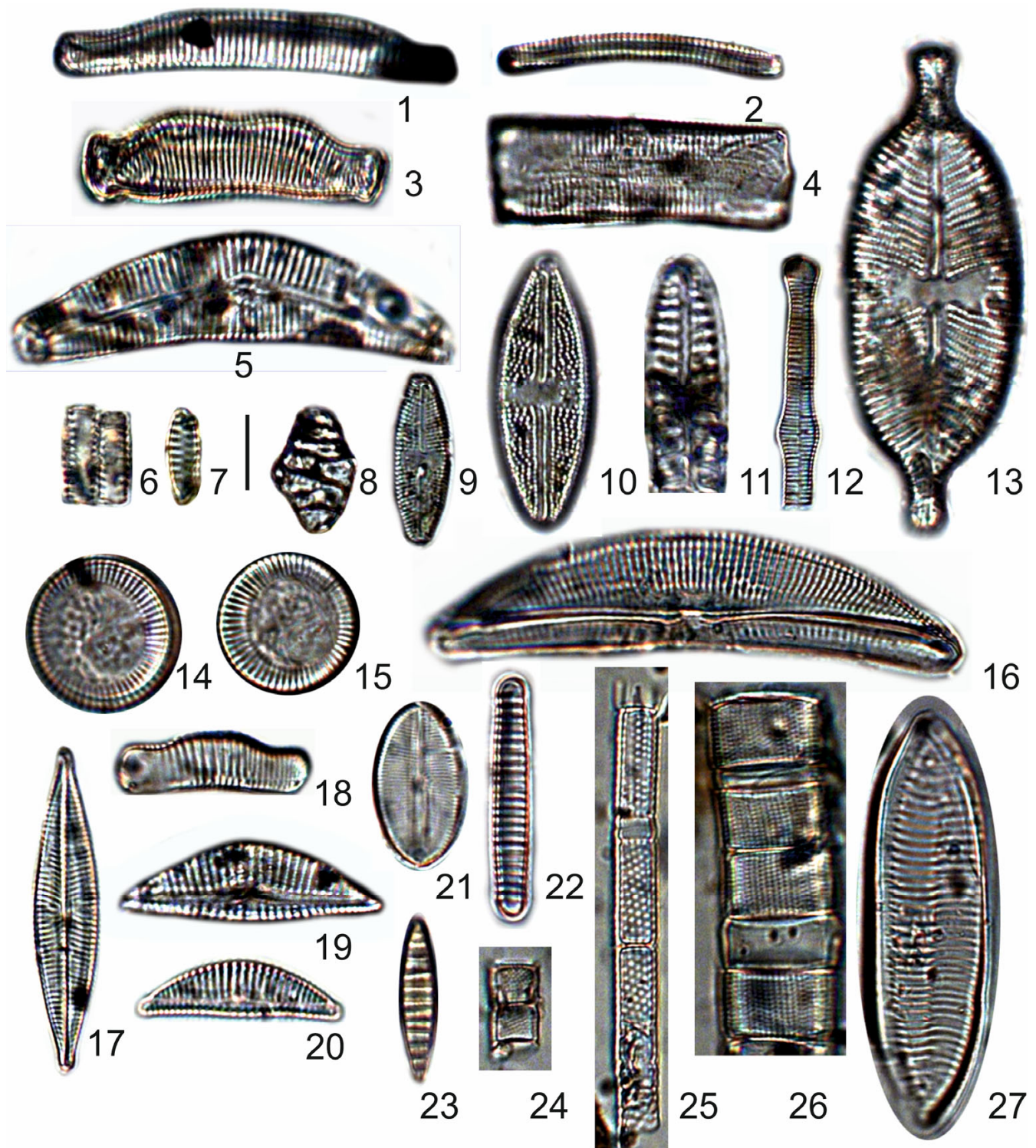


Figure 4. Diatoms of Assemblages 1 (1–13) and 2 (14–27). 1—*Eunotia praerupta*; 2, 4—*E. valida*; 3—*E. bidens*; 5—*Cymbella neocistula*; 6,7—*Staurosirella pinnata*; 8—*Tetracyclus strumosus*; 9—*Luticola arctica*; 10—*L. mutica*; 11—*Pinnularia borealis*; 12—*Tabellaria fenestrata*; 13—*Placoneis amphibola*; 14, 15—*Cyclotella striata*; 16—*Amphora ovalis*; 17—*Navicula cryptocephala*; 18—*Eunotia curtagrunowii*; 19—*Encyonema ventricosum*; 20—*E. silesiacum*; 21—*Diploneis littoralis* var. *arctica*; 22—*Diatoma tenuis*; 23—*D. moniliformis*; 24—*Aulacoseira subarctica*; 25—*A. granulata*; 26—*A. islandica*; 27—*Tryblionella levidensis*. Scale bar is 10 μ m.

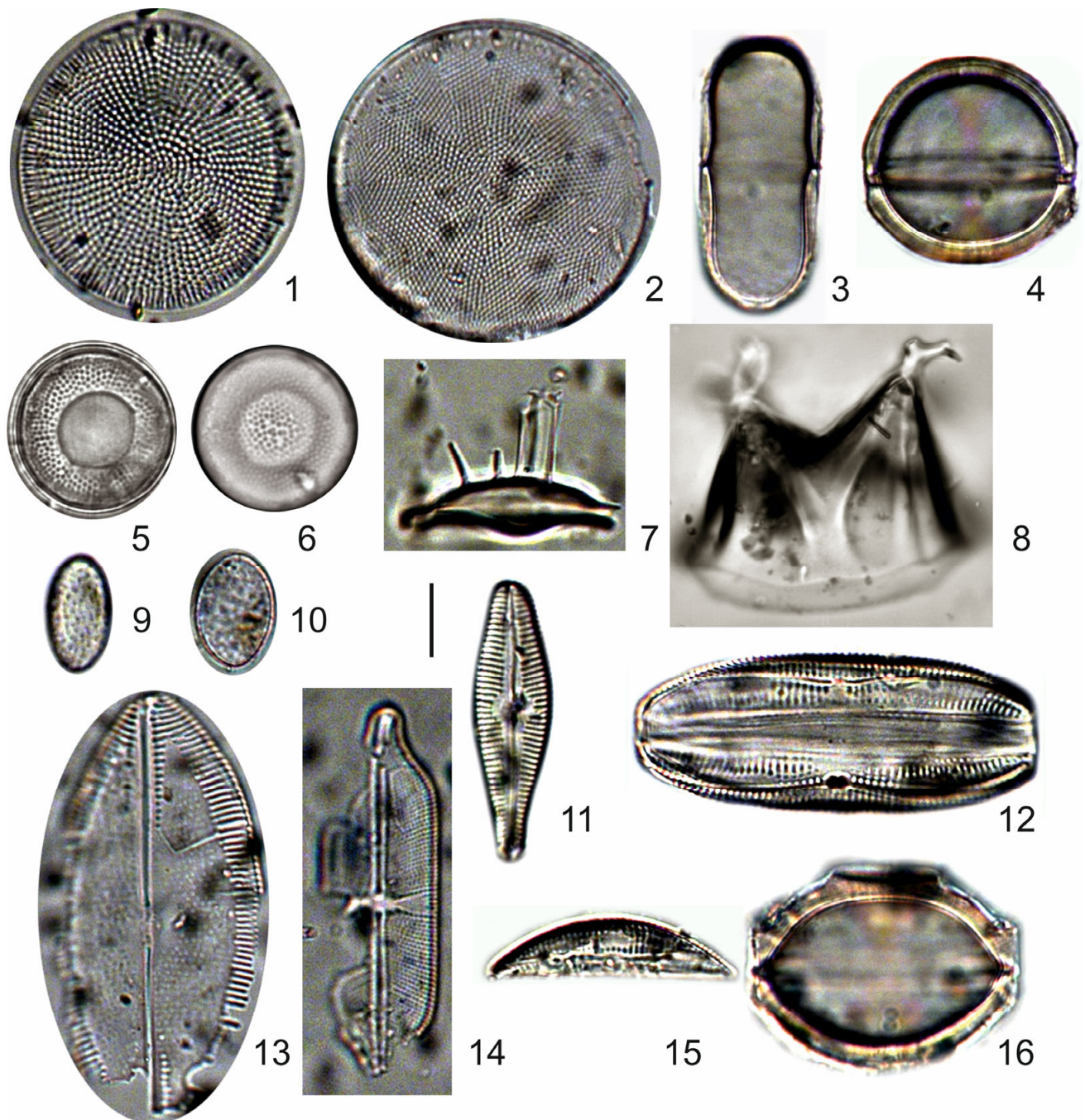


Figure 5. Diatoms of Assemblages 3 (1–11, 13, 14), 4 (12, 15), and 5 (16). 1—*Thalassiosira hyperborea*; 2—*Th. baltica*; 3—*Melosira lineata*; 4—*M. arctica*; 5, 6—*Bacterosira bathyomphala*; 7—*Chaetoceros diadema*; 8—*Ch. mitra*; 9, 10—*Chaetoceros* spp.; 11—*Gomphonema ventricosum*; 12—*Amphora proteus*; 13—*Craspedopleura kryophila*; 14—*Stauroneis siberica*; 15—*Amphora copulata*; 16—*Melosira moniliformis* var. *octogona*. Scale bar is 10 μ m.

Assemblage *Thalassiosira hyperborea*-*Aulacoseira* (interval 140–88 cm) differs from the previous one by a decrease in the concentration of diatoms in sediments ($0.004\text{--}0.27 \times 10^6$ valves/g) and a sharp expansion of the species composition (133 species), mainly due to freshwater species (106 species), which become subdominant (14.7–50.3%). Based on habitat, freshwater species are represented by an approximately equal number of benthic, planktonic, and planktonic–benthic species. Brackish water species dominate (32.2–76.7%), represented by 15 species; the abundance of marine species (8 species) decreases (2.6–19.7%) (Figure 3A). As in the previous assemblage, the species *Thalassiosira*

hyperborea dominates (20–72.5%), but the number of *Aulacoseira* species increases (2.9–26.6%). This assemblage is characterized by the brackish water planktonic–benthic species *Thalassiosira baltica* (0.3–11.5%), *Melosira lineata* (1–5.3%), and *M. arctica* (0–7.3%). A permanent element of the assemblage is the extinct Miocene species *Alveolophora robusta*, previously noted in the Holocene sediments of the LS in Buor-Khaya Bay [22]. Marine diatoms are represented by the species *Porosira glacialis*, *Pinnularia quadratarea* var. *bicontracta*, *Navicula valida*, and *Nitzschia polaris*, which are common in recent and Holocene sediments of the eastern Arctic Seas [14,17]. The oceanic species *Thalassiosira eccentrica* is noted in this interval. Assemblage 4 is similar in taxonomic composition and ecological structure to the diatom assemblages from the surface sediments of Buor-Khaya Bay, including the presence of the extinct species *Alveolophora robusta*.

Assemblage *Thalassiosira hyperborea*–*Aulacoseira*–*Melosira arctica* (interval 88–0 cm) is characterized by a low diatom content in sediments ($0.01\text{--}0.072 \times 10^6$ valves/g) and the highest species richness (150 species) of diatoms, most of which are freshwater (105 species). The species *Thalassiosira hyperborea* still dominates (27.9–74.7%); species of the freshwater genus *Aulacoseira* subdominate (4.6–27.9%); while the abundance of the ice-neritic species *Melosira arctica* increases (up to 18%), accumulating on the upper and lower surfaces of drift ice in the Arctic Basin [91–93]. A permanent component of assemblage 5 is the freshwater planktonic species *Lindavia costata*, common in the water bodies of the Lena Delta Natural Reserve [66] and recorded in the surface sediments of the LS in the zone of influence of the Lena River runoff [17]. The characteristic of this assemblage is the presence of marine endemic arctic-boreal ice-neritic species *Bacterosira bathyomphala*, *Detonula confervacea*, and *Porosira glacialis*, and the oceanic species *Rhizosolenia hebetata*, typical of the Pacific diatom flora. Brackish water and euryhaline diatoms (18 species) dominate (39.4–81.3%), while freshwater species subdominate (12.2–51%), among which planktonic and planktonic–benthic species prevail (up to 38%). The number of freshwater species sharply increases in the intervals of 36–37 cm and 80–81 cm to 50% and 51%, respectively, potentially indicating short-term increases in the influence of river waters at these intervals. Marine diatoms, the species composition of which is significantly expanded (20 species) in this interval, make up 0.9–13.1%. The assemblage is characterized by a significant amount (up to 7.7%) of the freshwater species *Alveolophora robusta*, which became extinct in the Miocene, and the marine species *Porosira punctata*, which is mainly typical of the Upper Miocene marine sediments of the Arctic coast of Chukotka, Northern Siberia [4].

4.3.2. Testate Amoebae Assemblages

Testate amoebae (Protozoa: Testacea; testaceans) are single-celled organisms in which the cell is enclosed within an external shell (testa). Some taxa in this group are covered by exogenous mineral particles (xenosomes), plant detritus, or endogenous inputs (idiosomes), such as silica platelets or, less commonly, phosphates [27]. They live in a wide variety of terrestrial and aquatic environments, including wetlands, lakes, salt marshes [94], and, less commonly, desalinated marine basins [95]. The ecological preferences of this group of assemblages and the good security of natural resources in peat and lake sediments allow them to be used for the reconstruction of environmental changes [96,97].

Testacean communities were found in the lower part of core LV83-32 in nine intervals from 245 to 143 cm (Supplementary Material S3). Preservation of the amoebae testes in the sediments is variable, mostly good, which allows for their taxonomic identification. The content in the studied sediments is extremely low. The most representative species diversity is noted in the intervals 245–244 cm (5 species) and 221–220 cm (8 species).

The testacean assemblage is represented by eurybiont, hydrophilic, calciophilic, sphagnophilic, and hydromorphic-soil species. The general taxonomic composition in-

cludes 15 species: *Cyclopyxis kahli*, *Cyclopyxis* cf. *eurystoma*, *Cyclopyxis* sp. 1, *Cyclopyxis* sp. 2, *Cyclopyxis* sp. 3, *Cyclopyxis* sp. 4, *Diffugia* cf. *globulus* var. *cashii*, *Diffugia* cf. *microstoma*, *Diffugia bryophila*, *Diffugia* cf. *globularis*, *Diffugia oblonga*, *Cylindrifiugia hiraethogii*, *Centropyxis* cf. *plagiostoma*, *Centropyxis sylvatica*, *Centropyxis* (?), the question mark refers to the preservation of the shells does not allow for a full identification of the species. It is accepted micropaleontological practice to put a ? sign if the species is in question) sp. (Figures 6 and 7). The most common are hydrophilic species of the genera *Diffugia* and *Cylindrifiugia*, which are active planktonic forms in freshwater basins, as well as sphagnophilic hydromorphic soil and calciphilic species of the genera *Centropyxis* and *Cyclopyxis*.

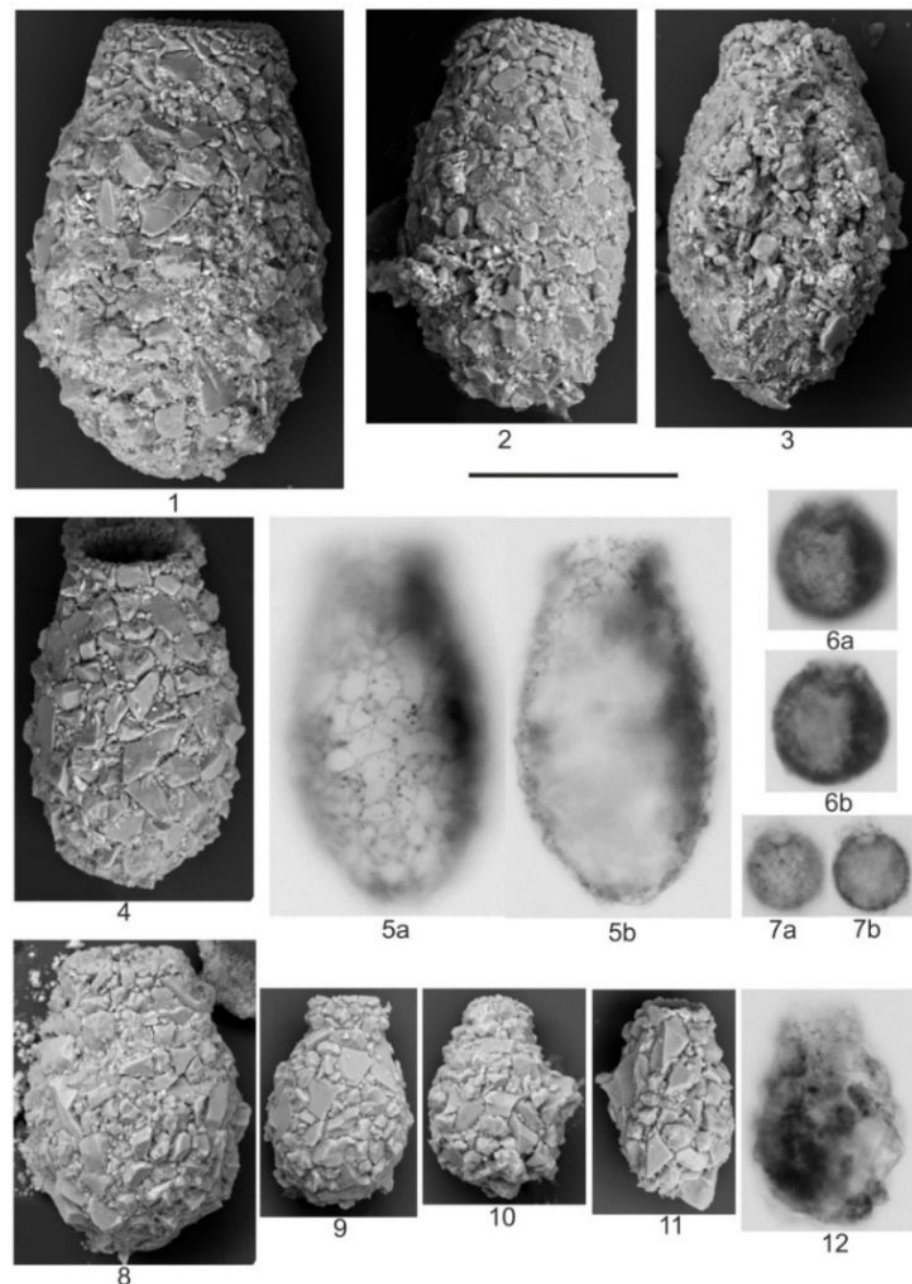


Figure 6. Hydrophilic testate amoebae in core LV83-32. 1—*Cylindrifiugia hiraethogii*; 2, 3—*Cylindrifiugia* cf. *hiraethogii*; 4, 5—*Diffugia oblonga*; 6—*Diffugia* cf. *microstoma*; 7—*Diffugia* cf. *globulus* var. *cashii*; 8—*Diffugia* cf. *globularis*; 9–12—*Diffugia bryophila*. 1, 7, 11 (244–245 cm); 2–5, 8, 10 (220–221 cm); 6, 12 (164–165 cm); 9 (148–149 cm). Scale bar is 100 μ m.

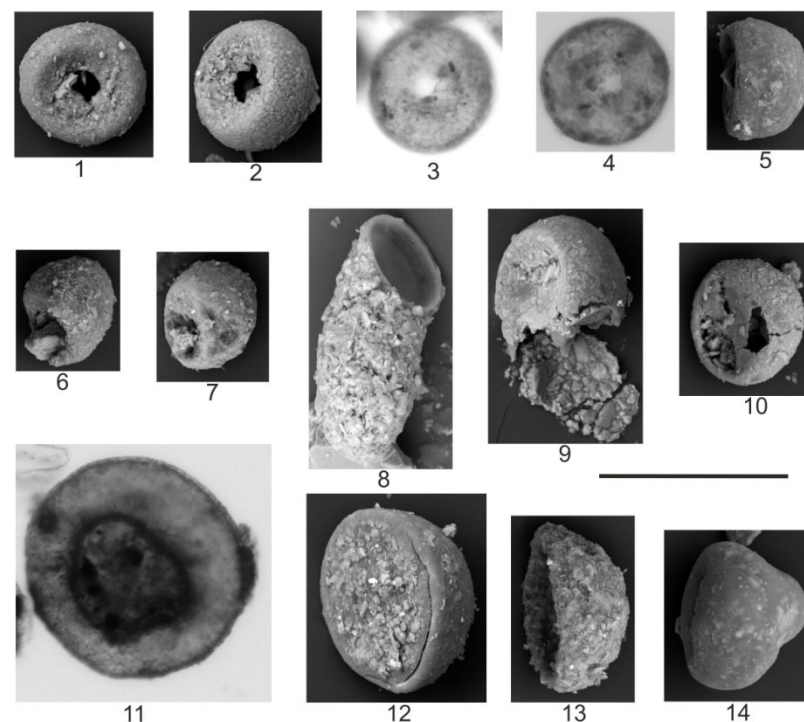


Figure 7. Calceophilic, sphagnophilic, and hydromorphic soil testate amoebae in core LV83-32. 1–4—*Cyclopyxis kahli*; 5—*Cyclopyxis* cf. *eurystoma*; 6, 7—*Centropyxis sylvatica*; 8—*Centropyxis* (?) sp.; 9, 10—*Centropyxis* cf. *plagiostoma*; 11—*Cyclopyxis* (?) sp. 1; 12—*Cyclopyxis* (?) sp. 2; 13—*Cyclopyxis* (?) sp. 3; 14—*Cyclopyxis* (?) sp. 4. 7, 13 (244–245 cm); 1, 6, 9, 10, 12 (220–221 cm); 2, 5, 14 (172–173 cm); 3, 11 (159–160 cm); 8 (148–149 cm); 4 (143–144 cm). Scale bar is 100 μ m.

Analysis of the testacean assemblage revealed some peculiarities in their distribution in the core sediments. Species of the genera *Diffugia*, *Cylindriiflugia*, and *Centropyxis* were found in the lower part of the core in three intervals from 245 to 220 cm. The exception is the species *Diffugia* cf. *microstoma*, one specimen of which was found in the interval 165–164 cm, and the species *Centropyxis* (?) sp., found in the interval 149–148 cm. Species of the genus *Cyclopyxis* are mainly distributed in four intervals from 189 to 143 cm, and were also found singly in the interval 221–220 cm. Among them, the most common is the calciphilic soil species *Cyclopyxis kahli*. Species of the genus *Cyclopyxis* are typical of wet soils, mosses, and sphagnum, and also indicate mesotrophic nutrient supply [70,98]. Thus, based on the differences in the taxonomic composition of the testacean in the lower part of core LV83-32, two assemblages can be distinguished (Supplementary Material S3):

Diffugia-*Cylindriiflugia*-*Centropyxis* assemblage (interval 245–220 cm) includes hydrophilic–sphagnophilic species; *Cyclopyxis kahli* assemblage (interval 189–143 cm) includes hydrophilic soil species.

It should be noted that the species *Cyclopyxis kahli*, *Cyclopyxis* sp. 2, and *Cyclopyxis* sp. 3 are found singly in the intervals 245–244 cm and 221–220 cm. Considering the significant differences in the taxonomic composition of these assemblages, as well as their separation by an “empty” interval of 25 cm, we assume that sediments including these assemblages were formed in different environments.

4.3.3. Tintinnid Assemblages

The order Tintinnida (Protozoa: Ciliates) is a group of solitary planktonic ciliates characterized by the presence of hyaline or agglutinated loricae (shells) [99]. Most of the species in this group live in sea waters. Some species may occur in inland benthic

habitats but are not benthic [100–102]. Tintinnid loricae are highly visible after fossilization, allowing their use as indicators of environmental and hydrographic changes [103].

Loricae of two species of tintinnids, *Tintinnopsis ventricosoides* and *Stenosemella nivalis*, were previously found in the upper part of core LV83-32 at intervals 61–60 cm, 37–36 cm, 29–28 cm, and 5–0 cm [42]. Additional study of the core yielded new information.

The most diverse taxonomic composition of tintinnids (5 species) is contained mainly in the middle part of the core in the interval 185–128 cm (Supplementary Material S3). The taxonomic composition includes *Tintinnopsis fimbriata*, *T. ventricosoides*, *Tintinnopsis turbo*, *Tintinnopsis* cf. *parvula*, and *S. nivalis* (Figure 8). The highest number of tintinnids (19 loricae per sample) was found in the interval 149–148 cm, while in other intervals, their number did not exceed 1–7 loricae per sample. The listed species, except *T. cf. parvula*, were previously identified in surface sediments of the LS and the East Siberian Sea [42].

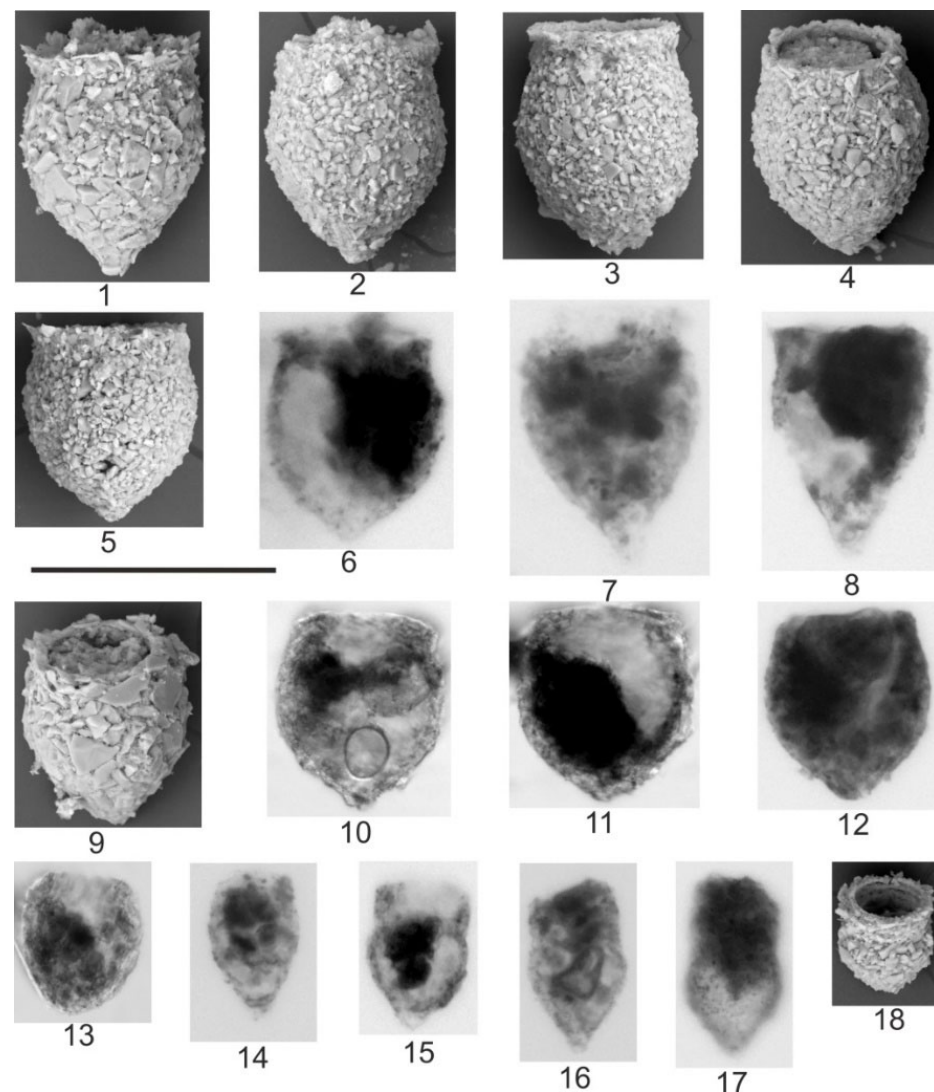


Figure 8. Agglutinated tintinnid loricae in core LV83-32. 1–8—*Tintinnopsis fimbriata*; 9–12—*Tintinnopsis ventricosoides*; 13—*Stenosemella* cf. *nivalis*; 14—*Tintinnopsis* cf. *parvula*; 15–18—*Tintinnopsis turbo*. 6, 7 (172–173 cm); 14 (159–160 cm); 16 (156–157 cm); 1–5, 8, 9, 12, 18 (148–149 cm); 17 (143–144 cm); 15 (140–141 cm); 11, 13 (36–37 cm); 10 (4–5 cm). Scale bar is 100 μ m.

All identified tintinnid species live in brackish water and inhabit coastal, mainly mesohaline waters and estuaries [31,39,104–108]. *Tintinnopsis fimbriata* was found in the 185–128 cm interval, with the highest number of specimens (11 loricae) in the 149–148 cm

interval. After a long “empty” interval, one specimen was found in the surface layer at 1–0 cm. Burkovsky [33] also found this species in plankton samples from the LS. *Tintinnopsis ventricosoides* occurs singly in the intervals 149–128 cm, 61–60 cm, 29–28 cm, and 5–0 cm. *Tintinnopsis turbo* was found in the intervals 173–168 cm and 157–143 cm. *Tintinnopsis* cf. *parvula* was encountered singly in the intervals 173–172 cm and 160–159 cm. This species was identified in the sediments of the studied core for the first time and has not been previously found in the LS. *Stenosemella nivalis* was found singly in the intervals 177–176 cm, 144–143 cm, and 5–0 cm. Thus, two assemblages can be distinguished (Supplementary Material S3) based on the presence of tintinnid ciliate loricae in the sediments of core LV83-32.

Tintinnopsis fimbriata assemblage (interval 185–128 cm) is characterized by small numbers and low species diversity (5 species) of tintinnids. There are brackish water species that inhabit coastal waters and estuaries, tolerating a wide range of water salinities and temperatures. *Tintinnopsis ventricosoides* assemblage (interval 61–0 cm) is characterized by extremely small numbers and poor species diversity (3 species) of tintinnids. There are species that inhabit the coastal brackish waters of the Arctic and subarctic regions, as well as in temperate latitudes.

The extremely low content of tintinnids and the large number of “empty” intervals were probably due to the destruction of their loricae under the influence of active hydrodynamic processes.

5. Discussion

5.1. Sedimentary Environments

The data obtained for sediment composition and diatom assemblages allow us to provide a more substantiated description of the conditions of the studied sediment formation. In addition to the diatom assemblages, the main proxies were the grain-size composition of sediments, carbon isotope, and the distribution of biogenic and redox-sensitive elements.

In our case, the most important indicator of changes in paleoconditions is variations in the salinity of the waters in which sedimentation occurred. For this purpose, the Br/TOC index was used, reflecting changes in the content of marine planktogenic organic matter in sediments, which accumulates bromine from seawater [109,110]. This index accurately reflects the different salinities of the aquatic environment during the accumulation of layers 1, 2, and 3 (Figure 2). In addition, the data for the isotopic composition of carbon in the organic matter of sediments ($\delta^{13}\text{C}_{\text{TOC}}$) indicate significant differences in water salinity during the accumulation of layers 2 and 3 (Figure 2). The $\delta^{13}\text{C}_{\text{TOC}}$ values established for layer 3 are less than -28‰ , which corresponds to the upper soil layer on permafrost ($-28.2 \pm 1.96\text{‰}$) and are significantly lower than that of the carbon from the ice complex (yedoma) (-26.3‰) [111,112].

Accordingly, the organic matter of the sediments of layer 3 is exclusively terrigenous. Based on the variations in Br/TOC and the isotopic composition of carbon, and taking into account the almost exclusively freshwater species composition of diatoms and testate amoebae (Figure 2), it can be concluded that the lower part of the core (below 190 cm) was formed in freshwater basins. In the upper part of the core, the $\delta^{13}\text{C}_{\text{TOC}}$ values are close to -24‰ , which is close to the values for marine planktogenic carbon ($-24 \pm 3.0\text{‰}$) used in the calculations for the East Siberian Sea [78,111]. The sharp variability in Br/TOC at the boundary of layers 1 and 2 (Figure 2) is probably determined by the relative increase in the accumulation of marine planktogenic carbon that occurred during the period (3.2–7.2 ka) when the ice-eroded sediment layer was accumulating. The boundary between layers 1 and 2 is also clearly distinguished by the parameters used in the grain-size distribution. The decrease in the content of clay ($<4\text{ }\mu\text{m}$) fractions of sediment and the increase in the content

of sand ($>63\ \mu\text{m}$) may be a consequence of the change from the low-dynamic conditions of the coastal lowland to the highly dynamic settings of shallow marine waters. The same contrasting change in the grain-size distribution of sediments, but with a transition to less dynamic conditions, is manifested at the boundary between layers 2 and 3 (Figure 2). The contrast in this transition is due to the loss of the sedimentary layer that had been accumulating for four thousand years, during which there was a gradual decrease in sea depth (Figure 2), the coastline moved away, and the influence of river runoff decreased [75]. The boundary between layers 2 and 3 is also clearly expressed by variations in Zr/Rb (Figure 2). This indicator reflects the content of sand fractions that accumulate zirconium minerals [18,55].

Redox-sensitive elements have been increasingly used in recent years to reconstruct the redox conditions of sedimentation environments. In this work, the molybdenum modulus Mo/Mn (Figure 2) is used to assess variations in the redox conditions of bottom waters; values greater than 0.02 indicate anoxic conditions in bottom waters during sediment accumulation [113]. According to this indicator, oxide conditions prevailed, and anoxic conditions could exist in certain periods of the accumulation of layer 2. High iron and arsenic contents (Figure 2) also indicate oxide conditions in bottom waters.

The contents of biogenic elements (Ca, Sr, TOC, Br) are often used as indicators of the bioproductivity of aquatic ecosystems [21,50,78,114]. In our case, Ca, Sr, and Br can, to some extent, serve as indicators of the productivity of marine phyto- and zooplankton. The total organic carbon of sediments includes a certain amount of ancient carbon entering the sea with river runoff and during the abrasion of yedoma on the coast [50,78,109]. Nevertheless, the distribution of TOC in marine sediments of core LV83-32 shows a correlation with the bromine content (Figure 2), which indicates a relatively low content of terrigenous TOC. Its comparatively high contents in continental sediments of layer 1 cannot be an indicator of high bioproductivity.

Using the presented sedimentological proxies and the results of microfossil analysis (Chapter 4.3), it is possible to substantiate the conditions at different stages of sediment accumulation in core LV83-32.

Layer 1 differs sharply in the sediment composition and microfossil assemblages from the overlying sediments and was not exposed by core LV83-32-3 (Appendix A, Figure A1), obtained at the same station. It lacks carbonate biogenic remains but has an increased content of organic carbon with minimal $\delta^{13}\text{C}_{\text{TOC}}$ (terrigenous) values, as well as minimal Br/TOC values. Based on the above characteristics and taking into account the age (Figure 2, Appendix A, Figure A1), these deposits can be classified as freshwater, formed in relatively stagnant conditions within a coastal lake. The exception is the layered sediments of the 196–228 cm horizon (Figure 2), which were probably formed by the episodic introduction of coarser sediment into the lake by the river.

Layer 2 is characterized by very high variability in the sediment composition and microfossil assemblages. According to the Br/TOC, $\delta^{13}\text{C}_{\text{TOC}}$ values, taking into account the age, the sediments can be classified as marine, formed in the mixing zone of sea and river waters. According to geochemical features, this layer can be divided into three sublayers.

Sublayer 2a is characterized by relatively low contents of diatoms, TOC, Mn, and Fe, with increased $\delta^{13}\text{C}_{\text{TOC}}$ and Mo/Mn ratio, which may indicate anoxic sedimentation conditions [113]. It can be assumed that sediment formation occurred in estuarine or lagoonal conditions.

Sublayer 2b differs by sharply increased and anomalous high contents of TOC, Br, Mn, Fe, and diatoms (Figures 2 and 9), with low Mo/Mn values. Values of $\delta^{13}\text{C}_{\text{TOC}}$ are relatively low and variable. This indicates that sedimentation occurred in the mixing zone of river

and sea waters under oxidizing conditions, with the supply of biogens and elements (Fe) by river waters activating bioproductivity [82,115].

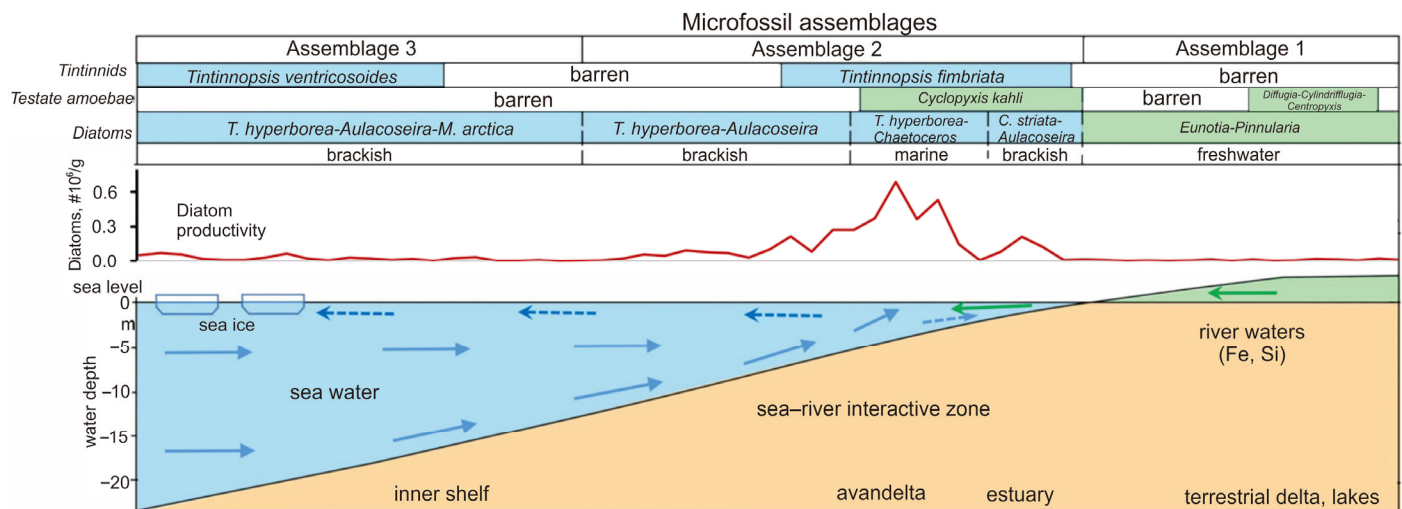


Figure 9. A model of the distribution of various diatom, tintinnid, and testate amoebae assemblages in bottom sediments of the estuarine shallow shelf of the LS.

Sublayer 2c is characterized by increased sand, strontium, Zr/Rb, and Mo/Mn values (Figure 2). The TOC, Br, Fe, Mn, and diatom contents are relatively low and gradually decrease toward the upper layer, while the $\delta^{13}\text{C}_{\text{TOC}}$ value gradually increases. This indicates that sediments accumulated on the outer part of the mixing zone of sea and river waters with a gradual increase in sea depth.

Layer 3 accumulated on the ice- or iceberg-eroded surface of *Sublayer 2c*. Its sediments are distinguished by a gradual increase in marine biogenic proxies (TOC, Br, Br/TOC, $\delta^{13}\text{C}_{\text{TOC}}$) toward the surface. This, as well as the microfossil assemblages, indicates that the sediments accumulated under conditions similar to those of the present day (inner shelf), with a gradual decrease in the role of river runoff. Its contact with the underlying sediments of *sublayer 2c* is sharply contrasting, clearly expressed in the contents of Sr, Fe, Zr, Br, Zn, grain-size fractions (Figure 2), as well as in color parameters (Appendix A, Figure A2, Supplementary Material S1), which is determined by the removal of the lower part of the layer as a result of ice erosion.

5.2. Microfossil Assemblages as a Proxy for Paleoenvironments

Three main environmental assemblages of microfossils are distinguished in the studied sediments of core LV83-32, reflecting the phases of the natural environment changes during the Holocene transgression in the land–sea transition zone with a significant influence of river runoff. The limits of their distribution are generally determined by the spatial and temporal boundaries of the previously identified sediment layers (Figure 2). The chronological boundaries of these layers, unfortunately, are rather arbitrary due to insufficient dating frequency, but the sequence of their replacement is obvious.

Assemblage 1 (Layer 1, interval 252–188 cm) accumulated at the beginning of the Holocene or earlier under lacustrine or deltaic conditions (Figure 9). This is indicated by the diatom assemblage that formed in freshwater, low-streaming water bodies overgrown with bryophytes and aquatic plants and surrounded by sphagnum bogs. Such water bodies were widespread in the Quaternary on the continental shelf of the Yana-Indigirka Lowland [116]. In addition, this assemblage includes sphagnophilic and hydrophilic species of testate amoebae (*Diffugia-Cylindroflugia-Centropixys*), living in shallow freshwater bodies of water with stagnant or slowly flowing water, mainly in an acidic environment

surrounded by sphagnum bogs (Figure 9). They indicate conditions typical of the lake phases of the Holocene evolution and modern bog ecosystems [28,117]. Almost all the species we discovered were found in the Pleistocene–Holocene deposits of the Bykovsky Peninsula [26,27], Cape Mamontov Klyk (near the Lena River delta) [28], and near the town of Tiksi [29]. One specimen of the species *C. kahli* was found in the interval 221–220 m. According to Bobrov et al. [27], the species *C. kahli*, first discovered in the high-latitude Arctic sediments of the Bykovsky Peninsula, is an indirect indication of a soil environment that is warmer than it is currently. In the area of Cape Mamontov Klyk [28] at the beginning of the Holocene (9480 ± 40 years), the testacean population was typical of meso-oligotrophic bogs, and the environmental conditions were humid and warm. The joint presence of the calciphilic species *C. plagiostoma* and *C. kahli* in the interval 221–220 m may indicate a slightly alkaline and neutral soil environment [28].

Assemblage 2 (Layer 2, interval 188–88 cm), presumably formed 9.2–7.2 thousand years ago, includes microfossil assemblages 2a and 2b.

Assemblage 2a is characterized by diatoms, testate amoebae, and the appearance of tintinnids. Diatoms are represented by the *Cyclotella striata*–*Aulacoseira* and *Thalassiosira hyperborea*–*Chaetoceros* assemblages (Figure 9). Assemblage 2a is subdominated by the freshwater species *Aulacoseira subarctica* and other species of this genus, which is typical of modern waters [118] and surface and Holocene sediments in the LS in the influence zone of the Lena River runoff [5,6,22]. The increase in the number of *Aulacoseira* species in continental waters is associated with warming, which leads to a reduction in the duration of freeze-up and an increase in the duration of open water [119]. The appearance of marine species and the subdominance of brackish water diatom species indicate an increased influence of marine waters. Assemblage 2b is characterized by the maximum concentration of diatoms in sediments and a high number of spores of the genus *Chaetoceros* and indicates high water productivity, typical of the estuaries of large Siberian rivers [82]. A high content of *Chaetoceros* is usually observed in waters enriched in iron and biogenic elements [115]. Sediments probably accumulated under more marine conditions than currently prevail in this area. This is evidenced by the richness and dominance of brackish water and marine species. In terms of taxonomic composition and ecological structure, it is close to the diatom complexes from the surface sediments of the Buor-Khaya Bay [17,22].

The microfauna is represented by brackish water species of tintinnids (from the genera *Tintinnopsis* and *Stenosemella*) and freshwater testate amoebae. Among tintinnids, cosmopolitan species (*T. fimbriata* and *T. turbo*) predominate, inhabiting coastal brackish waters (mainly in estuaries, sometimes in upwelling zones) and withstanding a wide range of water salinity and temperature [31,39,104,106,120]. Among testate amoebae, species of the genus *Cyclopyxis* are common, typical of wet soils, mosses, and sphagnum, indicating mesotrophic nutrient supply [70,98]. The community is dominated by *C. kahli*, which prefers coarse-grained sediments and warm soil environments [27]. Finds of freshwater testate amoebae in estuarine and deltaic sediments can be explained by their removal with riverine suspended matter and abrasion of coastal sediments. However, it is possible that these amoebae, found together with marine and brackish water diatoms and tintinnids, are more tolerant of salinity and may inhabit freshened marine waters [95]. Geochemical data also indicate estuarine or lagoonal sedimentation conditions.

Microfossil assemblage 2b is characterized by the disappearance of microfauna and includes the brackish water diatom assemblage *Thalassiosira hyperborea*–*Aulacoseira*, which is characterized by a decrease in diatom concentrations in the sediments and an expansion in the species composition and abundance of freshwater diatoms. Thus, the microfossil assemblages show that the accumulation of layer 2 sediments occurred first in estuarine or lagoonal conditions, and then in more seaward, relatively highly productive waters,

with a change in the influence of river runoff. Judging by the sharp fluctuations in $\delta^{13}\text{C}_{\text{TOC}}$ (Figure 2), during the period of accumulation of these sediments, periods of almost complete desalination occurred due to the movement of the river mouth or an increase in its runoff.

Assemblage 3 (Layer 3, interval 88–0 cm) characterizes sediments presumably formed over the period from 3.2 thousand years ago to the present on the inner shelf with depths close to modern ones (Figure 2) and under the significant influence of the fresh water of the Yana and Lena rivers. Similar conditions were probably characteristic of the greater part of the sedimentary layer accumulated 3.2–7.2 thousand years ago, but removed from the section as a result of ice erosion. These sediments are characterized by a low content of diatoms and a mixed assemblage with a predominance of planktonic brackish water (*Thalassiosira hyperborea*), freshwater (*Aulacoseira* spp.), and marine (*Melosira arctica*) species, which are common in surface sediments of the southern LS [5,6,10,17]. The presence of a significant amount of the extinct freshwater species *Alveolophora robusta* in this assemblage, the source of which is Miocene continental sediments [17,22], probably indicates an increase in the Lena River runoff during the period under consideration. Another extinct marine species, *Porosira punctata*, noted in this assemblage is typical of the Upper Miocene marine sediments of the Arctic coast of Chukotka and Northern Siberia [4], likely resulting from erosion, which was probably redeposited in LS sediments. The low content of diatoms in this assemblage is probably associated with a long-term ice cover, which is confirmed by the predominance of fine-grained sediments in this interval (0–88 cm). The microfauna is characterized by low numbers and poor species diversity of tintinnids, with *T. ventricosoides* dominating. The distribution and ecology of this species are poorly studied. It was found in marine and brackish waters and estuaries of the Barents, Baltic, Yellow Seas [30,106–108], and Narragansett Bay (Rhode Island, Atlantic) [105]. A successive change in microfossil assemblages from estuarine to modern, caused by rising sea levels and shelf flooding, was also observed in the middle and outer shelf areas of the Laptev Sea for other microfossil groups [20,121–124].

In the studied sediments of the Laptev Sea shelf off the Yana River mouth, near the modern sea/land boundary, a sequence of changes in paleoenvironments was established during the Holocene, occurring in three stages.

The first stage (early Holocene and earlier) was characterized by a terrestrial, periglacial environment. Sedimentation occurred in freshwater, slow-flowing reservoirs (lakes) overgrown with bryophytes and aquatic plants and surrounded by sphagnum bogs. A postglacial transgression began at this time, leading to widespread flooding of the outer Arctic shelf [125,126]. During this period, the climate in the Laptev Sea region was warmer and more humid [127]. In areas further north of the mouth of the Yana River, the conditions were estuarine and transitional, with an inner shelf [121,122]. The coastline was located further north and ran approximately along the 51 m isobath [20].

In the second stage (late early–middle Holocene, about 9.2–7.2 thousand years ago), terrestrial conditions were replaced by estuarine and/or lagoonal conditions, and then by more marine conditions, accompanied by a significant change in river runoff. The influence and productivity of marine waters increased, associated with the mixing of sea and fresh waters. Marine middle shelf conditions were established further north [121,122]. During this period, relatively warm conditions persisted in the Laptev Sea and the coast [127,128]. The progressive transgression of the sea continued, the coastline disappeared, and river runoff weakened [125,126].

During the last stage (the end of the late Holocene, the last 3.2 thousand years), sedimentation occurred on the inner shelf, with depths similar to modern ones, with a significant influence of fresh water from the Yana and Lena rivers and long-term ice cover. In the Laptev Sea, the climate became colder and close to that observed in modern

times [128], the ice cover area increased, and the boundary of drifting ice shifted to the south [129]. The change in conditions from estuarine to modern, caused by rising sea levels and shelf flooding, was also observed in the middle and outer shelf areas of the Laptev Sea, but occurred earlier [20,121–124]. The terrestrial conditions of the earliest Holocene on the Laptev Sea shelf have been established for the first time.

6. Conclusions

In the Holocene sediments of the LS shelf in the zone of influence of the Yana River runoff, a rich diatom flora, ciliates-tintinnids, and freshwater testate amoebae, discovered for the first time in shelf sediments, have been established. A sequence of changes in paleoenvironments in the Holocene was reconstructed based on the identified assemblages of microfossils, sediment composition and geochemical data.

Assemblage 1 (Layer 1), including freshwater assemblages of diatoms *Eunotia-Pinnularia* and testate amoebae *Diffugia-Cylindrodiffugia-Centropixis*, was formed at the beginning of the Holocene under terrestrial conditions in a freshwater lake basin, surrounded by sphagnum bogs. It is also confirmed by the presence of exclusively terrigenous organic matter ($\delta^{13}\text{C} < -28\text{‰}$) and low Br/TOC values

Assemblage 2 (Layer 2), characterized by the abundance and species diversity of microfossils, including diatoms (assemblages *C. striata-Aulacoseira*, *T. hyperborea-Chaetoceros*), testate amoebae (assemblage *C. kahli*), and tintinnids (assemblage *T. fimbriata*), was formed first in estuarine or lagoonal conditions, and then in more seaward, relatively highly productive waters, in the mixing zone of sea and fresh waters, with a change in the influence of river runoff. This is indicated by high TOC, Fe, Br, and Mn values, as well as the increase in diatom productivity, where the crucial value belongs to *Chaetoceros* spp., which is associated with the intensive supply of iron. The upper part of the sediments of layer 2 (the diatom assemblage *T. hyperborea-Aulacoseira*) probably accumulated in the outer part of the mixing zone of sea and river waters.

Assemblage 3 (Layer 3), including diatoms (assemblage *T. hyperborea-Aulacoseira-M. arctica*) and tintinnids (assemblage *T. ventricosoides*), was formed at a sea level position close to the modern one (inner shelf), with a gradual decrease in the role of river runoff and long-term ice cover. Key geochemical indicators, including TOC, Br, $\delta^{13}\text{C}$, Zr/Rb, and redox-sensitive elements, reveal a dynamic environment shaped by sea-level stabilization.

Thus, we have established a succession of microfossil assemblages reflecting the change in paleoenvironments from terrestrial to estuarine and then to modern ones, caused by a rise in sea level and shelf flooding. The data obtained confirm the existing models of the Holocene evolution of the Laptev Sea shelf [20,81–83], including transgression, salinity changes, and the role of river runoff, and complement them with new details, such as specific microfossil associations and geochemical markers. The identified microfossil assemblages may be useful for interpreting paleoenvironments in other Arctic seas. This emphasizes the value of an integrated approach for reconstructing paleoenvironments in the Arctic.

Supplementary Materials: The following supporting information (Supplementary Material S1. Organic carbon content and isotopes in the Core LV83-32 sediments, Supplementary Material S2. List of diatoms from Core LV83-32, their ecological and biogeographic characteristics, and abundances (%), Supplementary Material S3. Agglutinated tintinnid loricae and testate amoebae in the Core LV83-32 sediments) can be downloaded at: https://docs.google.com/spreadsheets/d/1HHvtlOc_wi2TzFW2gDo-1-TgjTIAduS/edit?usp=sharing&ouid=116334870618270057069&rtpof=true&sd=true or by request (accessed on 19 June 2025).

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Data Availability Statement: The datasets generated and/or analyzed during the current study are available in the Supplementary Information or from the corresponding author on reasonable request.

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Appendix A

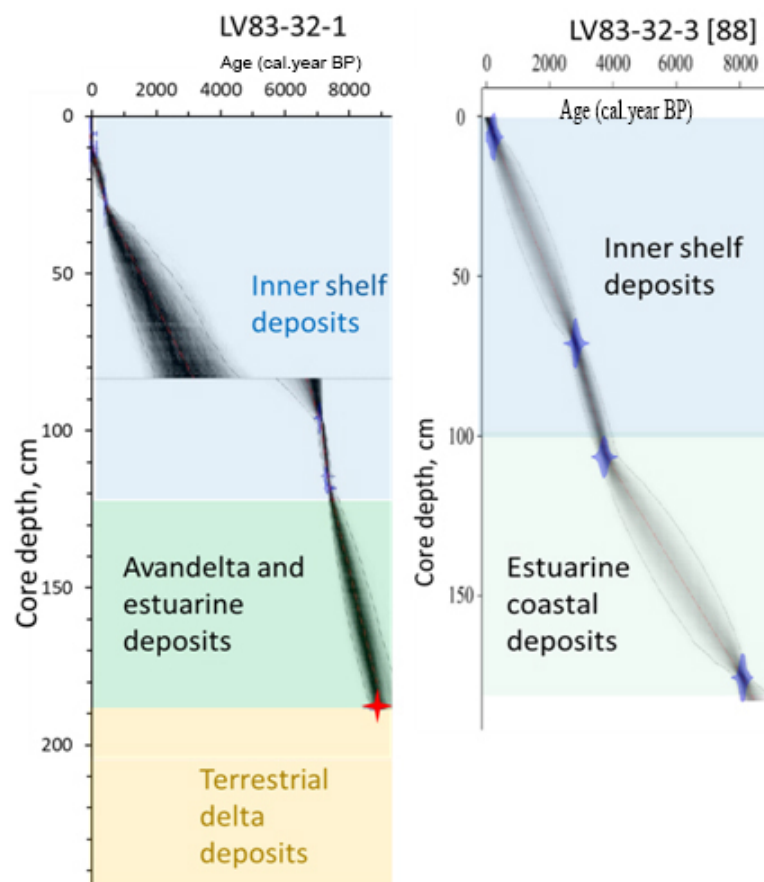


Figure A1. Comparison of age–environment models of core LV83-32 (LV83-32-1) and core LV83-32-3 [75]. The red asterisk on model LV83-32-1 shows the age marker determined by the change from continental to marine sediments.

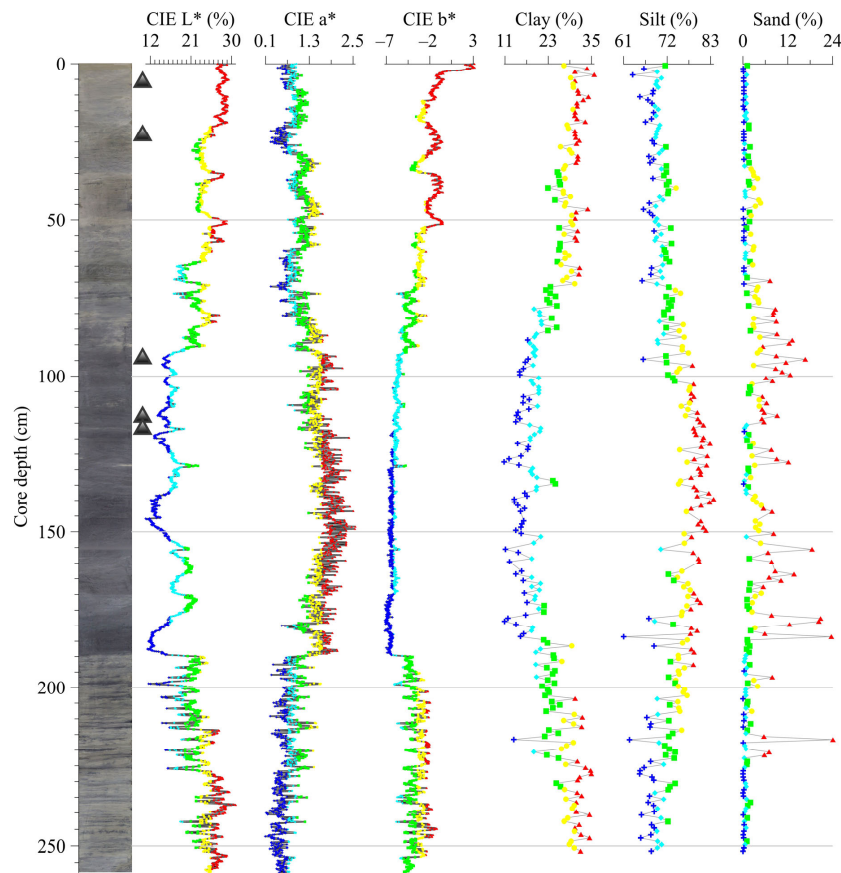


Figure A2. Photograph and distribution curves of color coordinates and granulometric fractions in core LV83-32 sediments. The colors in the distribution curves indicate elevated (red), slightly elevated (yellow), neutral (green), slightly lowered (blue), and lowered (blue) values relative to the average core value of the corresponding characteristic. Triangles indicate sampling locations for radiocarbon dating.

	L	a	b	Clay	Silt	Sand
the whole core						
$\bar{x}$	20.995	1.166	−4.200	23.8	73.1	3.1
Me	21.506	1.109	−4.187	24.3	72.4	1.5
x_{min}	10.965	0.092	−7.194	10.8	61.0	0.0
x_{max}	30.898	2.561	3.175	35.8	83.8	24.1
interval 258–188						
$\bar{x}$	23.024	0.711	−3.645	27.3	71.2	1.5
Me	23.337	0.672	−3.565	27.7	71.3	0.7
x_{min}	11.606	0.092	−6.909	13.4	62.5	0.0
x_{max}	30.898	2.071	−1.177	35.0	78.8	24.1
interval 188–88						
$\bar{x}$	16.472	1.651	−6.105	17.5	77.1	5.4
Me	16.438	1.650	−6.195	17.7	77.9	4.0
x_{min}	10.965	0.541	−7.194	10.8	61.0	0.2
x_{max}	24.029	2.561	−3.276	29.5	83.8	23.7
interval 88–0						
$\bar{x}$	24.521	0.977	−2.478	27.9	70.2	1.9
Me	24.223	0.963	−2.606	28.4	70.1	1.0
x_{min}	17.187	0.239	−5.795	19.1	63.3	0.1
x_{max}	29.382	1.795	3.175	35.8	76.3	9.1

Figure A3. Main statistical indicators for the identified lithological horizons in core LV83-32 sediments.

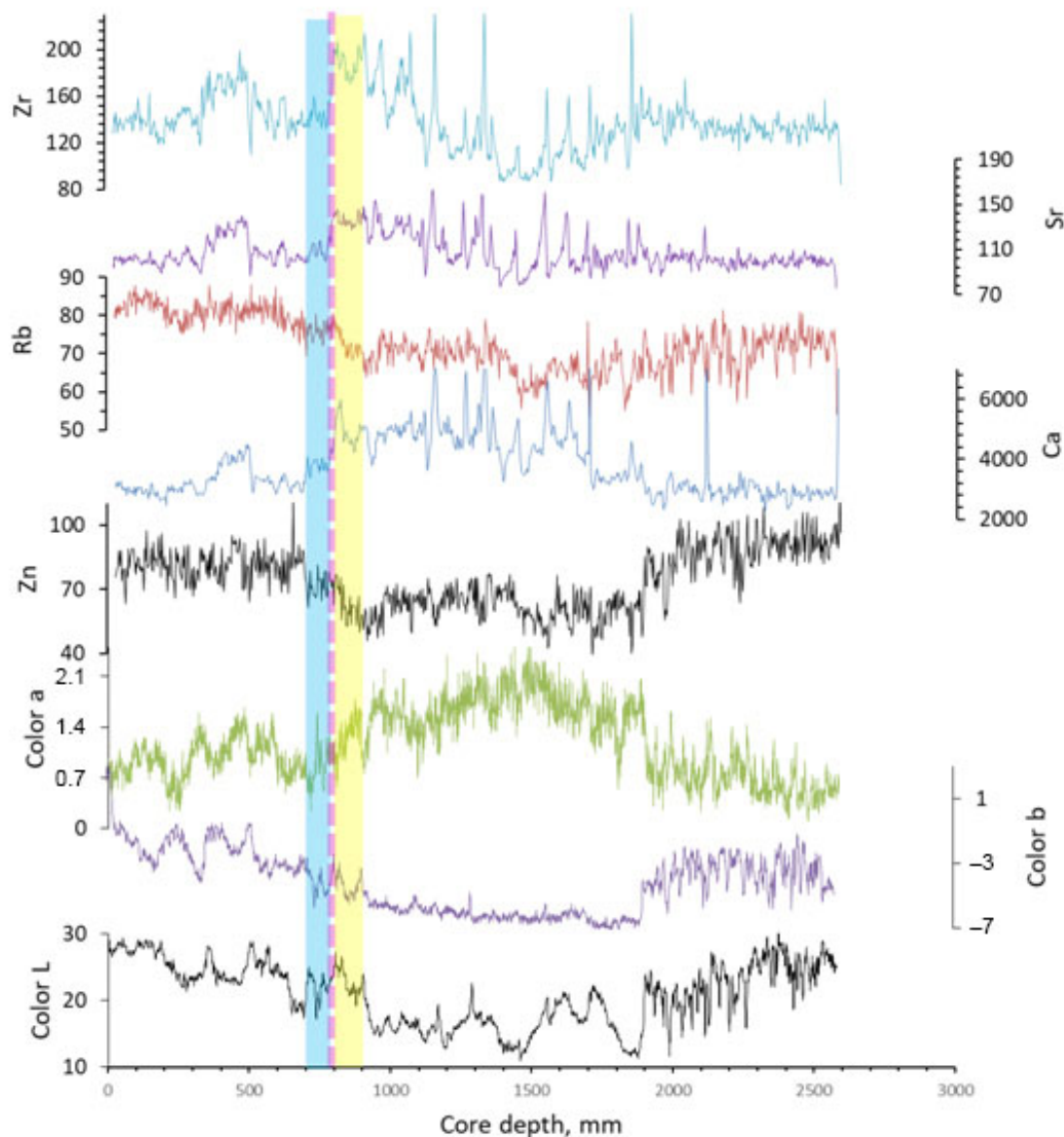


Figure A4. Reflection of hiatus by high-resolution variations in the chemical composition and color of sediments in core LV83-32 based on X-ray fluorescence scanning with a step of 3 mm and colorimetric analysis with a step of 1 mm. The pink dashed line shows the contact of the underlying and overlying sediments, the yellow fill shows the layer of underlying sediments that changed their properties, color, content of redox-sensitive elements (Zn) upon contact with sea water; the blue fill shows the layer of overlying sediments that accumulated with additional supply of material from the lateral ploughing furrow.

References

1. Gukov, A.U. The Great Siberian polynya, XXI century. *Sci. Technol. Yakutia* **2009**, *1*, 99–103. (In Russian)
2. Lobkovskii, L.I.; Nikiforov, S.L.; Shakhovab, N.E.; Semiletov, I.P.; Libina, N.V.; Anan'ev, R.A.; Dmitrevskii, N.N. Mechanisms Responsible for Degradation of Submarine Permafrost on the Eastern Arctic Shelf of Russia. *Dokl. Earth Sci.* **2013**, *449*, 280–283. [\[CrossRef\]](#)
3. Nikiforov, S.L.; Ananiev, R.A.; Libina, N.V.; Dmitrievskiy, N.N.; Lobkovskii, L.I. Ice gouging on Russia's Arctic shelf. *Oceanology* **2019**, *59*, 422–424. [\[CrossRef\]](#)
4. Polyakova, Y.I. *The Eurasian Arctic Seas During the Late Cenozoic*; Scientific World: Moscow, Russia, 1997. (In Russian)
5. Cremer, H. Diatoms in the Laptev Sea (Arctic Ocean): Taxonomy and biogeographic distribution. *Ber. Polarforsch.* **1998**, *260*, 222.
6. Cremer, H. Distribution patterns of diatom surface sediment assemblages in the Laptev Sea (Arctic Ocean). *Mar. Micropaleontol.* **1999**, *38*, 39–67. [\[CrossRef\]](#)

7. Polyakova, Y.I.; Stein, R. Holocene paleoenvironmental implications of diatom and organic carbon records from the southeastern Kara Sea (Siberian Margin). *Quat. Res.* **2004**, *62*, 256–266. [\[CrossRef\]](#)
8. Mukhina, V.V.; Yushina, I.G. Diatoms in bottom sediments of the Laptev and Kara seas. *Ber. Polarforsch.* **1999**, *306*, 110–119.
9. Jiang, H.; Seidenkrantz, M.S.; Knudsen, K.L.; Eiríksson, J. Diatom surface sediment assemblages around Iceland and their relationships to oceanic environmental variables. *Mar. Micropaleontol.* **2001**, *41*, 73–96. [\[CrossRef\]](#)
10. Obrezkova, M.S.; Kolesnik, A.N.; Semiletov, I.P. The Diatom Distribution in the Surface Sediments of the Eastern Arctic Seas of Russia. *Russ. J. Mar. Biol.* **2014**, *40*, 465–472. [\[CrossRef\]](#)
11. Astakhov, A.S.; Bosin, A.A.; Kolesnik, A.N.; Obrezkova, M.S. Sediment geochemistry and diatom distribution in the Chukchi Sea: Application for bioproductivity and paleocenography. *Oceanography* **2015**, *28*, 190–201. [\[CrossRef\]](#)
12. Polyakova, Y.I.; Novichkova, Y.A.; Lisitzin, A.P.; Shevchenko, V.P.; Kravchishina, M.D. Diatoms and aquatic palynomorphs in surface sediments of the White Sea Bays as indicators of sedimentation in marginal filters of rivers. *Oceanology* **2016**, *56*, 289–300. [\[CrossRef\]](#)
13. Polyakova, Y.I.; Agafonova, E.; Novichkova, E.; de Vernal, A. Holocene Paleoenvironmental Implications of Diatom, Non-Pollen Palynomorph, and Organic Carbon Records from the Kandalaksha Bay of the White Sea (European Arctic). *Geosciences* **2023**, *13*, 56. [\[CrossRef\]](#)
14. Tsoy, I.B.; Obrezkova, M.S. *Atlas of Diatom Algae and Silicoflagellates from Holocene Sediments of the Russian East Arctic Seas*; POI FEB RAS: Vladivostok, Russia, 2017. (In Russian)
15. Miettinen, A. Diatoms in Arctic regions: Potential tools to decipher environmental changes. *Polar Sci.* **2018**, *18*, 220–226. [\[CrossRef\]](#)
16. Obrezkova, M.S.; Pospelova, V.; Kolesnik, A.N. Diatom and dinoflagellate cyst distribution in surface sediments of the Chukchi Sea in relation to the upper water masses. *Mar. Micropaleontol.* **2023**, *178*, 102184. [\[CrossRef\]](#)
17. Obrezkova, M.S.; Tsoy, I.B.; Kolyada, A.E.; Shi, X.; Liu, Y. Distribution of Diatoms in the Surface Sediments of the Seas of Eastern Siberia and the Arctic Ocean Distribution of diatoms in seafloor surface sediments of the Laptev, East Siberian, and Chukchi seas: Implication for environmental reconstructions. *Polar Biol.* **2023**, *46*, 21–34. [\[CrossRef\]](#)
18. Astakhov, A.S.; Babich, V.V.; Shi, X.; Hu, L.; Obrezkova, M.S.; Aksentov, K.I.; Alatorsev, A.V.; Darin, A.V.; A Kalugin, I.; Karnaukh, V.N.; et al. Climate and Ice conditions of East Siberian Sea during Holocene: Reconstructions based on sedimentary geochemical multiproxy. *Holocene* **2023**, *33*, 3–13. [\[CrossRef\]](#)
19. Bauch, H.A.; Polyakova, Y.I. Diatom-inferred salinity records from the Arctic Siberian margin: Implications for fluvial runoff patterns during the Holocene. *Palaeoclimatol. Palaeoecol.* **2003**, *18*, 501–510. [\[CrossRef\]](#)
20. Polyakova, Y.I.; Bauch, H.A.; Klyuvitkina, T.S. Early to Middle Holocene changes in Laptev Sea water masses deduced from diatom and aquatic palynomorph assemblages. *Glob. Planet. Change* **2005**, *48*, 208–222. [\[CrossRef\]](#)
21. Matul, A.G.; Khusid, T.A.; Mukhina, V.V.; Chekhovskaya, M.P.; Safarova, S.A. Recent and Late Holocene environments on the southeastern shelf of the Laptev Sea as inferred from microfossil data. *Oceanology* **2007**, *47*, 80–90. [\[CrossRef\]](#)
22. Obrezkova, M.S.; Tsoy, I.B.; Semiletov, I.P.; Vagina, N.K.; Karnaukh, V.N.; Dudarev, O.V. Micropaleontological assessment of sediments from Buor-Khaya Bay (Laptev Sea). *Quat. Int.* **2019**, *508*, 60–69. [\[CrossRef\]](#)
23. Scourfield, D.J. Contributions to the non-marine fauna of Spitzbergen: I. Preliminary note and reports on the Rhizopoda. *Proc. Zool. Soc. Lond.* **1897**, *45*, 784–792. [\[CrossRef\]](#)
24. Beyens, L.; Chardez, D.; Van de Vijver, B. A contribution to the protist-diversity in the polar regions: Testate amoebae date from the Russian Arctic. In *Topics in Ecology. Structure and Function in Plants and Ecosystems*; Ceulemans, R., Bogaert, J., Deckmyn, G., Nijs, I., Eds.; University of Antwerpen: Wilrijk, Belgium, 2000; pp. 101–110.
25. Komarov, A.A.; Mazei, Y.A. Testate amoebae in tundra biotopes of South Chukotka. *Izv. Penz. Gos. Pedagog. Univ.* **2010**, *17*, 45–50.
26. Bobrov, A.A.; Siegert, C.; Andreev, A.A.; Schirrmeister, L. Testaceans (Protozoa: Testacea) in Quaternary permafrost sediments of Bykovsky Peninsula, Arctic Yakutia. *Biol. Bull. Russ. Acad. Sci.* **2003**, *30*, 191–206. [\[CrossRef\]](#)
27. Bobrov, A.A.; Andreev, A.A.; Schirrmeister, L.; Siegert, C. Testate amoebae (Protozoa: *Testacealobosea* and *Testaceafilosea*) as bioindicators in the Late Quaternary deposits of the Bykovsky Peninsula, Laptev Sea, Russia. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2004**, *209*, 165–181. [\[CrossRef\]](#)
28. Bobrov, A.A.; Müller, S.; Schirrmeister, L.; Andreev, A.A. Testate amoebae in Late Quaternary sediments of the Cape Mamontov Klyk (Yakutia). *Biol. Bull.* **2009**, *36*, 363–372. [\[CrossRef\]](#)
29. Schirrmeister, L.; Bobrov, A.A.; Andreev, A.A. Recent shell-bearing amoebae (tecamoebae) from Tiksi area, 2002—Surface or near-surface samples from different landscapes around Tiksi during an expedition in 2002 [dataset]. *PANGAEA* **2024**. [\[CrossRef\]](#)
30. Meunier, A. *Microplankton des Mers de Barents et de Kara. Duc d'Orléans. Campagne arctique de 1907*; Imprimerie Scientifique Charles Bulens: Bruxelles, Brussels, 1910.
31. Echols, R.J.; Fowler, G.A. Agglutinated tintinnid loricae from some Recent and Late Pleistocene shelf sediments. *Micropaleontology* **1973**, *19*, 431–443. [\[CrossRef\]](#)

32. Jensen, F.; Hansen, B.W. Ciliates and heterotrophic dinoflagellates in the marginal ice zone of the central Barents Sea during spring. *J. Mar. Biol. Assoc. UK* **2000**, *80*, 45–54. [\[CrossRef\]](#)
33. Burkovsky, I.V. New data on tintinnids (*Tintinida*, *Ciliata*) of the Arctic and revision of the fauna. *Zool. Zhurnal* **1976**, *55*, 325–336. (In Russian)
34. Mironova, E.I.; Telesh, I.V.; Skarlato, S.O. Planktonic Ciliates of the Baltic sea (a review). *Inland. Water Biol.* **2009**, *2*, 13–24. [\[CrossRef\]](#)
35. Strom, S.L.; Fredrickson, K.A. Intense stratification leads to phytoplankton nutrient limitation and reduced microzooplankton grazing in the southeastern Bering Sea. *Deep Sea Res. Part II Top. Stud. Oceanogr.* **2008**, *55*, 1761–1774. [\[CrossRef\]](#)
36. Sherr, E.B.; Sherr, B.F.; Hartz, A.J. Microzooplankton grazing impact in the Western Arctic Ocean. *Deep Sea Res. Part II Top. Stud. Oceanogr.* **2009**, *56*, 1264–1273. [\[CrossRef\]](#)
37. Nelson, R.J.; Ashjian, C.J.; Bluhm, B.; Conlan, K.E.; Gradinger, R.R.; Grebmeier, J.M.; Hill, V.J.; Hopcroft, R.R.; Hunt, B.P.V.; Joo, H.M.; et al. *Biodiversity and biogeography of the lower trophic taxa of the Pacific Arctic region: Sensitivities to climate change* In *The Pacific Arctic Region: Ecosystem Status and Trends in a Rapidly Changing Environment*; Grebmeier, J.M., Maslowski, W., Eds.; Springer: Dordrecht, The Netherlands, 2014; pp. 269–336.
38. Meunier, A. Microplankton de la mer Flamande: Les Tintinnides. *Mémoires du Musée Royal d'Histoire Naturelle de Belgique* **1919**, *8*, 1–59.
39. Agatha, S. Redescription of the tintinnid ciliate *Tintinnopsis fimbriata* Meunier, 1919 (*Spirotricha*, *Choreotrichida*) from coastal waters of Northern Germany. *Denisia* **2008**, *23*, 261–272. [\[PubMed\]](#)
40. Braarud, T.; Gaarder, K.R.; Nordli, O. Seasonal changes at various points off the Norwegian west coast. 1958. *Fiskeridir. Skr. Ser. Havunders.* **1985**, *12*, 1–77.
41. Feng, M.; Zhang, W.; Xiao, T. Spatial and temporal distribution of tintinnid (*Ciliophora*: *Tintinnida*) communities in Kongsfjorden, Svalbard (Arctic), during summer. *Polar Biol.* **2014**, *37*, 291–296. [\[CrossRef\]](#)
42. Vasilenko, L.; Vasilenko, Y.; Bosin, A.; Tsoy, I.; Shi, X.; Liu, Y. Distribution of radiolarians and tintinnid ciliates in Upper Holocene sediments of Laptev and East Siberian Seas. *Polar Biol.* **2023**, *46*, 35–51. [\[CrossRef\]](#)
43. Holmes, M.L.; Creager, Y.S. Holocene history of the Laptev Sea Continental shelf. In *Marine Geology and Oceanography of the Arctic Seas*; Herman, Y., Ed.; Springer: Berlin/Heidelberg, Germany, 1974; pp. 211–229. [\[CrossRef\]](#)
44. Dmitrenko, I.A.; Holemann, J.A.; Kirillov, S.A.; Berezovskaya, S.L.; Kassens, H. Role of barotropic sea level changes in current formation on the eastern shelf of the Laptev Sea. *Dokl. Earth Sci.* **2001**, *377*, 243–249.
45. Timokhov, L.A. Regional characteristics of the Laptev and the East Siberian Seas: Climate, topography, ice phases, thermohaline regime, circulation. *Ber. Polarforsch.* **1994**, *144*, 15–31.
46. Borodachev, V.A.; Borodachev, V.E. Laptev Sea ice extent in Arctic Climate fluctuation conditions. *Arct. Antarct. Res.* **2016**, *3*, 60–73. (In Russian)
47. Astakhov, A.S.; Aksentov, K.I.; Babich, V.V.; Darin, A.V.; Kalugin, I.A.; Melgunov, M.M.; Hu, L.; Shi, X.; Sattarova, V.V. Ice Coverage of the Laptev Sea and air temperature variation During Recent Centuries: Observed Data and Reconstructions Using a Geochemical Proxy. *Curr. Chin. Sci.* **2022**, *2*, 198–212. [\[CrossRef\]](#)
48. Bauch, D.; Hölemann, J.A.; Dmitrenko, I.A.; Janout, M.A.; Nikulina, A.; Kirillov, S.A.; Krumpfen, T.; Kassens, H.; Timokhov, L. Impact of Siberian coastal polynyas on shelf-derived Arctic Ocean halocline waters. *J. Geophys. Res.* **2012**, *117*, C00G12. [\[CrossRef\]](#)
49. Arctic Monitoring and Assessment Programme (AMAP). AMAP Assessment Report: Arctic Pollution Issues [online]. Oslo, Norway. 1998. Available online: <http://hdl.handle.net/11374/924> (accessed on 5 April 2025).
50. Dudarev, O.V.; Charkin, A.I.; Shakhova, N.E.; Mazurov, A.K.; Semiletov, I.P. *Modern Litho-Morphogenesis on the Eastern Arctic Shelf of Russia*; Polytechnic University: Tomsk, Russia, 2016. (In Russian)
51. Dmitrenko, I.A.; Kirillov, S.A.; Eicken, H.; Markova, N. Wind-driven summer surface hydrography of the Eastern Siberian shelf. *Geophys. Res. Lett.* **2005**, *32*, L14613. [\[CrossRef\]](#)
52. Osadchiv, A.; Frey, D.; Spivak, E.; Shchuka, S.; Tilinina, N.; Semiletov, I. Structure and Inter-Annual Variability of the Freshened Surface Layer in the Laptev and East-Siberian Seas During Ice-Free Periods. *Front. Mar. Sci.* **2021**, *8*, 735011. [\[CrossRef\]](#)
53. Gordeev, V.V.; Sidorov, I.S. Concentrations of major elements and their outflow into the Laptev Sea by the Lena River. *Mar. Chem.* **1993**, *43*, 33–45. [\[CrossRef\]](#)
54. Rachold, V.; Alabyan, A.; Hubberten, H.W.; Korotaev, V.N.; Zaitsev, A.A. Sediment transport to the Laptev Sea—hydrology and geochemistry of the Lena River. *Polar Res.* **1996**, *15*, 183–196. [\[CrossRef\]](#)
55. Behrends, M.; Hoops, E.; Peregovich, B. Distribution Patterns of Heavy Minerals in Siberian Rivers, the Laptev Sea and the Eastern Arctic Ocean: An Approach to Identify Sources, Transport and Pathways of Terrigenous Matter. In *Land-Ocean Systems in the Siberian Arctic: Dynamics and History*; Kassens, H., Bauch, H.A., Dmitrenko, I., Eicken, H., Hubberten, H.W., Melles, M., Thiede, J., Timokhov, L., Eds.; Springer: Berlin/Heidelberg, Germany, 1999; pp. 265–286. [\[CrossRef\]](#)

56. Osadchiev, A.; Adamovskaya, P.; Myslenkov, S.; Dudarev, O.; Semiletov, I. Satellite-Based Evaluation of Submarine Permafrost Erosion at Shallow Offshore Areas in the Laptev Sea. *Remote Sens.* **2023**, *15*, 5065. [CrossRef]
57. Charkin, A.N.; van der Loeff, M.; Shakhova, N.E.; Gustafsson, Ö.; Dudarev, O.V.; Cherepnev, M.S.; Salyuk, A.N.; Koshurnikov, A.V.; Spivak, E.A.; Gunar, A.Y.; et al. Discovery and characterization of submarine groundwater discharge in the Siberian Arctic seas: A case study in the Buor-Khaya Gulf, Laptev Sea. *Cryosph* **2017**, *11*, 2305–2327. [CrossRef]
58. Kolesnik, A.N.; Kolesnik, O.N.; Yanchenko, Y.A.; Bosin, A.A.; Vasilenko, Y.P.; Selyutin, S.A.; Vologina, Y.G. A new colorimetric apparatus for marine geology and lithostratigraphy. *Underw. Investig. Robot.* **2023**, *3*, 41–55. (In Russian)
59. Shepard, F.P. Nomenclature Based on Sand-silt-clay Ratios. *J. Sediment. Res.* **1954**, *24*, 151–158. [CrossRef]
60. Jousé, A.P.; Proschkina-Lavrenko, A.I.; Sheshukova-Poretskaya, V.S. Method of research. In *Diatoms of the USSR Fossil and Recent*; Nauka: Leningrad, Russia, 1974; Volume 1; pp. 50–79. (In Russian)
61. Chudaev, D.A.; Gololobova, M.A. *Diatom Algae of Glubokoe Lake (Moscow Region)*; Association of Scientific Publications KMK: Moscow, Russia, 2016; 447p. (In Russian)
62. Kulikovskiy, M.S.; Glushchenko, A.M.; Genkal, S.I.; Kuznetsova, I.V. *IV Identification Book of Diatoms from Russia*; Filigran: Yaroslavl, Russia, 2016. (In Russian)
63. Bahls, L.L.; Boynton, B.; Johnston, B. Atlas of diatoms (Bacillariophyta) from diverse habitats in remote regions of western Canada. *PhytoKeys* **2018**, *105*, 1–186. [CrossRef]
64. Genkal, S.I.; Gabyshev, V.A. *Catalog of Diatoms in the Wate Bodies of the Ust-Lensky Reserve and Adjacent Territories*; Nauka: Novosibirsk, Russia, 2023. (In Russian)
65. Barinova, S.S.; Bilous, O.P.; Tsarenko, P.M. *Algal Indication of Water Bodies in Ukraine: Methods and Perspectives*; University of Haifa Publisher: Haifa, Israel, 2019; Volume 2, pp. 98–99.
66. Barinova, S.; Gabyshev, V.; Gabysheva, O. Phytoplankton in the Ecological Assessment of the Mining Facilities Influence on the Anabar River in the Permafrost Zone of the Arctic, Eastern Siberia, Russia. *Land* **2023**, *12*, 1775. [CrossRef]
67. Round, F.E.; Crawford, R.M.; Mann, D.G. *The Diatoms. Biology and Morphology of the Genera*; Cambridge University Press: Cambridge, CA, USA, 1990; p. 747.
68. Gavrilova, N.A.; Dovgal, I.V. *Tintinnid Ciliates (Ciliophora, Tintinnida) of the Black Sea and the Sea of Azov*; AO Kovalevsky Institute of Biology of the Southern Seas: Sevastopol, Russia, 2019; 176p. [CrossRef]
69. Foissner, W.; Korganova, G.A. Redescription of Three Testate Amoebae (*Protozoa, Rhizopoda*) from a Caucasian Soil: *Centropyxis plagiotoma* Bonnet & Thomas, *Cyclopyxis kahli* (Deflandre) and *C. intermedia* Kufferath. *Arch. Protistenkd.* **1995**, *146*, 13–28. [CrossRef]
70. Todorov, M.; Bankov, N. *An Atlas of Sphagnum-Dwelling Testate Amoebae in Bulgaria*; Pensoft Publishers: Sofia, Bulgaria, 2019.
71. González-Miguéns, R.; Todorov, M.; Blandenier, Q.; Duckert, C.; Porfirio-Sousa, A.L.; Ribeiro, G.M.; Ramos, D.; Lahr, D.J.; Buckley, D.; Lara, E. Deconstructing Diffugia: The tangled evolution of lobose testate amoebae shells (*Amoebozoa: Arcellinida*) illustrates the importance of convergent evolution in protist phylogeny. *Mol. Phylogenetics Evol.* **2022**, *175*, 107557. [CrossRef] [PubMed]
72. Astakhov, A.S.; Shi, X.; Darin, A.V.; Kalugin, I.A.; Hu, L.; Tsoy, I.B.; Kolesnik, A.N.; Obrezkova, M.; Alatortsev, A.; Babich, V.; et al. Reconstructing ice conditions in the southern Chukchi Sea during the last millennium based on chemical composition of sediments and diatom assemblages. *Mar. Geol.* **2020**, *427*, 106220. [CrossRef]
73. Nieuwenhuize, J.; Maas, Y.E.M.; Middelburg, J.J. Rapid analysis of organic carbon and nitrogen in particulate materials. *Mar. Chem.* **1994**, *45*, 217–224. [CrossRef]
74. Bauch, H.A.; Mueller-Lupp, T.; Taldenkova, E.; Spielhagen, R.; Kassens, H.; Grootes, P.; Thiede, J.; Heinemeier, J.; Petryashov, V. Chronology of the Holocene transgression at the North Siberian margin. *Glob. Planet. Change* **2001**, *31*, 125–139. [CrossRef]
75. Li, Q.; Qiao, S.; Shi, X.; Hu, L.; Yu, Y.; Bosin, A.; Vasilenko, Y.; Feng, H.; Dong, J.; Jin, L.; et al. Sedimentary record of sea ice rafting in the Laptev Sea during the Holocene: Evidence from the improved ice rafting debris (IRD) proxy. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2025**, *660*, 112667. [CrossRef]
76. Blaauw, M.; Christeny, J.A. Flexible paleoclimate age-depth models using an autoregressive gamma process. *Bayesian Anal.* **2011**, *6*, 457–474. [CrossRef]
77. R Development Core Team. *A Language and Environment for Statistical Computing*; R Foundation for Statistic Computing: Vienna, Austria, 2018; Available online: <https://www.R-project.org> (accessed on 28 June 2025).
78. Keskitalo, K.; Tesi, T.; Bröder, L.; Andersson, A.; Pearce, C.; Sköld, M.; Semiletov, I.P.; Dudarev, O.V.; Gustafsson, Ö. Sources and characteristics of terrestrial carbon in Holocene-scale sediments of the East Siberian Sea. *Clim. Past.* **2017**, *13*, 1213–1226. [CrossRef]
79. Alatortsev, A.V.; Kolesnik, A.N.; Shi, X.; Hu, L.; Karnaukh, V.N.; Astakhov, A.S. Lithological and geochemical indicators of ice gouging: Evidences from Holocene sediments in the East Siberian Sea. *Russ. Geol. Geophys.* **2023**, *64*, 1040–1047. [CrossRef]

80. Lobkovskiy, L.I.; Nikiforov, S.L.; Dmitrevskiy, N.N.; Libina, N.V.; Semiletov, I.P.; Ananiev, R.A.; Meluzov, A.A.; Roslyakov, A.G. Mechanisms Responsible for Gas Emission and Underwater Permafrost Degradation on Laptev Sea Shelf. *Rus. J. Oceanol.* **2015**, *55*, 312–320. [\[CrossRef\]](#)
81. Bauch, H.A.; Kassens, H.; Naidina, O.D.; Kunz-Pirrung, M.; Thiede, J. Composition and Flux of Holocene Sediments on the Eastern Laptev Sea Shelf, Arctic Siberia. *Quat. Res.* **2001**, *55*, 344–351. [\[CrossRef\]](#)
82. Polyakova, Y.I.; Klyuvitkina, T.S.; Novichkova, E.A.; Bauch, H.A.; Kassens, H. Changes in the Lena River runoff during the Holocene. *Water Resour.* **2009**, *36*, 273–283. [\[CrossRef\]](#)
83. Taldenkova, E.; Bauch, H.A.; Gottschalk, J.; Nikolaev, S.; Rostovtseva, Y.; Pogodina, I.; Ovsepyan, Y.; Kandiano, E. History of ice-rafting and water mass evolution at the northern Siberian continental margin (Laptev Sea) during Late Glacial and Holocene times. *Quat. Sci. Rev.* **2010**, *29*, 3919–3935. [\[CrossRef\]](#)
84. Gleser, S.I.; Jousé, A.P.; Makarova, I.V.; Proshkina-Lavrenko, A.I.; Sheshukova-Poretzkaja, V.S. *The Diatoms of the USSR (Fossil and Recent)*; Publishing House Nauka: Leningrad, Russia, 1974; Volume 1; p. 400. (In Russian)
85. Krammer, K.; Lange-Bertalot, H. Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. In *Susswasserflora von Mitteleuropa*; Ettl, H., Gerloff, J., Heynig, H., Mollenhauer, D., Eds.; Gustav Fisher Verlag: Stuttgart, Germany, 1991; Volume 2; pp. 1–576.
86. Kociolek, J.; Spaulding, S.A. Eunotiid and Asymmetrical Naviculoid Diatoms. In *Freshwater Algae of North America*; Academic Press: London, UK, 2003; pp. 655–668.
87. Kulikovskiy, M. Species composition and morphology of the pinnate diatoms (Bacillariophyta) from the some sphagnum bogs of Russian Plain. 1. The genus Eunotia. *Bot. J.* **2007**, *92*, 1809–1817. (In Russian)
88. Razjigaeva, N.; Ganzey, L.; Grebennikova, T.; Ponomarev, V. “Cold-Dry” and “Cold-Wet” Events in the Late Holocene, Southern Russian Far East. *Climates* **2023**, *11*, 91. [\[CrossRef\]](#)
89. Poulin, M. Craspedopleura (Bacillariophyta), a new diatom genus of arctic sea assemblages. *Phycologia* **1993**, *32*, 223–233. [\[CrossRef\]](#)
90. Pike, J.; Crosta, X.; Maddison, E.J.; Stickley, C.E.; Denis, D.; Barbara, L.; Renssen, H. Observations on the relationship between the Antarctic coastal diatoms *Thalassiosira antarctica* Comber and *Porosira glacialis* (Grunow) Jørgensen and sea ice concentrations during the late Quaternary. *Mar. Micropaleontol.* **2009**, *73*, 14–25. [\[CrossRef\]](#)
91. Melnikov, I.A.; Bondarchuk, L.L. Ecology of mass aggregations of colonial diatom algae under drifting Arctic ice. *Rus. J. Oceanol.* **1987**, *27*, 317–321. (In Russian)
92. Lee, S.H.; McRoy, C.P.; Joo, H.M.; Gradinger, R.; Cui, X.; Yun, M.S.; Chung, K.H.; Kang, S.-H.; Kang, C.-K.; Choy, E.J.; et al. Holes in progressively thinning Arctic sea ice lead to new ice algae habitat. *Oceanography* **2011**, *24*, 302–308. [\[CrossRef\]](#)
93. Sapozhnikov, P.V.; Kalinina, O.Y.; Reichard, L.E.; Solovjov, B.A.; Kowan, A.; Farmer, L. Mass macrocolonies *Melosira arctica* forming on the surface of ice in the North Pole area. *J. Oceanol. Res.* **2019**, *47*, 53–61. [\[CrossRef\]](#)
94. Charman, D.J. Biostratigraphic and palaeoenvironmental applications of testate amoebae. *Quat. Sci. Rev.* **2001**, *20*, 1753–1764. [\[CrossRef\]](#)
95. Golemansky, V. Adaptations morphologiques des thecamoebiens psammobiontes du psammal supralittoral des mers. *Acta Protozool.* **1978**, *17*, 141–152.
96. Meisterfeld, R. Die horizontale und vertikale Verteilung der Testaceen (Rhizopoden Testacea) in Sphagnum. *Arch. Hydrobiol.* **1977**, *79*, 319–356.
97. Tolonen, K. Rhizopod analysis. In *Handb Holocene Palaeoecol Palaeohydrology*; Berglund, B.E., Ed.; Wiley: Chichester, UK, 1986; pp. 645–666.
98. Mazei, Y.; Tsyganov, A. *Freshwater Testate Amoebae*; KMK: Moscow, Russia, 2006. (In Russian)
99. Laval-Peuto, M. Construction of the lorica in Ciliata Tintinnina. In vivo study of Favella ehrenbergi: Variability of the phenotypes during the cycle, biology, statistics, biometry. *Protistologica* **1981**, *17*, 249–272.
100. Carey, P.G. *Marine Interstitial Ciliates: An Illustrated Key*; Chapman and Hall: London UK; New York, NY, USA, 1992. Available online: <https://books.google.fr/books?id=I5IdqNnN06wC> (accessed on 28 June 2025).
101. Jonsson, P.R.; Johansson, M.; Pierce, R.W. Attachment to suspended particles may improve foraging and reduce predation risk for tintinnid ciliates. *Limnol. Oceanogr.* **2004**, *49*, 1907–1914. [\[CrossRef\]](#)
102. Strathmann, R.R.; Grünbaum, D. Good eaters, poor swimmers: Compromises in larval form. *Integr. Comp. Biol.* **2006**, *46*, 312–322. [\[CrossRef\]](#)
103. Dolan, J.R.; Pierce, R.W. Diversity and Distributions of Tintinnids. In *The Biology and Ecology of Tintinnid Ciliates: Models for Marine Plankton*; Dolan, J.R., Montagnes, D.J.S., Agatha, S., Coats, D.W., Stoecker, D.K., Eds.; UK Wiley-Blackwell: Oxford, UK, 2013; pp. 214–243.

104. Bakker, C.; Phaff, W.J. Tintinnida from coastal waters of the S.W.-Netherlands, I. the genus *Tintinnopsis* Stein. *Hydrobiologia* **1976**, *50*, 110–111. [\[CrossRef\]](#)
105. Verity, P.G. Growth rates of natural tintinnid populations in Narragansett Bay. *Mar. Ecol. Prog.* **1986**, *29*, 117–126. [\[CrossRef\]](#)
106. Telesh, I.; Postel, L.; Heerkloss, R.; Mironova, E.; Skarlato, S. *Zooplankton of the Open Baltic Sea: Atlas*; BMB Publication No. 20; Meereswiss. Ber.: Warnemünde, Germany, 2008; Volume 73; pp. 1–251.
107. Mironova, E.; Telesh, I.; Skarlato, S. Ciliates in plankton of the Baltic Sea. *Protistology* **2014**, *8*, 81–124.
108. Zhang, Q.; Agatha, S.; Zhang, W.; Dong, J.; Yu, Y.; Jiao, N.; Gong, J. Three rDNA Loci-Based Phylogenies of Tintinnid Ciliates (*Ciliophora*, Spirotrichea, Choreotrichida). *J. Eukaryot. Microbiol.* **2017**, *64*, 226–241. [\[CrossRef\]](#) [\[PubMed\]](#)
109. Malcolm, S.J.; Price, N.B. The behaviour of iodine and bromine in estuarine surface sediments. *Mar. Chem.* **1984**, *15*, 263–271. [\[CrossRef\]](#)
110. Mayer, L.M.; Schick, L.L.; Allison, M.A.; Ruttenberg, K.C.; Bentley, S.J. Marine vs. terrigenous organic matter in Louisiana coastal sediments: The uses of bromine:organic carbon ratios. *Mar. Chem.* **2007**, *107*, 244–254. [\[CrossRef\]](#)
111. Tesi, T.; Muschitiello, F.; Smittenberg, R.H.; Jakobsson, M.; Vonk, J.E.; Hill, P.; Andersson, A.; Kirchner, N.; Noormets, R.; Dudarev, O.; et al. Massive remobilization of permafrost carbon during post-glacial warming. *Nat. Commun.* **2016**, *7*, 13653. [\[CrossRef\]](#)
112. Vonk, J.E.; Sánchez-García, L.; van Dongen, B.E.; Alling, V.; Kosmach, D.; Charkin, A.; Semiletov, I.P.; Dudarev, O.V.; Shakhova, N.; Roos, P.; et al. Activation of old carbon by erosion of coastal and subsea permafrost in Arctic Siberia. *Nature* **2012**, *489*, 137–140. [\[CrossRef\]](#)
113. Kholodov, V.N.; Nedumov, R.I. Application of the molybdenum module for reconstruction of the gas composition of water in the Cretaceous Atlantic. *Dokl. Earth Sci.* **2005**, *400*, 116–118. (In Russian)
114. Hörner, T.; Stein, R.; Fahl, K.; Birgel, D. Post-glacial variability of sea ice cover, river run-off and biological production in the western Laptev Sea (Arctic Ocean)—A high-resolution biomarker study. *Quat. Sci. Rev.* **2016**, *143*, 133–149. [\[CrossRef\]](#)
115. Ren, J.; Gersonde, R.; Esper, O.; Sancetta, C. Diatom distributions in northern North Pacific surface sediments and their relationship to modern environmental variables. *Palaeogeogr. Palaeoclim. Palaeoecol.* **2014**, *402*, 81–103. [\[CrossRef\]](#)
116. Pirumova, L.G. Diatoms of Quaternary sediments of the north of the Yana-Indigirka Lowland and Bolshoi Lyakhovsky Island. In *Fossil Diatoms of the USSR*; Nauka: Moscow, Russia, 1968; pp. 80–83. (In Russian)
117. Bobrov, A.A. Ecological and Geographical Regularities of Distribution and Structure of Shell Amoebae Community (Protozoa: Testacea). Ph.D. Thesis, Moscow State University, Moscow, Russia, 1999. (In Russian).
118. Sukhanova, I.N.; Flint, M.V.; Georgieva, E.J.; Lange, E.K.; Kravchishina, M.D.; Demidov, A.B.; Nedospasov, A.A.; Polukhin, A.A. The structure of phytoplankton communities in the eastern part of the Laptev Sea. *Oceanology* **2017**, *57*, 75–90. [\[CrossRef\]](#)
119. Palagushkina, O.V.; Wetterich, S.; Schirrmeister, L.; Nazarova, L.B. Modern and fossil diatoms of the Bolshoy Lyakhovsky Island (Novosibirsk archipelago, Siberian Arctic). *Siberian Ecol. J.* **2017**, *4*, 440–455. [\[CrossRef\]](#)
120. Agatha, S. Redescription of *Tintinnopsis parvula* Jörgensen, 1912 (*Ciliophora*: Spirotrichea: Tintinnina), Including a Novel Lorica Matrix. *Acta Protozool.* **2010**, *49*, 213–234.
121. Taldenkova, E.E.; Bauch, H.A.; Stepanova, A.Y.; Demyankov, S.; Ovsepyan, A. Last postglacial environmental evolution of the Laptev Sea shelf as reflected in molluscan, ostracodal, and foraminiferal faunas. *Glob. Planet. Change* **2005**, *48*, 223–251. [\[CrossRef\]](#)
122. Taldenkova, E.E.; Bauch, H.A.; Stepanova, A.Y.; Pogodina, I.A.; Ovsepyan, Y.S.; Simstich, J. Paleoenvironmental changes of the Laptev and Kara sea shelves during the Postglacial transgression (inferred from fossil ostracods and foraminifers). In *Sistema Morya Laptevykh i Prilegayushchikh Morei Arktiki: Sovremennoe Sostoyanie i Istoriya Razvitiya*; Moscow University Press: Moscow, Russia, 2009; pp. 384–409. (In Russian)
123. Klyuvitkina, T.S.; Polyakova, Y.I. Changes in the Paleohydrological Conditions in the Laptev Sea during the Late Pleistocene and Holocene Based on a Study of Aquatic Palynomorphs. *Oceanology* **2019**, *59*, 392–405. [\[CrossRef\]](#)
124. Rudenko, O.; Taldenkova, E.; Ovsepyan, Y.; Stepanova, A.; Bauch, H.A. A multiproxy-based reconstruction of the mid- to late Holocene paleoenvironment in the Laptev Sea off the Lena River Delta (Siberian Arctic). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2020**, *540*, 109502. [\[CrossRef\]](#)
125. Bauch, H.A.; Kassens, H.; Erlenkeuser, H.; Grootes, P.M.; Thiede, J. Depositional environment of the Laptev Sea (Arctic Siberia) during the Holocene. *Boreas* **1999**, *28*, 194–204. [\[CrossRef\]](#)
126. Darby, D.A.; Polyak, L.; Bauch, H.A. Past glacial and interglacial conditions in the Arctic Ocean and marginal seas: a review. *Prog. Oceanogr.* **2006**, *71*, 129–144. [\[CrossRef\]](#)
127. Andreev, A.A.; Schirrmeister, L.; Tarasov, P.E.; Ganopolski, A.; Brovkin, V.; Siebert, C.; Wetterich, S.; Hubberten, H.-W. Vegetation and climate history in the Laptev Sea region (Arctic Siberia) during Late Quaternary inferred from pollen records. *Quat. Sci. Rev.* **2011**, *30*, 2182–2199. [\[CrossRef\]](#)

128. Andreev, A.A.; Tarasov, P.E.; Lenz, M.; Lenz, M.M.; Scheidt, S.; Fedorov, G.B.; Wagner, B.; Melles, M. Environmental changes on the northern Taymyr Peninsula (Russian Arctic) during the last 62 ka inferred from the lacustrine pollen record. *Boreas* **2024**, *54*, 431–446. [[CrossRef](#)]
129. Averkina, N.O.; Taldenkova, E.E.; Ovsepyan, Y.S. The Holocene history of the eastern continental margin of the Laptev Sea: Lithological and micropaleontological evidence. *Mosc. Univ. Bulletin. Ser. 5 Geogr. (Vestn. Mosk. Universiteta. Ser. 5 Geogr.)* **2021**, *1*, 43–53.

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