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Evolution of the Postglacial Vegetation in the Western Laptev Sea Region (Siberian Arctic)

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Abstract: On the basis of a detailed study of the pollen-spore spectra and a detailed radiocarbon chronology of a sediment core obtained from the western outer Laptev Sea shelf, the long-term and high-resolution changes of vegetation in the northwestern Laptev Sea region were reconstructed for the last 12.0 cal. ka. Three major phases in the development of paleoenvironments and vegetation on the surrounding hinterland and the exposed Laptev Sea shelf were recognized. The period between 12.0 and 10.3 cal. ka BP was characterized by predominance of grass-sedge and moss tundra. Rapid expansion of herbaceous tundra with dwarf birch and alder started at about 10.3 and lasted until 8.0 cal. ka. Pollen spectra from this time interval evidence the warmest and most favorable climate conditions. After 8.0 cal. ka mosses and lichen vegetation with scare herbs typical for the modern arctic tundra dominated.

Zusammenfassung: Auf der Grundlage detaillierter Pollen- und Sporenspektren aus einem ^{14}C-datierten Sedimentkern vom äußeren Schelf des westlichen Laptewmeeres wurden die langfristigen und hochaufgelösten Veränderungen der Vegetation in den letzten 12 cal. ka in der nordwestlichen Laptewmeer-Region rekonstruiert. Es wurden drei Hauptphasen der Entwicklung von Umwelt und Vegetation im umgebenden Hinterland erkannt. Die Zeit zwischen 12,0 und 10,3 cal. ka BP war charakterisiert durch Riedgras- und Moos-Tundra. Rasche Ausdehnung der Kraut-Tundra mit Zwergbirke und Erle begann etwa um 10,3 cal. ka und dauerte bis 8,0 cal. ka. Pollenspektren aus diesem Zeitintervall beschreiben die wärmsten und besten Klimabedingungen. Nach 8,0 cal. ka dominierte die für die heutige arktische Tundra typische Moos- und Flechtenvegetation mit wenigen Kräutern.

INTRODUCTION

The Arctic is highly sensitive to climate variations and plays an important role in the global climate system. The high-latitude Laptev Sea constitutes the central part of the wide Siberian shelf north of Eurasia and is regarded as a key area for understanding present and past climate changes in the Arctic (e.g., Kassens et al. 1999, Thiede et al. 2001). It is clear from existent research that this region remained uncovered by the last glacial ice sheet (Svendsen et al. 2004, Hubberten et al. 2004) and due to its shallow bathymetry was sub-aerially exposed during the last eustatic global sea-level fall. During postglacial sea-level rise and rapid inundation of the flat coastal plain, the landscape gradually changed from a terrestrial-fluvial to marine environments (Bauch et al. 2001, Bauch & Polyakova 2003, Polyakova et al. 2003).

Fossil pollen records are a source of information about past changes of vegetation and can be used for quantitative reconstruction of climate changes. Despite long-term palynological investigations of last glacial and postglacial terrestrial sediments carried out in Arctic Siberia (e.g., Velichko et al. 1997, Khotinsky 1977), detailed reconstructions of the vegetation history were limited by the scarcity of radiocarbon data. During the last decades numerous pollen-spore records and ^{14}C data obtained from the Taymyr Peninsula (e.g. Kienast et al. 2001, Andreev et al. 2002b, 2003, 2004a), Lena River Delta and Yana River lowland (Pisaric et al. 2001, Andreev et al, 2002a, 2004b, Janitskii et al. 1998) have provided ample information regarding major vegetational changes in the Laptev Sea region during the Last Glacial Maximum and after it.

Previous studies of marine pollen sequences from the inner Siberian shelf, including the Kara and Laptev seas, showed the potential of pollen for reconstructing vegetation and climatic changes in the adjacent coastal regions and linking the terrestrial and marine paleoclimate records (Naidina & Bauch 2001, Kraus et al. 2003). Using a radiocarbon-dated sediment core from the northwestern Laptev Sea, this study gives a first detailed insight into the evolution of vegetation on the exposed western Laptev Sea shelf and the adjacent hinterland during the late Pleistocene/Holocene transition.

ENVIRONMENTAL SETTING

Oceanography

The Laptev Sea is a broad shelf sea area, located at the northern Eurasian margin of Central Siberia (Fig. 1), and bounded by the New Siberian Islands in the east and the Severnaya Zemlya Islands in the west. Large parts of the Laptev Sea shelf are fairly shallow, averaging less than 50 m water depth, whereas the continental slope breaks steeply near 100 m water depth. The topography of the Laptev Sea is characterized by a gently northward-dipping plain, cut by submarine channels, which are regarded as paleoriver valleys (Holmes & Creager 1974, Kleiber & Niessen 1999, 2000).

The modern hydrological situation of the Laptev Sea is generally a result of the advection of the arctic water masses from the north and the annual river discharge of about 714 km^3 from the south (Ivanov & Piskun 1995, Gordeev 2000). The Lena River discharge, comprising approximately 70 % of the total water and suspended matter input to the Laptev Sea, strongly affects hydrological and sedimentation processes, especially in the eastern part (e.g., Kassens et al. 1998, 1999). The freshwater supply into the western Laptev Sea is mainly controlled by the outflow of Anabar and Khatanga rivers, which discharge approximately 15 % of the total annual

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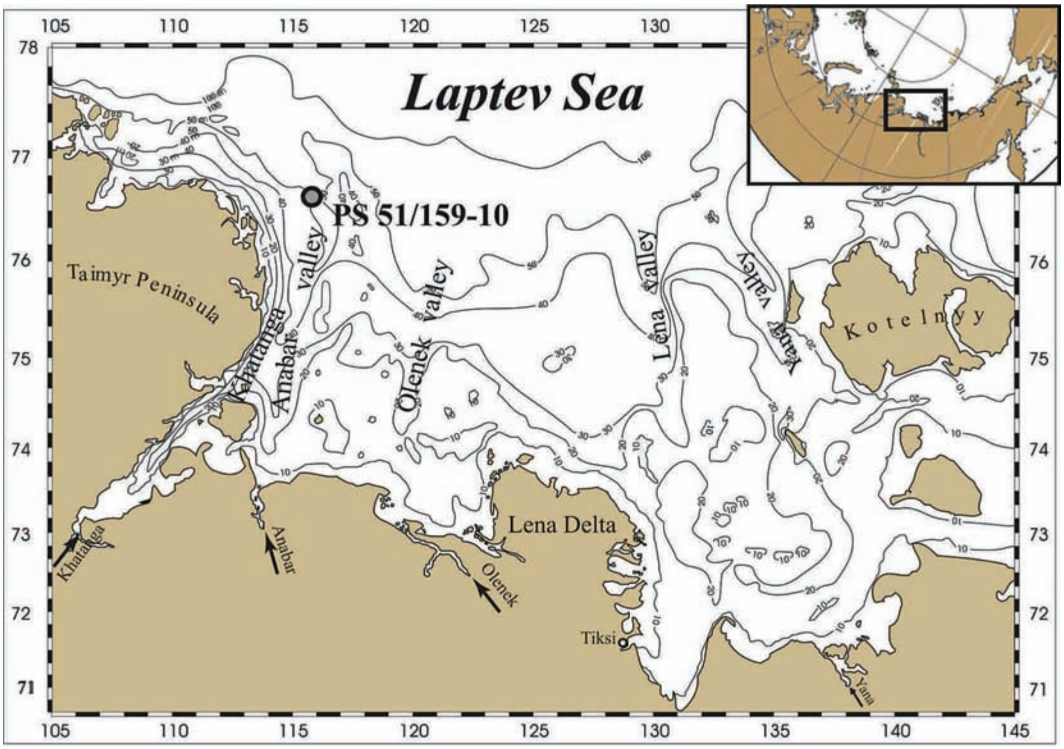

Fig. 1: Bathymetric map of the Laptev Sea showing the position of sediment core PS51/150-10 used for studying pollen-spore spectra (bathymetric contours in m).

Abb. 1: Bathymetrische Karte des Laptewmeeres mit der Lage des Sedimentkerns PS51/159-10, an dem die Pollen-Sporenuntersuchungen durchgeführt wurden (Tiefenlinien in m).

runoff. Their waters are mainly directed to the north and northeast.

Most of the fresh water is discharged onto the shelf during late spring when the ice of the rivers breaks and during the ensuing summer months when the Laptev Sea is relatively ice-free (GORDEEV 2000). The seasonal offshore spreading of riverine waters is well manifested in surface water salinity, which shows the lowest value in the southeastern part of the shelf (KASSENS et al. 1999). The major surface water currents in the Laptev Sea are of cyclonic manner starting north of the Severnaya Zemlya Island, then following southward along the Taimyr Peninsula, and then eastward and northward in the middle and eastern parts of the Laptev Sea shelf, respectively.
The winter environments in the Laptev Sea are significantly governed by the large, persistent area of open water (polynya), separating the fast ice from the pack ice. The Laptev Sea polynya maintained by persistent offshore winter winds is one of the major sources for sea ice in the Siberian branch of the Transpolar Drift (ZAKHAROV 1997, PFIRMAN et al. 1997, DETHLEFF et al. 1998).

Vegetation and Climate

The recent vegetation on the New Siberian and Severnaya Zemlya islands adjacent to the Laptev Sea and the coastal regions of its hinterland is characterized by rather treeless landscapes. A cold arctic continental climate with seasonal extremes dominates in the region. Average temperature in the Laptev Sea region is <-30 °C in February and varies between ±0 and +8 °C in July. Total annual precipitation is approximately 100-200 mm, with most of it falling in the summer (ATLAS ARKTIKI 1985). Anticyclone regime with strong offshore winds dominates in the Laptev Sea region during winter time, whereas mainly eastward-directed surface winds prevail during the summer time.

The major parts of the New Siberian and Severnaya Zemlya islands are located in the zone of arctic desert and high arctic tundra with landscapes dominated by mosses and lichen vegetation, and scarce herbs occurring mainly along the river valleys. Landscapes of the southern Bol'shoi Lyakhovsky Island of the New Siberian Archipelago belong to the northern tundra zone (ATLAS ARKTIKI 1985). Moss-grass-low-shrub tundra dominates the vegetation, with vascular plant species such as *Salix pulchra, Cassiope tetragona, Dryas punctata, Poa arctica, Carex ensifolia* and *Eriophorium medium,* mosses such as *Aulaconium turgidum, Drepanocladus iniciatus* and *Calliergon sarmentosum,* and lichens such as *Alectoria ochroleuca, Cetraria cuculliata* and *C. hiascus.*

The vast area of the Taimyr Peninsula extends over the three tundra subzones (high arctic tundra, arctic tundra and typical tundra), bounded to the north by the polar desert and to the south by the forest-tundra zone (ATLAS ARKTIKI 1985, MATVEEVA 1994). Small patches of arctic tundra occur also on the coast between the Anabar River and the Lena Delta. The flora of flowering plants is very poor within this subzone. Sods are formed by mosses, dwarf willow, and miscellaneous herbs (saxifrage, whitlow grass, gramines).

The northern borders of the typical tundra subzone approximately correspond to the July isotherm of 8-10 °C. Eastward of the Taimyr Peninsula the lower part of the Anabar, Olenek and Yana river catchment areas is located within the typical tundra (ATLAS ARKTIKI 1985). Mosses, lichens, sedges, and shrubs are the most important plant cover components. Low shrubs, such as shrub birch *(Betula nana),* alder *(Alnus fruticosa* and *A. crispa),* willow (*Salix* spp.), and heaths (Ericaceae) dominate the vegetation of the lower relief. Dwarf shrub species include *Vaccinium vitis, Empetrum hermaphrodium,* and *Dryas punctata, Carecs* ssp., *Eriophorum vaginatum,* and mosses such as *Tomenthypnum nitens* and *Drepanocladius uncinatus* characterize wetter sites, while alders *(Alnus* *fruticos, A. crispa)* grow on south-facing slopes.

The southern tundra subzone is located in the lower Khatanga River and the lower Lena River catchments (Atlas Arktiki 1985). The southern border of this subzone mostly corresponds to the July isotherm of +10-12 °C. Vegetation of this subzone is characterized generally by the lack of trees and predominance of shrubby communities at the watersheds. Sparse crooked and elfin woods can be found in the river valleys of these regions. But only single trees that make up the forest border in the area grow at the watersheds. Shrubby communities of the dwarf birch *Betula nana,* shrubby alder and some shrubby willow species like gray willow, long-leaved, flat-leaved species, etc. dominate the plant structure.

The northern treeline border limited by the July isotherm of approximately +12 °C stretches from 68 °N in the Western Taymyr to 72 °N in the eastern part of the peninsula, and then follows eastward from the Khatanga River mouth to the east through the lower part of the Lena River catchment area (Atlas Arktiki 1985).

Pollen and spores in the surface sediments of the Laptev Sea

For the purpose of paleoenvironmental reconstructions using pollen-spore spectra from the studied sediment core as a principal proxy we analyzed distribution patterns of pollen and spore grains in the surface sediments from the Laptev Sea, represented by Naidina & Bauch (1999). These authors revealed that pollen-spore spectra in the sediments of this arctic sea are mainly (up to 93 %) represented by arboreal pollen from coniferous trees (particularly, *Pinus pumila, Pinus siberica* and *Picea*). Their pollen grains, due to their special morphology, are transported for a longer distance in the Arctic (Shevchenko et al. 1995, 2004). The maximum percentage contents of *Pinus pumila* and *Pinus siberica* grains are observed in the offshore regions adjacent to the Lena Delta, and near the estuaries of the Olenek and Yana rivers, indicating that riverine runoff also accounts for the pollen transportation into the Laptev Sea. Although the *Larix* is one of the most widespread trees in Northern Yakutia, only individual specimens were found in the Laptev Sea sediments because of poor preservation of these pollen grains.

Pollen of deciduous trees comprised about 4 % of the spectra in the Laptev Sea surface sediments and included Salix, Alnus and *Betula* sect. *Nanae* (Naidina & Bauch 1999). The pollen of herbaceous plants (Ericaceae, Gramineae, Asteraceae, Rosaceae, Saxifragaceae, Ranunculaceae, Caryophillaceae, Cyperaceae) did occur, but abundances were generally low, with the maximum relative abundances observed in the western part of the sea. Among the spore plants, the Bryales mosses were dominant and reached 82 % in the submarine valley of the Lena. Sphagnales percentages increased near the Taymyr Peninsula coast (up to 40 %) and varied in the eastern part of the sea between 2-30 % (Naidina & Bauch 1999).

MATERIAL AND METHODS

Kasten core PS51-159/10 was obtained from the western outer Laptev Sea shelf (60 m water depth, total sediment recovery 490 cm) during the Russian-German TRANSDRIFT V expedition in 1998 (Fig. 1). The sedimentary sequence of the core consists of grey to dark silty clay enriched in organic matter. To analyze the fossil pollen-spore spectra, the core was sampled in 10 cm intervals. After freeze-drying, the bulk sediments were treated in the Alfred Wegener Institute (Potsdam, Germany) and the Russian-German Otto Schmidt Laboratory for Polar and Marine Research (AARI, St. Petersburg, Russia) using standard HF techniques of pollen preparation (Berglund & Ralska-Jasiveczowa 1986). The concentrations of pollen and spore grains per gram of dry sediment were calculated according to the marker grain method using tablets with Lycopodium spores (Stockmarr 1971). The identification of pollen and spore grains was carried out under the microscope Olympus BX-60 with magnification x 400 in the AARI (St. Petersburg, Russia), and mainly based on Kupriyanova & Aleshina (1972, 1978) and Reille (1992, 1995, 1998).

At least 200 pollen and spores were counted in every sample, with the exception of a few samples from the lowermost part of the core which do not contain a sufficient amount of pollen grains. We assumed that indeterminable, poorly preserved and mineralized pollen (including several broad-leaved species) and spores were obviously re-deposited taxa. The relative proportion of arboreal and non-arboreal pollen taxa (including pollen of aquatic plants) was calculated based on the sum of terrestrial pollen taxa. The relative proportion of pollen was calculated based on the tree and herb pollen sum; the percentage of spores was based on the sum of pollen and spores; the percentage of re-deposited taxa (Pterocarya, Pinaceae, Tilia, *Ulmus,* etc.) was based on the sum of pollen and re-deposited taxa (Berglund & Ralska-Jasiveczowa 1986). The TILIA plotting program was used for graphing the pollen data (Grimm 1991).

The chronology of the core is based on eight radiocarbon dates (Fig. 2) measured on bivalves using the accelerator mass spectrometer at the Leibniz Laboratory in Kiel (Germany). Original radiocarbon dates were converted into calendar years BP using CALIB 4.3, and a regional reservoir correction (Stuiver et al. 1998, Bauch et al. 2001).

DOWNCORE DISTRIBUTION PATTERNS OF POLLEN AND SPORES

According to AMS ^{14}C dating the studied core PS51/159-10 encompasses the last 12.8 cal. ka (Bauch et al. 2001). Due to high sedimentation rates (>110 cm y^{-3}, Bauch et al. 2001) in this region during the time interval between 12.8 and 9.6 cal. ka, the obtained pollen-and-spore assemblages from this core are the basis for a detailed reconstruction of high-latitude paleovegetation evolution during the postglacial times. The lowest sedimentary unit of the core (interval 400-485 cm) contains very few pollen grains. The extremely low pollen concentration and poor pollen preservation from these sediments make the calculation of pollen percentages impossible. Therefore, these results are not presented in the pollen diagram (Fig. 2).

The pollen and spore concentrations in the sediment samples from 0-400 cm reach 2500 grains per gram of dry sediment (Fig. 2). The pollen-spore spectra from these samples are

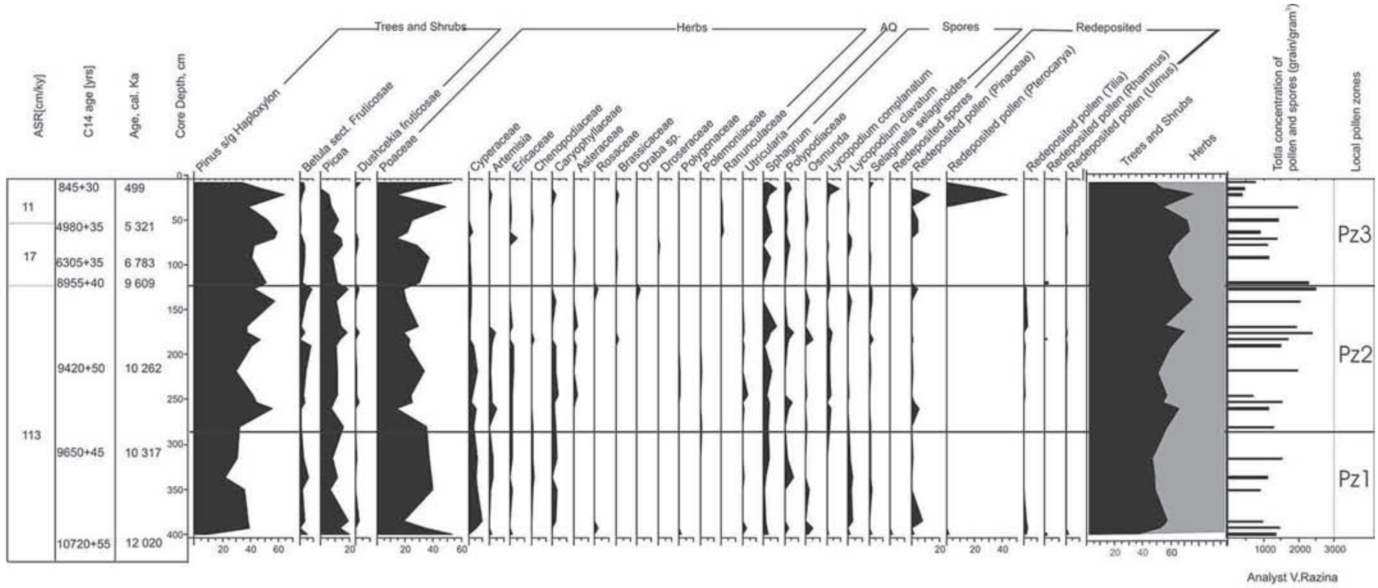

Fig. 2: Percentage of pollen and spore diagram of core PS51/159-10, NW Laptev Sea.

Abb. 2: Prozentdiagramm der Pollen-/Sporenverteilung im Sedimentkern PS551/159-10, NW Laptewmeer.

dominated by arboreal taxa (up to 73 %). Most of them belong to pollen of coniferous trees, transported over long distances. Pollen of these trees are typical for the spectra from the Laptev Sea Holocene and surface sediments (NAIDINA & BAUCH 1999, 2001). Among arboreal plants, pollen of *Pinus* subgen. *Haploxilon (Pinus pumila, P. siberica)* and Picea are the most abundant (up to 80 % in the group of trees and shrubs) in the studied core assemblages. Although pollen of *Betula* sect. *Fruticosae & B.* sect. *Nanae* (types) and *Dushcekia fruticosae* occur in most of the studied samples, their relative proportions in the spectra do not exceed 10 %. A general up-core tendency of an increase in relative abundances of tree and shrub pollen, and decrease in abundances of herb pollen grains is observed (Fig. 2), which gives evidence for the northward migration of the tree line in the Laptev Sea region during the postglacial time.

The group of nonarboreal plants is dominated by pollen of Poaceae (up to 60 %). From this group pollen of the small shrubs Ericaceae, grasses Cyperaceae, and herbs *Artemisia,* Caryophyllacea, Rosaceae, Ranunculaceae and other species are characteristic for the assemblage, but their relative proportions do not exceed 5-10 % in the core spectra. Spore plants are mainly represented by *Bryales, Sphagnum,* Polypodiaceae, *Osmunda, Lycopodium complanatum, L. clavatum, Selaginella selaginoides.*

The re-deposited group in the core sediments includes pollen and spores of Quaternary, Paleogene and Neogene plants. Most of the re-deposited forms are poorly preserved; grains are crumpled, flattened, crushed and sometimes undeveloped. The pollen spectra of core PS51-159/10 was zoned visually (Pz) using the major changes of dominant species recognized in the pollen-and-spore spectra.

Pz 1 (400-280 cm core depth)

This zone, radiocarbon-dated to the time interval between 11.8 and 10.3 cal. ka BP (Fig. 2), is characterized by the lowest relative abundance of arboreal pollen (down to 35 %), with predominance of pollen of *Pinus* subgen. *Haploxilon* (up to 40 %) and *Picea* (up to 20 %) transported over long distances by winds and riverine outflow to the Laptev Sea (see above). Pollen of *Betula* sect. *Fruticosae & B.* sect. *Nanae* (types) comprise less than 5 % and pollen of *Dushcekia fruticosae* occur sporadically. Pollen-spore spectra from this zone are characterized by the maximum amount of nonarboreal pollen (up to 50 %), represented mainly by Poaceae (up to 60 %) and Cyperaceae (up to 10 %). Among spores only *Lycopodium clavatum* and *Bryales* occur constantly. Spores of Polypodiaceae and *Selaginella selaginoides,* typical for wet landscapes, are marked in the uppermost part of Pz 1. Species composition and relative abundance of the plant group in Pz 1 suggest the prevalence of grass-sedge dominated vegetation with herbs (Caryophillaceae, *Artemisia,* Chenopodiaceae, Rosaceae) on the exposed Laptev Sea shelf between approximately 11.8 and 10.3 cal. ka BP.

Pz 2 (280-125 cm core depth)

This zone corresponding to the time interval 10.3-9.6 cal. ka BP, is characterized by a gradual increase in the total concentration of pollen and spore grains in the sediments (up to 2500 grains per g of sediment). A general tendency of increase of relative proportions of arboreal pollen (up to 70 %), mainly represented by *Pinus* subgen. *Haploxilon* (up to 50 %), is observed in this part of the core, which suggests a northward migration of tree and shrub line on the adjacent hinterland. The content of *Picea* pollen in this part of the core varies between 7 and 20 %. Relative abundances of *Betula* sect. *Fruticosae & B.* sect. *Nanae* (types) reach 10 % and proportions of *Dushcekia fruticosae* pollen in the spectra do not exceed 5 %. The decrease in abundances of sedge and grass pollen along with the occurrence of Ericales and various herbs (*Artemisia,* Chenopodiaceae, Caryophillaceae, Asteraceae, Brassicaceae, Polemoniaceae) gives evidence for a herbaceous tundra with rare plants, such as dwarf birch, willow and heather on the exposed Laptev Sea shelf. The sharp increase in relative proportions of *Sphagnum,* Polypodiaceae and *Selaginella* spores (up to 10 %) allows us to assume the development of wetlands and *Sphagnum* bogs in the nearby regions of the exposed shelf during the time interval of approximately 10.3 and 9.6 cal. ka BP.

Pz 3 (125-0 cm core depth)

This zone corresponds to the last 9.6 cal. ka. Although the relative abundance of dominant arboreal pollen taxa varies in a high degree within this zone (between 45 and 73 %), their total abundance constantly remains above the 60 % level (Fig. 2). A slight increase in abundance of *Pinus* subgen. *Haploxilon* pollen and a gradual decrease in the upper part of this Pz in abundances of *Picea* pollen are observed. The relative proportions of *Betula* sect. *Fruticosae & B.* sect. *Nanae* (types) and *Dushcekia fruticosae* pollen do not exceed 5 %. The pollen group of herbs is characterized by the predominance of Poaceae pollen and elimination of other herbs, which are represented in low content by Cyperaceae, *Artemisia,* Chenopodiaceae, Caryophillaceae, and Ranunculaceae. Because of the sharp decrease in sedimentation rates after 9.6 cal. ka (down to 11 cm y^{-3}, Bauch et al. 2001), we were not able to divide the upper part of the core (100 cm) into more detailed pollen zones.

VEGETATION HISTORY OF THE WESTERN LAPTEV SEA REGION OVER THE LAST 12 CAL. KA

During the Late Pleistocene regression, the shallow Laptev Sea shelf was sub-aerially exposed, and the arctic marginal plain extended 400-700 km north of its modern location, to about 78 °N incorporating all the present-day islands (Bauch et al. 2001). According to available bio- and geochemical data the specific vegetation named “tundra-steppe”, represented mostly by open grass-sedge associations with various cryoxerophiteous herbs (e.g., Yurtsev 2001), dominated in the southern Laptev Sea region (Lena River Delta) under cold and dry conditions during the Late Pleistocene (Andreev et al. 2002a, Schirrmeister et al. 2002, Sher et al. 2005). Climate amelioration started in this region at the end of the Sartan (Late Weichselian) stadial and correlates with the Bölling and Allerød warming (Pisaric et al. 2001, Andreev et al. 2002a, 2004b).

Similar tundra-steppe vegetation and extremely cryoxeric climatic conditions were reconstructed in the Taymyr Peninsula for the Late Glacial on the basis of radiocarbon-dated plant microfossils and pollen associations (Hahne & Melles 1999, Kienast et al. 2001, Andreev et al. 2002b, 2003, 2004a). Scarce steppe-like vegetation with Poaceae, Artemisia and Cyperaceae, and tundra-like herb communities with dwarf Betula and Salix dominated in the northern and central parts of the Taymyr Peninsula during the Sartan (Late Weichselian) stadial. The statistical information method shows that the coldest climate in this Arctic region was between approximately 20 and 17 ^{14}C ka BP, and a warming (Allerød Interstadial) with summer air temperature higher than today occurred at about 12 ^{14}C ka BP (Andreev et al. 2002b).

The destruction of the tundra-steppe biome in the Laptev Sea region was very rapid. Late-glacial pollen data show several warming events followed by a climate deterioration, which correlated with the Bölling and Allerød warming and middle and Younger Dryas cooling (Hahne & Melles 1999, Andreev et al. 2002b, 2003, 2004a). The late Pleistocene/Holocene transition at about 10.3-10 ^{14}C ka BP was characterized by major changes in the vegetation from predominantly open herb communities to shrub tundra ones in the Laptev Sea hinterland and considerable climate amelioration (e.g., Schirrmeister et al. 2002, Sher et al. 2005, Hahne & Melles 1999, Andreev et al. 2002a, b, 2004a).

Our pollen-spore records from sediment core PS51-159/10, obtained on the western outer Laptev Sea shelf, in the Anabar-Khatanga paleoriver valley (Fig. 1), allow us to distinguish several phases in the development of vegetation in the western Laptev Sea region for the last approximately 12 cal. ka. High sedimentation rates (~113 cm y^{-3}) observed in this core until 9.6 cal. ka BP (Bauch et al. 2001) offer the opportunity for detailed reconstruction of vegetation on the exposed western Laptev Sea shelf and the adjacent hinterland during the late Pleistocene/Holocene transition.

Phase 1 (Pz 1) dated back to the time interval between 11.8 and 10.3 cal. ka BP (c. 10.6-9.6 ^{14}C ka BP) generally corresponds to the end of the Younger Dryas stadial and the beginning of Preboreal periods (Khotinsky 1984). At this time the sea level was approximately 50 m below the modern level, and the major part of the shallow Laptev Sea shelf was sub-aerially exposed (Bauch et al. 2001). According to the aquatic palynomorph and ostracod records the study site located within the Anabar-Khatanga paleovalley was strongly influenced by riverine discharge until approximately 9.6 cal. ka BP (Klyuvitkina 2006, Stepanova 2004), which is confirmed by the high sedimentation rates observed in the studied core for this time (Bauch et al. 2001).

Our pollen-spore records give evidence for the development of grass-sedge vegetation, dominated by Poaceae with various herbs (Cyperaceae, *Artemisia,* Chenopodiaceae, Caryophillaceae, Rosaceae) on the exposed western Laptev Sea shelf. Maximum content of Cyperaceae pollen particularly between 11.8 and 11.0 cal. ka BP reflects the development of wetlands and habitat conditions such as flood-lands. This assumption is corroborated by the abundant green algae in the aquatic palynomorph associations (Klyuvitkina 2007) and reconstructed deltaic or river-proximal environments for this time. The presence of aquatic pollen (Utricularia) in the lower spectrum may evidence the development of bogs around the study area. Due to a very low content of shrub alder pollen *(Dushcekia fruticosae)* in these spectra we assume that shrub vegetation was not spread on the exposed Laptev Sea shelf.

Available pollen records for the Younger Dryas cooling, obtained from the southern coast of the Laptev Sea, within the Lena River Delta, give evidence for the prevalence of open herb-dominated communities with abundant Cyperaceae and few shrubs under cold but relatively moist climate (Pisaric et al. 2001). In the central and northern regions of the Taymyr Peninsula a decrease in Betula pollen percentages and an increase in the amount of herb pollen taxa (mostly Cyperaceae) correspond well with the Younger Dryas stadial, when the reconstructed mean July temperatures were about 3-4 °C cooler than at present and precipitation about 100 mm lower (Hahne & Melles 1997, 1999, Andreev et al. 2002b, 2003, 2004a). The Younger Dryas/Preboreal transition, which occurred in these regions c. 10.3-10.0 ^{14}C ka BP, is characterized by a significant increase in *Betula* sect. *Nanae* and *Salix* pollen, Polypodiaceae and *Sphagnum* spores and a significant decrease in herbs pollen content (Andreev et al. 2003). Similar but less pronounced changes in pollen-spore spectra we observed at the studied site from the western Laptev Sea shelf also around 10.3 ^{14}C ka BP (11.1 cal. ka BP; Fig. 2).

Phase 2 (Pz 2) encompasses the time interval between 10.3 and 9.6 cal. ka BP (c. 9.6-9.0 ^{14}C ka BP) and roughly correlates with the second half of the Preboreal and Boreal periods of the Holocene (Khotinsky 1984, Björck et al. 1996). During this time the sealevel in the Laptev Sea rose by approximately 10 m, flooding the 43-m isobath (Bauch et al. 2001). This caused a mainly southward retreat of the coastline and a landward shift of the Anabar-Khatanga paleoestuary to approximately 150 km south of the study site. Nevertheless the major part of the shallow Laptev Sea shelf remained sub-aerially exposed during this time interval (Fig. 1).

The notable increase of the windblown pollen of *Pinus* s/g *Haploxilon,* birch and shrub alder pollen in the spectra, and a sharp decrease of herbaceous pollen, first of all Poaceae and Cyperaceae, indicate the onset of a substantial change in vegetation and a trend to warmer climatic conditions around 10.3-9.6 cal. ka BP. The growing variance of herbs, represented by *Artemisia,* Caryophillacea, Asteraceae, Brassicaceae, Rosaceae, along with constant occurrence of Ericales gives evidence for the northward progradation of the herbaceous tundra with dwarf birch and willow. The increase in relative proportions of *Sphagnum* spore and *Utricularia* pollen allow us to assume the occurrence of wetlands and *Sphagnum* bogs in the nearby regions of the exposed shelf. The appearance of moss typical for the forest community *Lycopodium complanatum* may indicate the northward extension of the tree-line due to climate amelioration.

The considered time interval was characterized by the development of shrubby tundra with *Betula* sect. *Nana* and *Salix* in the northern regions of the Taymyr Peninsula and *Betula Nana – Alnus fruticosa* shrub tundra in its central part (Hahne & Melles 1999, Andreev et al. 2002b, 2003, 2004a). *Alnus fruticosa* reached the 75 °N latitude approximately 9.0-8.5 ^{14}C ka BP, and larch appeared in central regions (72 °N) about 9.4 ^{14}C ka BP (Andreev et al. 2002b, 2003). A Holocene temperature maximum between 10.2 and 9.2 14C ka BP is reported for the Severnaya Zemlya Archipelago, which is located approximately 200-300 km northwestward of the studied site (Makeev et al. 1991). Therefore, the revealed warming event in the marine records is in good accordance with the climatic warming trend observed in the nearby hinterland regions.

Our pollen results correlate well with those obtained from the Holocene sediment section of the Zhokhov Island, which is located northward of the New Siberian Archipelago as far as of 77 °N latitude. The shrub pollen maximum (dwarf birch, alder, willow) is most typical for the sediments formed during the time interval 10-8.5 ^{14}C ka BP, corresponding to the Preboreal period (Makeyev 1992).

The available pollen records for the Preboreal period from the Lena Delta area, which nowadays lies within the arctic tundra and typical tundra, indicates that shrubby *Alnus fruticosa* and *Betula exilis* tundra dominated in the northern and southern parts of the delta during this time (Pisaric et al. 2001, Andreev et al. 2004b). An increase of *Picea, Pinus* s/g *Haploxilon*-type, and *P. sylvestris* pollen reflects the increasing significance of long-distance transport. Climate reconstructions based on the pollen and chironomid records suggest that the climate during c. 10.3-9.2 cal. ka BP was up to 2-3 °C warmer than the present day climate (Andreev et al. 2004b). Other pollen and plant macrofossil data from the area (McDonald et al. 2000, Pisaric et al 2001, Andreev et al. 2002a) also imply that the warmest Holocene climate occurred during that time.

Phase 3 (Pz 3) encompasses the last 9.6 cal. ka BP (Fig. 2) and corresponds to the Atlantic, Subboreal and Subatlantic periods of the Holocene (Khotinsky 1984). Sedimentation patterns indicate that ASR steeply decreased at the studied site after 9.6 cal. ka BP from 113 cm y^{-3} to 11-17 cm y^{-3} (Fig. 1; Bauch et al. 2001). Due to continuous sea-level rise the Laptev Sea shelf was completely flooded at approximately 5 cal. ka BP, when the sealevel stabilized at its modern position (Bauch et al. 2001).

According to the published pollen records from the surrounding hinterland, forest *(Larix, Piceae, Pinus)* advanced to or near the current southern coastline of the Laptev Sea between 8.5 and 3.5 ^{14}C ka BP and retreated to its present position between 4-3 ^{14}C ka BP (McDonald et al. 2000, Pisaric et al. 2001, Andreev et al. 2002b). Pollen-based reconstructions show that the climate in the Laptev Sea region was relatively warm during 9.2-6.0 cal. ka BP, and both climate and vegetation became similar to modern-day conditions after 3.5-3.0 cal. ka BP (McDonald et al. 2000, Pisaric et al. 2001, Andreev et al. 2001, 2002b, Naidina & Bauch 2001). The warmest time was between 6 and 4.5 ^{14}C ka BP with fluctuations in temperatures and precipitation at that time. Mean seasonal and annual temperatures were up to 2 °C warmer than modern ones and annual precipitation was about 75 mm greater than today (Klimanov 1992, Klimanov et al. 1992, Andreev et al. 2001, 2002).

Because of very low rates of sedimentation, observed in the upper part of the core, we are not able to carry out detailed reconstructions of vegetation for the last 9.6 cal. ka BP (Fig. 2). Nevertheless, our pollen-spore records show an increase in relative abundances of long-distance transported pollen (mainly *Pinus* and *Picea*) and a decline of abundances and variety of shrub and herb pollen. This decline of pollen of local origin is obviously caused by the increasing distances, due to the continuing sea-level rise, of the study site from the land and rivers as the major sources of pollen and spores in marine sediments (Naidina & Bauch 1999, 2001). However, the relatively constant content of spores, dominated by *Sphagnum* and Polypodiaceae along with abundant Poaceae, may indicate the establishment of modern-like vegetation in the nearby coastal regions as high arctic tundra and arctic tundra with landscapes dominated by mosses and lichen vegetation, and scarce herbs.

Moreover, it is interesting to note the sharp increase in the content of re-deposited Cretaceous/Palaeogene pollen at around 1.5-1 cal. ka BP (Fig. 1). This event coincides with the interval of an increase of coarse sediment fraction in the studied core (TALDENKOVA et al. in press), which correlates with renewed iceberg production at the ice cap on the northern island of the Severnaya Zemlya Archipelago.

CONCLUSION

From the present pollen-and-spore study carried out on a marine sediment core obtained from the western outer Laptev Sea shelf within the Anabar-Khatanga paleovalley and a detailed AMS ^{14}C chronology, several phases in the development of vegetation in the western Laptev Sea region were distinguished for the last approximately 12 cal. ka. High sedimentation rates (~113 cm y^{-3}) before 9.6 cal. ka BP offer the opportunity for detailed reconstruction of vegetation on the exposed western Laptev Sea shelf and the adjacent hinterland for the late Pleistocene/Holocene transition.

During the time interval between 11.8 and 10.3 cal. ka BP, when the sea level was approximately 50 m below its modern position (BAUCH et al. 2001), grass-sedge vegetation, dominated by Poaceae with various herbs (Cyperaceae, *Artemisia,* Chenopodiaceae, Caryophillaceae, Rosaceae), developed on the exposed western Laptev Sea shelf. The maximum content of Cyperaceae pollen particularly between 11.8 and 11.0 cal. ka BP reflects the predominance of wetlands and flood-land conditions within the Anabar-Khatanga paleovalley. The pronounced changes in vegetation coincided with the Younger Dryas/Preboreal transition, which occurred in this region around 11.1 cal. ka BP.

The period 10.3-9.6 cal. ka BP is characterized by the onset of a substantial change in vegetation and a trend to warmer climatic conditions. The growing variance of herbs, represented by *Artemisia,* Caryophillacea, Asteraceae, Brassicaceae, Rosaceae, along with constant occurrence of Ericaceae gives evidence for the northward progradation of the herbaceous tundra with dwarf birch and alder.

After 9.6 cal. ka BP ASR steeply decreased in the Anabar-Khatanga paleovalley (BAUCH et al. 2001), and the studied pollen-spore spectra only outline the general tendency in the development of the vegetation in the western Laptev Sea region. The decline of pollen of local origin coincides with the continuing postglacial sea-level rise and reflects the increaseing distances of the study site from the land and rivers as the major sources of pollen and spores in marine sediments. The predominance of *Sphagnum* and Polypodiaceae spores along with abundant Poaceae indicates the development of mosses and lichen vegetation with scarce herbs typical for the modern arctic tundra landscapes.

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