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Paleogeography of the Laptev Sea Eastern Shelf in the First Half of Holocene Based on Faunal and Palynological Evidence

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Abstract—The Holocene paleogeography of the Laptev Sea eastern shelf is reconstructed based on mollusks, foraminifers, ostracodes, spores and pollen found for the first time. Environmental changes in the course of the postglacial (Holocene) transgression are detectable from quantitative analysis of three ostracod assemblages. Three phases of the transgression are established based on ostracode assemblages from the AMS ^{14}C-dated core from the ancient valley of Yana River, central part of the Laptev Sea eastern shelf. After the first phase of coastal brackish-water environment (11.3–11.1 ka), shallow-water marine taxa appeared in the transitional phase (11.1–10.3 ka), and the third phase of modern sea conditions commenced 10.3 ka ago. Spore and pollen assemblages from the core indicate that the early Holocene land vegetation was dominated by tundra plant communities adapted to climatic conditions not warmer than at present. In the interval of 9.3–8.0 ka, climate was increasingly humid and warm, and forest–tundra vegetation occupied more favorable zones of the region.

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Key words: Holocene climate, Siberian Arctic region, shelf sediments, ostracodes, spores and pollen spectra.

INTRODUCTION

The current necessity to forecast Arctic climate stimulated multidisciplinary research (including micropaleontological and palynological investigations) of bottom sediments and environments in the Laptev Sea. Holocene climatic changes developed in relatively short periods from tens to few thousand years long. The global warming is a distinctive feature of Holocene time. It influenced continental areas of middle and high latitudes to a greater extent than other regions. The Arctic is very sensitive to global climatic changes. That is why shelf seas of Siberian, especially the Laptev Sea and contiguous land areas, which connect polar margins of Siberia with the Arctic Ocean and global system of oceanic circulation, are of great interest. Hydrodynamics of the Laptev Sea is controlled by a severe glacial regime and by system of currents and intense freshwater inflow from Siberian rivers. Rivers, such as Lena and Yana, transport a great amount of suspended matter (Lisitsyn et al., 2000), pollen included, which is accumulated in the shelf zone.

The Laptev Sea with its coasts, river deltas and estuaries, on the one hand, and the deep-water Arctic basin, on the other, are important elements of the Arctic natural system. The Laptev Sea, one of the interesting and unique regions of the Arctic, is characterized by the following natural phenomena (Danilov et al., 1994):

– the greatest volume of sea ice is formed in this sea called “the ice factory” of the Arctic Ocean;

– the Atlantic water masses lose more heat capacity in the Laptev Sea than in other shelf seas of Siberia;

– the fresh-water inflow affects the whole region up to the North Pole;

– the sea is interaction zone of western and eastern baric and thermal conditions;

– owing to equal distance from the Pacific and Atlantic oceans, biological species from both provinces co-exist in this sea basin;

– a vast shallow-water zone of the sea hosts islands, which may disappear like, for instance, the Vasil’evskii and Semenovskii islands formed by glacial complexes and annihilated by thermal abrasion (Are, 1983).

These and many other phenomena stimulated multidisciplinary study of interacting natural system *land–river–shelf–ocean*.

During the last glaciation, when sea level was lowering, extensive ice-free land areas emerged in the Laptev Sea (Romanovskii et al., 1997a; Alekseev, 1997; Bauch et al., 1999). The succeeding rapid sea level rise of the late Pleistocene–Holocene brought about shelf flooding considered recently in detail (Kassens et al., 1998). The related changes and variations in the river water supply and parameters of sea water are recorded in stratigraphically successive assemblages of mollusks, ostracodes, and foraminifers from marine sediments. Among these fossils, ostracodes are most sensitive to depth and salinity variations. Analyzing

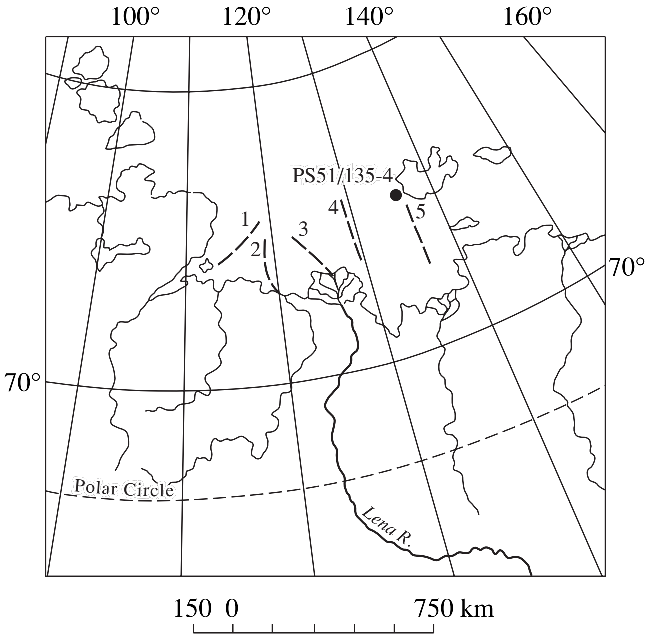

Fig. 1. Submarine continuations of the Valley valleys into the Laptev Sea (after Churun and Timokhov, 1995, Fig. 1): (1) Anabar–Khatanga Valley; (2) Olenek Valley; (3) Western Lena Valley; (4) Eastern Lena Valley; (5) Yana Valley (black dot denotes site of PS51/135-4 core section.

their assemblages, we can reconstruct depositional environment in detail. Because of their significance for understanding past environments, present-day and fossil ostracodes of the Laptev Sea little known before have been comprehensively studied recently (Stepanova, 2004; Stepanova et al., 2003, 2004; Taldenkova et al., 2005).

The multidisciplinary environmental research of the Laptev Sea and adjacent areas of Siberia includes palynological analysis as one of the basic methods of paleoclimatic reconstruction. Study of modern pollen rains over oceans shows that pollen composition reflects general character of terrestrial vegetation in adjacent regions and almost over the entire continent and, hence, elucidates climatic conditions of extensive regions (Sanchez-Goni et al., 2004). In the East Siberian Arctic, the Laptev Sea shelf and relevant land areas closely interact via rivers, especially via Lena and Yana rivers. Pollen spectra in marine sediments of the sea eastern sector are formed therefore predominantly under influence to submarine river runoff. The investigation results show that pollen spectra in coastal marine sediments reliably record influence of climatic factors on vegetation in land areas contiguous to the Laptev Sea (Naidina and Bauch, 1999, 2001; Naidina et al., 2000, 2002).

In terms of geobotany, the eastern part of Siberia adjacent to the Laptev Sea and the New Siberian Islands correspond to the Arctic desert and tundra zones, where vegetation development is affected by severe climatic conditions. Analysis of pollen spectra in recent and upper Holocene sediments of the Laptev Sea (Naidina and Bauch, 1999, 2001; Naidina et al., 2000) revealed that they adequately reflected composition of adjacent land vegetation and could be used for paleoclimatic reconstructions.

This article presents results of the complex micropaleontological (faunal and palynological) study of AMS^{14}C-dated core from the central part of the eastern shelf (oldest dates for the core base are 11.3 to 11.1 ka). The core contains *marine* fossils closely *associated* with diverse pollen spectra of *terrestrial* vegetation, thus being suitable for getting a deeper insight into evolution of the Holocene transgression and climates.

GENERAL HYDROLOGICAL CHARACTERISTICS OF THE LAPTEV SEA

The marginal Laptev Sea of the Arctic Ocean is bounded by the Taimyr Peninsula in the west and by the New Siberian Islands in the east (Fig. 1). It is 662 000 km^2 in area. The larger, southern part of the sea represents a shelf zone. Paleovalleys of five major rivers (Khatanga, Anabar, Olenek, Lena, and Yana) are distinctly observed there. The valleys represented main depocenters since the latest global sea-level rise (Bauch et al., 1999; Mueller-Lupp et al., 2000).

Being situated in high latitudes far away from the Atlantic and Pacific oceans but close to the Asian continent, the polar ice-covered Laptev Sea is one of the most severe seas of the Russian Arctic. The regional climate can be defined as continental with distinct marine features. The continental character is evident from considerable fluctuations of annual air temperature, although their amplitude is not as large as in continent.

The river runoff, primarily that of the Lena River, is an important regulator of water balance in the Laptev Sea. The Lena River runoff exceeds essentially that of other rivers realizing up to 70% of the fresh-water inflow into the eastern part of the sea. Salinity anomalies are caused exactly by the continental runoff as is established (Bauch et al., 1999). Salinity of bottom and surface waters is generally lower in the eastern part of the sea (Dmitrenko et al., 2001a).

Water temperature agrees with salinity gradients. The annual temperature in near-bottom water layer is about –1.5 to –2°C (Romanovskii, 1997b) and changes in average from –0.8 to –1.8°C (Dmitrenko et al., 2001b). In summertime, it rises in coastal zone ranging here from 0 to 4°C (Gukov, 1999).

The Atlantic water masses are principal climate-affecting factor of the region. They penetrate into the Laptev Sea from the west at the depth beneath 80–100 m elevating here the temperature up to –1.0 or even +0.6°C. Recent oceanological investigations (Dmitrenko et al., 2001b) show that the Atlantic bottom cur-

Radiocarbon and calendar dates for the PS51/135-4 core section (Bauch et al., 2001b)

Depth, cm	Sample number	Bivalve	^{14}C date	Calendar age
562	KIA-6918	*Portlandia arctica*	10.360 ± 55	11339
456	KIA-6917	*Portlandia arctica*	10.187 ± 60	11142
403	KIA-6916	*Portlandia arctica*	9.580 ± 45	10306
266	KIA-6915	*Macoma calcarea*	8.945 ± 55	9613
143	KIA-6914	Foraminifers + ostracodes	8.460 ± 70	8956
80	KIA-6913	*Nuculana* sp.	7.100 ± 55	7610
40	KIA-6912	*Yoldia amygdalea hyperborea*	6.480 ± 50	7017
8	KIA-6911	*Macoma* cf. *calcarea*	4.920 ± 40	5301
4	KIA-6910	*Leionucula bellotii*	0	0

rents may penetrate sometimes into the shelf at the depth of 20–40 m.

SOME DATA ON THE HOLOCENE TRANSGRESSION IN THE LAPTEV SEA

The postglacial transgression flooded step by step the modern shelf zone. It was a factor of steady erosion and sediment redistribution.

According to available data on the Holocene transgression development in the Laptev Sea shelf (Polyakova, 1997; Bauch et al., 2001b), the sea level reached modern isobaths of –40 and –50 m about 10 or 11 ka ago. It was starting moment of sediment deposition. Normal marine settings in the shelf zone appeared 9.5 ka ago, as it is evident from increased δ^{13}C values in organic matter and higher concentration of marine biomarkers (Mueller-Lupp et al., 2000; Stein and Fahl, 2000). The transgression developed very irregularly. Isobaths of –50, –43, and –31 m were flooded 11.1, 9.8, and 8.9 ka ago, when rates of sea-level rise corresponded to 5.4, 13.3, and 7.9 mm/year, respectively. In the outer shelf of the Laptev Sea, sedimentation rates reduced about 9 ka ago. The sea level approached the present-day mark rising since 6 ka ago and decreasing simultaneously sedimentation rates in the outer and middle shelf zones. During the late Holocene, the situation remained stable (Bauch et al., 1999, 2001b).

Gukov (1999) suggested that the Yana River mouth originated about 11.5 ka ago approximately 300 km northward of the current site. Formation of the Lena River delta commenced since the time of gradual stabilization of sea level (Andreeva et al., 1982; Romanovskii et al., 2000; Schwamborn et al., 2002).

MATERIALS AND METHODS

Sediments for micropaleontological (faunal and palynological) analysis were sampled from a core section recovered by the Russian–German Expedition TRANSDRIFT that was tasked by the project "Laptev Sea System". The PS51/135-4 core section was recovered by special box corer. Sampled sediment batches first frozen and dried in vacuum were weighted then on electron balance. Preliminary lithological description was done by H.A. Bauch and E.E. Musatov on board of RV "Polarstern" during the TRANSDRIFT Expedition in the Laptev Sea, August, 1998.

Fauna is studied in 20 samples irregularly selected from core section 562 cm long. Percentages of brackish-water, euryhaline, and marine ecological groupings of ostracodes are calculated per each sample and shown in graphs. Percentage of juvenile valves in each sample was also determined (Stepanova, 2004). Distribution of mollusks and foraminifers throughout the core section was examined as well (Taldenkova et al., 2005).

Pollen and spores are studied in fifty 10-cm-spaced samples of the core section. As is established, sediments accumulated from 11.3 to 5.3 ka (the calendar ages). The time resolution is from 50 to 200 years, depending on sedimentation rates. To macerate palynomorphs, dried and weighted samples were treated in acids (HCl, HF) according to conventional procedure. Standard tablets containing spore-markers were added to samples in order to determine concentration of palynological components (in grams per dry residue). The total sum includes all counted spores and grains of arboreal and herbaceous pollen. In addition, 300 to 400 grains of spore-markers were counted in each sample. The results of absolute palynological analysis are used to plot diagrams illustrating percentages of four pollen zones (PZ). Each zone reflects phases of vegetation development and climatic oscillations reconstructed based on changes in vegetation composition.

Scanning electron microscopy (SEM) was used to identify confidently the index pollen species. Pollen grains are examined and photographed under scanning electron microscope HITACHI S-405A with computer records at the Laboratory of Electron Microscopy, the Biological Faculty of the Moscow State University.

Based on radiocarbon and calendar geochronology, past hydrological events, phases of vegetation and climatic evolution, which are inferred from investigation results, are correlated with the Holocene climatic periods. Ages were determined by radiocarbon dating of bivalve shells from studied sediments using the AMS method at the Leibniz Laboratory of Kiel, Germany (Bauch et al., 2001b). The radiocarbon dates are converted into calendar ages B.P. (table) using the Calib 4.3 Program (Stuiver et al., 1998) and taking into account the results of ^{14}C reservoir age determination of the Laptev Sea. The reservoir-corrected basin age is estimated by means of ^{14}C dates for tree annual rings (Table 1 in Bauch et al., 2001b).

CORE SECTION

The coring site is in the Yana paleovalley, eastern shelf of the Laptev Sea, 76°09′92″ N and 133°14′68″ E (Fig. 1). The entire core 562 cm long is divided into following sections.

562–514 cm: gray silty clay. The radiocarbon date of 11 339 years is obtained at the level of 562 cm.

514–415 cm: dark gray silty clay with abundant black inclusions of organic matter, sulfides, shell detritus and a sand–clay lens few millimeters thick at the level of 467 cm. The date of 11 142 years corresponds to the level of 456 cm.

415–330 cm: gray silty clay with black inclusions and striae of organic matter (less abundant than below), thin sandy interbeds, and black sulfide inclusions. Sediments are bioturbated. Contact with underlying sediments is gradual, marked by a thin sand–clay lens. The date of 10 306 years characterizes level of 403 cm.

330–210 cm: dark gray sandy to silty clay with abundant inclusions of organic matter and sulfides; very thin bioturbated sandy interbeds contain fine detritus of shell. Transition to underlying sediments is gradual. The level of 266 cm is dated at 9613 years.

210–47 cm: dark gray sandy–silty clay with inclusions and striae of organic matter and sulfides, enclosing very thin sandy interbeds. Heavy bioturbation is typical of sediments containing shell fragments and intact valves of bivalve mollusks. A wood fragment is found at the level of 58 cm. Gradual contact with underlying sediments is determined at the level of dark-colored bed oriented slantwise from 209 to 211 cm. Dates of 8956 and 7610 years are determined for the levels of 147 and 80 cm, respectively.

47–0 cm: dark gray bioturbated sandy–silty clay with thin sandy interbeds, shell fragments, intact valves of bivalve mollusks, and black inclusions of organic matter. A wood fragment is found at the level of 24 cm. Dates of 7017 and 5301 years correspond to levels of 40 and 4 cm, respectively.

RESULTS AND DISCUSSION

Faunal and Palynological Assemblages

Ostracodes. The oldest assemblage (interval 514–460 cm, age 11.3–11.1 ka) consists of six predominantly shallow-water neritic forms characteristic of coastal brackish-water environments. These are *Heterocyprideis sorbyana* (Jones) (up to 10%), *Paracyprideis pseudopunctillata* Swain (40–60%), *Cytheromorpha macchesneyi* (Brady et Crosskey) (10–30%), and *Roundstonia globulifera* (Brady) (up to 18%) (Fig. 2). In the succeeding, transitional assemblage of eight species (interval 460–120 cm, age 11.1–10.3 ka) these forms are substituted by *Semicytherura complanata* (Brady, Crosskey et Robertson) (up to 10%) and *Cytheropteron elaeni* Cronin (up to 12%) typical of marine normal-salinity settings. A high percentage (up to 60%) of juvenile valves and intact shells can be explained by a high sedimentation rate under relatively low-energy conditions. The upper, most diverse assemblage consists of 11 species (interval 120–0, age 10.3 ka to Recent), the first appearing marine species *Cluthia cluthae* (Brady, Crosskey et Robertson) (up to 10%) and *Jonesia acuminata* (Sars) (up to 10%) included (Stepanova, 2004, fig. 3).

Mollusks. Fourteen taxa are identified in the core studied, but only a half of them at the species level. The lower assemblage (interval 562–460 cm) comprises only two species of typical Arctic genus *Portlandia* and a single gastropod form tolerant to brackish-water coastal conditions and dwelling down to the depths of 10 m. The transitional assemblage (interval 460–120 cm) is represented mostly by species of genera *Portlandia* and *Macoma*, the latter typical of the Arctic. The more diverse upper assemblage (interval 120–0 cm) is dominated by *Macoma* species (Taldenkova et al., 2005).

Foraminifers. An assemblage of 25 taxa consists predominantly of Elphidiidae forms. Taxonomic difference between fossils from the core lower part (below 50 cm) and higher is insignificant (Taldenkova et al., 2005).

It is interesting that tests of planktonic foraminifers occur in abundance (up to 50% of all tests) in the sediments older than 10 ka, being scarce in younger deposits. Numerous tests of planktonic foraminifers were described (Taldenkova et al., 2005) from recent near-shore sediments to the northwest of the Lena River delta. They are supposed to represent a thanatocoenosis from an area where the Atlantic waters meet river flows. At the core base, planktonic foraminifers could be redeposited from older sediments, but they are perfectly preserved, suggesting their periodic transportation by Atlantic waters at the commencement of transgression (Taldenkova et al., 2005).

Spores and pollen. Taxonomic diversity of pollen and spores found in the studied marine sediments is typical of tundra vegetation in the high latitudes.

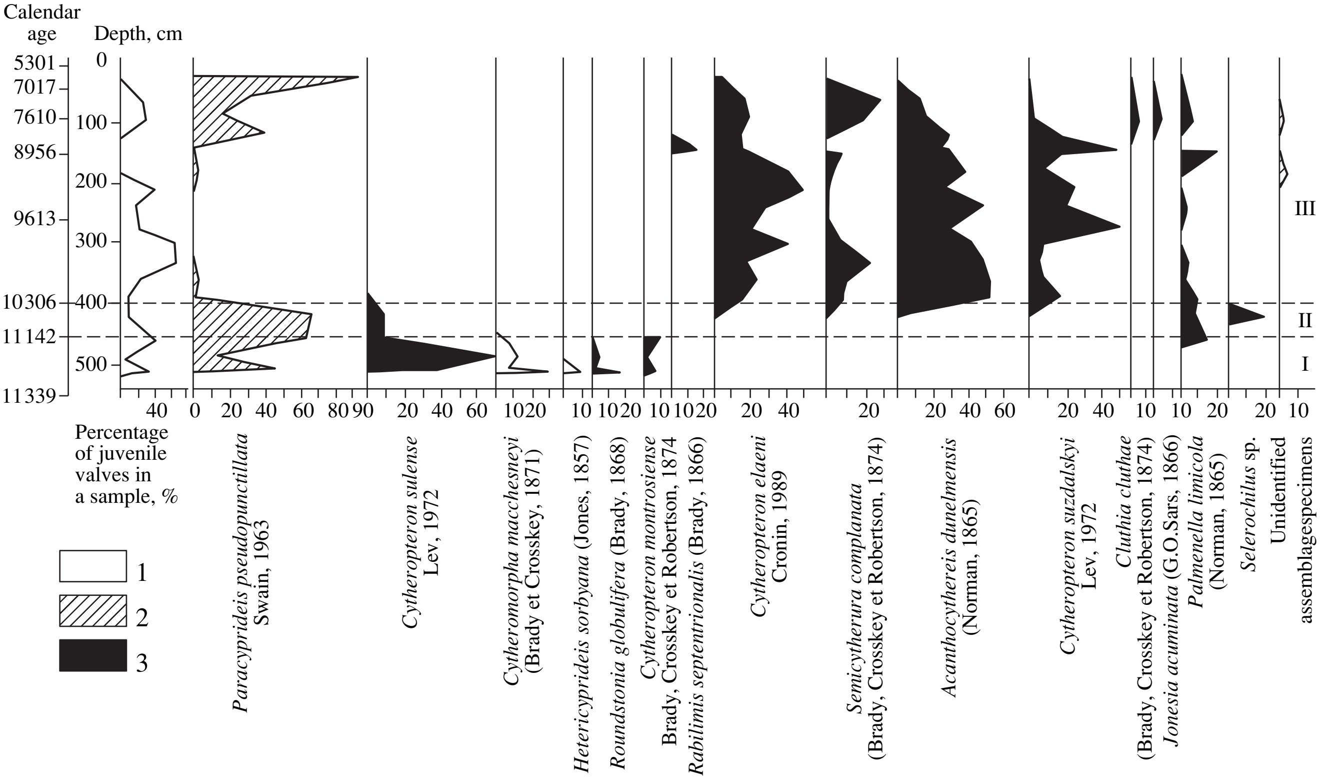

Fig. 2. Stratigraphic ranges of ostracode taxa typical of (I) inner, (II) transitional and (III) middle shelf zones in the lower Holocene interval of PS51/135-4 core section, the Yana River paleovalley (after Stepanova, 2004, Fig. 3): (1) brackish-water, (2) euryhaline and (3) marine ostracode groupings.

Palynological spectra consist of arboreal (AP) and nonarboreal (NAP) pollen and spore (SP) plants. In total 37 taxa are identified. Variations in taxa proportions determine four pollen zones (PZ) represented in the core from the Yana paleovalley numbered successively with index “Ya” (Fig. 3).

PZ Ya-1 (interval 500–400 cm, age 11.3–10.3 ka) is dominated by pollen of hypo-Arctic trees and shrubs (AP up to 58%); more than a half of spectrum is represented by pollen of *Betula* sect. *Nanae* and *Alnus fruticosa* Rupr. The greatest amount of *Alnus fruticosa* Rupr. pollen (>20%) is found at the core base (500 cm, the oldest date 11.3 ka). Conifer pollen is dominated by that of *Pinus* (4–21%). The NAP group is represented mainly by Cyperaceae (up to 24%) and Poaceae (up to 14%). Almost all samples include single grains of Ericaceae, Caryophyllaceae, Asteraceae, *Artemisia* included, and Rosaceae. There are sporadic pollen grains of *Rumex*, *Thalictrum, Plantago*, and *Saxifraga* and very scarce pollen of *Valeriana* and *Epilobium.* Spore plants are represented by *Sphagnum* (1–8%) and green moss *Bryales* (0.8–12%). The maximal amount of *Sphagnum* spores is detected at the level of 400 cm (10.3 ka). Spores of cryoxerophytic *Selaginella rupestris* (L.) Spring occur almost in all samples.

PZ Ya-2 (interval 400–210 cm, age 10.3–9.6 ka and younger than ~9.3 ka) is characterized by approximately equal proportion of AP and NAP and by a higher content of spores (8–39%) than in previous assemblage. The AP content decreases here down to 47% owing to reduced amount of *Betula* sect. *Nanae* (16%) and especially *Alnus fruticosa* Rupr. pollen (7%). Conifer spectrum shows an increased proportion of *Pinus* (up to 39%) and *Picea* pollen (up to 4%). The NAP is dominated by pollen of Cyperaceae (0.7–28%) and Poaceae (2–17%). The maximal abundance of Caryophyllaceae pollen (up to 8%) is recorded in this interval. Single grains of Ericaceae, Asteraceae, Rosaceae are common. The SP group includes spores of *Bryales* (up to 28%), *Sphagnum* (up to 6%), Polypodiaceae (up to 9%) and *Selaginella* (8%). Pollen is less concentrated in this interval than in underlying sediments, and three samples contain here only black films of unidentified organic matter (sulfides?). With due account for minimal pollen content in some beds of the interval, it is possible to suggest a strong influence of bottom currents on pollen accumulation, when oceanic waters penetrated into the Laptev Sea.

PZYa-3 (interval 210–90 cm, age 9.3–8.9 ka and younger than ~8.0 ka) is characterized by increased amount of conifer pollen. The AP spectra contain more *Pinus* pollen (up to 53% in the interval of 130–140 cm, age slightly younger than 8.9 ka). The maximal amount of *Picea* pollen (up to 8%) is detected at the level of

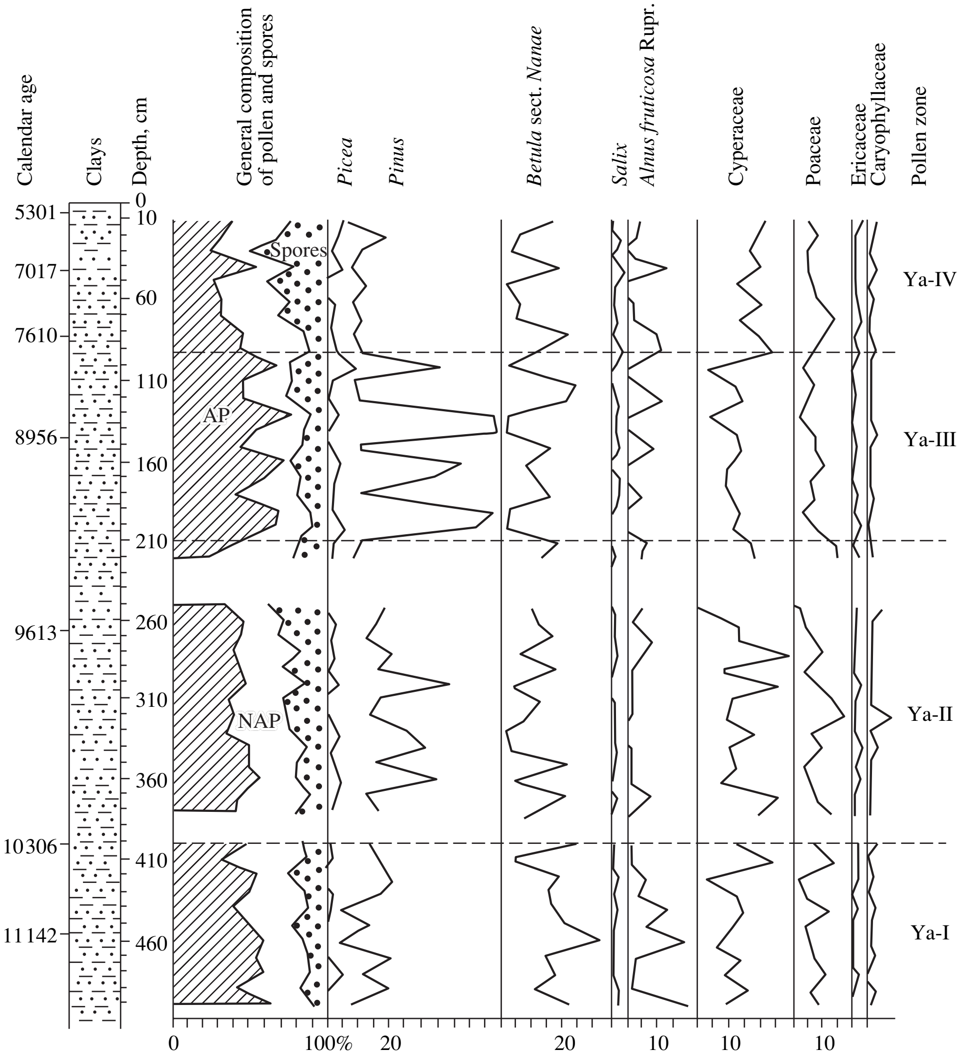

Fig. 3. Pollen and spore spectra characterizing distribution of indicative arboreal and shrub (AP), herbaceous (NAP), and spore taxa in lower Holocene sediments of core section PS51/135-4.

100 cm. Single *Abies* grains occur throughout the interval. Abundance of *Betula* sect. *Nanae* pollen varies from 1 to 23%. Pollen of *Alnus fruticosa* Rupr. is found only in four samples. The NAP spectrum (up to 39%) includes pollen of Cyperaceae (2–20%, i.e., slightly more than below) and Poaceae (1–8%). Pollen of Ericaceae and tundra herbs Caryophyllaceae, Asteraceae, Rosaceae, and Ranunculaceae decreases in abundance. Single grains of *Rumex* pollen occur almost in all samples. Spores (up to 25%) are dominated by those of *Bryales* (4–19%). *Selaginella rupestris* is scarce.

The PZ Ya-3 is characterized by distinct alternation of spectra, which are dominated either by conifer pollen (the greatest abundance of *Pinus* is within the interval of 130–140 cm, younger than 8.9 ka) or by pollen of *Betula sect.* Nanae. Abundance of reworked and deformed conifer pollen may be related to fossilization factor.

PZ Ya-4 (interval 90–12 cm, age 7.6–5.3 ka) is characterized by equal percentages of AP (18–49%), NAP (21–42%), and SP (10–51%) groups that is typical of tundra spectra. The AP group shows a decreased amount of *Pinus* pollen (42%) being relatively enriched in pollen of *Betula* sect. *Nanae* (1–22%), *Alnus fruticosa* Rupr. (1–11%), and *Salix* (up to 3%). The maximal amount of *Alnus fruticosa* Rupr. at the level of 40 cm (7.0 ka) is indicative of somewhat warmer conditions, while scarcity of Cyperaceae pollen and moss spores suggest a more arid climate. At the level of 5.3 ka, the AP group (up to 43%) is dominated by pollen of *Betula* sect. *Nanae*. Among the NAP, Cyperaceae (5–22%) and Poaceae (3–12%), and single pollen grains of Ericaceae, Caryophyllaceae, Asteraceae, Rosaceae, *Rumex, Thalictrum*, and *Epilobium* are recorded. *Bryales* spores (2–7%) with abundance peaks at the levels of 50 and 30 cm is indicative of intense swamping of adjacent land.

LAPTEV SEA EASTERN SHELF IN THE LATE NEOPLEISTOCENE THROUGH THE FIRST HALF OF THE HOLOCENE

Three assemblages of ostracodes and mollusks, the oldest of brackish-water inner shelf, transitional one, and marine assemblage of the middle shelf, are established (Fig. 2). Their upward succession reflects a gradual shelf flooding during the Holocene transgression.

Data on distribution of ostracodes, mollusks, and foraminifers throughout the core section (Stepanova et al., 2004; Taldenkova et al., 2005) supplements the previous data on the Holocene transgression in the region (Bauch et al., 2001a, 2001b; Mueller-Lipp et al., 2000).

The lower Holocene sediments (11.3–8.2 ka) representing the thickest interval of core section beginning from the depth of 51 m are most fully characterized in paleontological aspect. When the current 50-m isobath was flooded, the Yana paleovalley was populated by taxonomically poor benthic community of species tolerant to brackish-water conditions and abundant terrigenous influx provided by rivers and coastal abrasion. The community consisted of brackish-water and euryhaline organisms. Among brackish-water ostracodes there were *Cytheromorpha macchesneyi* (Brady, Crosskey) and *Heterocyprideis sorbyana* (Jones). Euryhaline ostracodes were represented by *Paracyprideis pseudopunctillata* Swain only. These were the only species capable to exist in the estuary-like parts of the paleovalley at the depth of 5 to 10 m and even less. Salinity was probably 18–20‰ near bottom and less than 7–9‰ in surface layer as suggested by diatom assemblages from the core (Polyakova et al., 2005). A high rate of sea level rise was combined with a considerable sedimentation rate up to 500 cm/kyr in the Yana paleovalley. The coastal brackish-water assemblages of ostracodes and mollusks existed during a very short period (from 11.3 to 11.1 ka).

Higher in the core section, some shallow-water marine species appear parallel to gradual disappearance of brackish-water taxa. This indicates the increasing sea depth and salinity in the course of progressive shelf flooding. The transitional assemblage consisting predominantly of euryhaline and brackish-water ostracode species is similar to modern assemblage dwelling in the inner shelf zone of the sea. A great mass of fresh-water diatom frustules accumulated in a short time from 11.1 to 10.7 ka (Polyakova et al., 2005). As is assumed, the abundance peaks of microfossils may be indicative of a high bioproductivity at the surface owing to intense supply of nutrients and diminished influx of terrigenous material as compared to the beginning of transgression, when the high sedimentation rate was caused by a rapid sea level rise and active thermoabrasion of coastal and bottom deposits. A considerable influence of fresh water inflow on the water mass in middle shelf of the sea eastern part is confirmed by carbon isotope records (Mueller-Lupp et al., 2000) and by maximal influx of terrestrial organic matter to the continental slope 10–9.6 ka ago (Stein and Fahl, 2000). Marine conditions were set about 9.5–8 ka ago in the continental margin of the Laptev Sea (Boucsein et al., 2000) and 9.8 ka ago in the thermokarst lakes of watersheds (Bauch et al., 2001b; Romanovskii et al., 2004). The taxonomic composition of benthic assemblages suggests that the sea depth was 20–25 m and average salinity near bottom reached 26–28‰ 10.3 ka ago.

Molluscan and ostracode assemblages consisting of shallow-water marine species adapted to normal salinity (Taldenkova et al., 2005) suggest a distinct transition to current sea conditions at about 10.3 ka ago. Among marine ostracodes, there are *Rabilimis septentrionalis* (Brady), *Cytheropteron elaeni* Cronin, *Semicytherura complanata* (Brady, Crosskey, Robertson), *Acanthocythereis dunelmensis* (Norman), *Cytheropteron suzdalskyi* Lev, *Cluthis cluthae* (Brady, Crosskey, Robertson), *Jonesia acuminata* (Sars), and *Palmenella limicola* (Norman) (Fig. 2).

The shoreline migration farther southward brought about a decrease of sedimentation rate down to about 15 cm/kyr. High diversity of all fossil groups studied and disappearance of all brackish-water taxa together with many euryhaline forms evidence that the bottom water salinity reached the modern values of 30–32‰. The high abundance of ostracodes and complete absence of juvenile specimens point to a more intense bottom hydrodynamics and reduced rate of sedimentation (Fig. 2). A sharp increase of sandy fraction from 3 or 4 to 10–12% at the same time could be caused by active erosion of former islands turned into submarine rises. At present, there are strong bottom currents in the flooded Yana paleovalley (Dmitrenko et al., 2001a). Consequently, the greater influx of sandy fraction may be caused by similar conditions and bottom currents.

PALEOGEOGRAPHY OF THE LAPTEV SEA REGION IN THE LATEST NEOPLEISTOCENE AND FIRST HALF OF HOLOCENE

Changes in climatic conditions and vegetation on land in relation with sea transgressions and regressions are considered in many publications (Kozhevnikov et al., 1982; Beniamovski and Naidina, 1992; Naidina, 1989, 1995, 1999). Stages of the Laptev Sea expansion and reduction in the Holocene were controlled mainly by climatic factors, which greatly influenced the land vegetation. It is reasonable therefore to reveal correlation between changes in climate and vegetation, on the one hand, and paleobasin evolution, on the other.

Information on climatic and vegetation evolution during the first half of the Holocene that is inferable from dated continental sections has been essentially supplemented recently (Siegert et al., 1999; Schirrmeister et al., 2002). Palynological analysis of the AMS^{14}C-dated marine section was used for the first time to reconstruct paleogeography of the eastern Laptev Sea. A general trend of the early–middle

Holocene evolution of climate and vegetation in the Arctic coast was as follows. From 11.3 to nearly 5.3 ka there were some short-term changes in climate and vegetation induced primarily by humidity variations.

The high-resolution climatostratigraphic units in palynology are phases and subphases characterizing zonal and formational features of paleophytocoenoses under reconstruction. In pollen diagrams, they correspond to pollen zones and subzones, which represent one or several pollen spectra different from the others in composition and percentages of pollen and spores (Bolikhovskaya, 2002).

If zones in pollen diagrams correspond to phases in vegetation development, they can be used to figure out paleoclimatic conditions. The climate and vegetation dynamics in the eastern Laptev Sea region during the first half of the Holocene was likely as follows.

The moss–shrub tundra vegetation with dwarf birch and sedge-dominated herbs prevailed in the early Holocene (11.3 up to almost 10.3 ka). Such composition of flora is typical of the modern Arctic tundra. Climatic conditions were similar to modern ones. Some short-term (~100 years) episodes of warming and cooling occurred. In the initial Holocene (at approximately 11.3 ka) for instance, climate was, probably, warmer than now, as one can judge from widespread *Alnus* shrubs. Dominating shrubby alder is a characteristic element of southern tundra areas with smoother climatic conditions.

Later on (10.3 to almost 9.0 ka), climate became more humid, because thin pine–birch forests with heather on the ground developed in the watersheds, whereas swamped bushy areas with aquatic–marshy sedge groupings were characteristic of relief depressions and creek valleys. Short-term climatic fluctuations accompanied the general trend of increasing humidity and, probably, warming. For instance, colder and more arid conditions in the first half of the period under consideration are inferable from relevant pollen spectra characterizing of grass–herb-dominated tundra vegetation, while swamping at 9.6 ka led to development of sedge–moss tundra vegetation.

From approximately 9.3 to nearly 8.0 ka, climate was getting warmer and more humid. The sea expanded over the land again, and warming approached optimum; climate became warmer than now (Alekseev, 1997). Tundra gave way to forest–tundra advanced to the seacoast. Thin forest–tundra formations of pine and, probably, larch with dwarfed birches and alders were dominants. Presence of larch at that time is evident from its needles and stomata found in estuarine sediments of the Lena valley (Pisaric et al., 2001). Approximately 9.0 ka ago, the forest line migrated northward in lowered areas of the Lena delta (Laing et al., 1999). Palynological records in marine sediments show distinct and frequent changes of vegetation types, when moss–shrub tundra vegetation with dwarf birch and sedge–herb-dominated groupings became substituted by forest–tundra formations of pines and, probably, larches during relatively short periods ~200 years long. Shrub birch and alder dominated in underwood, whereas ground cover consisted of heathers and mosses. Shrub tundra vegetation has been typical in the period of severe climatic conditions (8.9–8.5 ka), while the peak development of light coniferous forest–tundra at 8.5 ka is indicative of warmer and more humid climate at that time.[1] The SEM analysis of *Pinus* pollen confirmed that *Pinus sylvestris* L., an indicator of warming, was more frequent in the conifer grouping than *Pinus pumila* (Pall.) Regel common of high mountain zone.

A series of short-time climatic fluctuations is detectable in the period of 7.6–5.3 ka, when humid and arid conditions alternated. Disappearance of thin coniferous forests in this period is indicative of progressing cooling. It was regeneration time of shrub vegetation with swampy tundra areas and sedge marshes.

CONCLUSIONS

The comprehensive bed-by-bed study of different *marine* organisms (mollusks, ostracodes, and foraminifers) and *terrestrial microfossils* (spores and pollen) in marine core section elucidated important details of paleogeographic reconstructions. The mentioned groups of microfossils are objects of independent studies discussed in many publications.

All the fossils studied represent remains of marine benthic organisms. Their distribution in the Laptev Sea was controlled by several basic factors, such as temperature, salinity, hydrodynamics, gas regime, depth of *the sea.* Spores and pollen are indicators of landscape and climatic condition in contiguous *land areas.*

Three phases of transgression are established based on distribution of fossil ostracodes, mollusks, and foraminifers throughout the core section:

(1) 11.3–11.1 ka: coastal brackish-water conditions; sea depth less than 10 m; diminished and seasonally varying salinity of bottom waters (18–20‰ in average); high sedimentation rate (up to 500 cm/kyr); intense influx of terrigenous plant detritus as a result of shelf–coast erosion and continental runoff.

(2) 11.1–10.3 ka: shallow-water conditions; considerable effect of continental runoff; sea depth about 20–25 m; average salinity of bottom waters 26–28‰; reduced but still high sedimentation rate (~100 cm/kyr).

(3) Since 10.3 ka: conditions close to current ones with bottom water salinity of 30–32‰ and low sedimentation rate of 15 cm/kyr (in the Yana paleovalley, very low rate since 5 ka) and strong bottom currents.

According to palynological data, the sea transgression commenced after continental stage of the region

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[1] A characteristic feature of present-day pollen spectra from central Yakutia is persistent abundance of *Pinus sylvestris* L. pollen that is consistent with distribution areas of this taxon (L'vova and Grigor'eva, 2002).

development (prior to 10.3 ka): tundra vegetation dominated, and climate was like at present. Later on until 9.6 ka, the initial phase of transgression was in progress according to increased abundance of arboreal plants in vegetation. An irregular development of transgression is suggested by unstable hydrodynamics caused by intense river inflow and accompanied by specific sedimentation in a zone of river runoff and seawater mixing. The increased abundance of arboreal pollen in marine sediments coincides with the level of elevated $\delta^{13}C$ and higher concentration of marine biomarkers (Mueller-Lupp et al., 2000; Stein and Fahl, 2000).

According to palynological records, transgression expanded at 8.9–8.0 ka. The sea depth was 31 m. Rate of sea level rise was 7.9 mm/year (Bauch et al., 1999, 2001b). Forest-free land areas adjacent to the sea were replaced by forest–tundra. Groupings of light coniferous forest–tundra with larches dominated. Composition of dendroflora suggests temperate–cold and humid climate. This dendroflora migrated southward along river valleys during the transgression peak 8.9 ka ago. Development of forest–tundra and light coniferous vegetation in places was in progress. Climate at that time was likely the warmest and more humid. The increased abundance of arboreal pollen in shelf zone can be interpreted as response to the northward displacement of the treeline after 9.0 ka (Laing et al., 1999; MacDonald et al., 2000). Later on, the area with typical marine conditions was reduced. The regression brought about less humid and colder climate suitable for periglacial shrub–herbaceous vegetation. During the subsequent transgression phase, climate remained cold but increasingly humid, typical of tundra landscapes. Phases of shrub and swampy vegetation alternated repeatedly. The abundance peak of sedge pollen and moss spores indicates swamping of large land areas near the sea. Frequent changes in vegetation suggest migration of shoreline during expansion and reduction of the basin.

Thus, palynological data enable reconstruction of climatic fluctuations and related changes in vegetation on land areas adjacent to the Laptev Sea. Alternating palynological assemblages can be used to figure out pulsations of shoreline.

Being applied jointly, methods of palynology and micropaleontology reveal diverse interesting data elucidating past environmental evolution of the Laptev Sea and adjacent land.

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