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Vegetation of the Western Coast of the Baidaratskaya Bay at the End of the Late Pleistocene

A. A. Andreev*, P. E. Tarasov**, F. A. Romanenko**, L. D. Sulerzhitskii***, and K. I. Terekhov†, *

*Institute of Geography, Russian Academy of Sciences, Staromonetnyi per. 29, Moscow, 109017 Russia
**Moscow State University, Vorob'evy Gory, Moscow, 119899 Russia
***Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia
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Abstract—The results of palynological analysis of a section of unconsolidated deposits in the 12-m-high coastal escarpment of the Baidaratskaya Bay (68°51'N, 66°54'E), the southeastern part of the Yugorskii Peninsula, are outlined. The section includes the lower member of sandy loam rich in ice, presumably accumulated in the late glacial time. The upper peat member was accumulated between 8 and 4 ka ago. The rough boundary between peat and oxbow-lake loams with cryoturbation marks suggests a hiatus in sedimentation between 10.9 and 8.2 ka ago. The age of deposits was determined by the radiocarbon method. The results of palynological analysis reveal several phases of vegetation development in the study area and specify their time limits. We believe that the Allerod warming period was more favorable than the Middle Holocene for the development of arboreal–fritucose vegetation in the region now occupied by typical tundras. This is likely a result of the sea level rise at the end of the late Pleistocene and in the first half of the Holocene up to altitudes somewhat exceeding the recent level, when the influence of the ocean upon climate and vegetation was enhanced.

Key words: *unconsolidated deposits, terraces, peat, pollen analysis, radiocarbon dating, vegetation changes, sea-level fluctuations, late Pleistocene, Holocene.*

INTRODUCTION

The Yugorskii Peninsula and the western coast of the Baidaratskaya Bay are so far the least investigated areas of the Russian Arctic region. At the same time, their geographic position at the border between Europe and Asia, where they are open to the influence of the late Pleistocene glaciers of the Polar Urals and Pai Khoi, makes them the key areas for reconstructing the development of nature in the Arctic coast of Eurasia. New data, obtained through the interdisciplinary research of unconsolidated deposits of the organic–mineral Baidara section, greatly contribute to a better understanding of the evolution of vegetation and natural processes in the region during the period from the late Pleistocene up to the 4 ka ago.

Natural Environment in the Study Area

Our investigations were carried out in the southwestern coast of the Baidaratskaya Bay (Fig. 1). It is a shallow bay of the Kara Sea extending deep into the land between the Yugorskii and Yamal peninsulas. The surface of the coastal plain is flat or gently inclined, with abundant swamps and lakes. The Quaternary sediments are predominant sands with interbeds of loam, plant detritus, and peat. Northern spurs of the Polar Urals (altitude 500–1300 m) and Pai Khoi Ridge (467 m) are situated at a distance of about 50–80 km southwest and west of the section, and diminish the influence of the Atlantic air mass. As reported by the Ust Kara meteostation situated 100 km farther northwest, the July mean temperature is 7°C, the mean temperature in January is –22°C, and the frost-free period is 67 days. The precipitation in July is about 50 mm, the mean annual precipitation is 425 mm (*Spravochnik...*, 1967, 1969). As the 50 m isobath is detected at a distance of 150–200 km northward, near the Bay mouth, it may be suggested that the continental climatic parameters around the section were intensified at the very end of the late Pleistocene during the low sea-level stand. Low summer temperatures and relatively high humidity are responsible for a poor recent vegetation that is represented by moss, herbaceous, and fruticose tundras. Adjacent areas, occupied by the pretundra zone of thin forests of Siberian spruce and arborescent birch, are situated at a distance of 200 km south-southeast of the section, whereas fruticose alders are typical of the Pai Khoi and Polar Urals.

Samples for the palynological, botanical, and radiocarbon analyses were collected from the Baidara sec-

† Deceased.

tion (68°51′N, 66°54′E) in September–October, 1993. The upper 10-m-thick organic–mineral part of the coastal escarpment of the Baidaratskaya Bay (12 m high in total) is under the influence of intense wave abrasion. The lower part of the escarpment is covered by talus and unsuitable for sampling. The section is located near the border of an ancient lacustrine depression. In the northern part, the depression surface was cut off by wave abrasion, and its eastern part was affected by lateral erosion of a small river, flowing from south to north. Another river (Ngoyuyakha), whose source is in the Polar Urals, flows into the Baidaratskaya Bay, 3 km west of the section. In the uppermost part, the surface of the coastal escarpment is dissected by fractures (about 0.8 m wide and 0.6 m deep), formed above thawing ice wedges.

RESULTS AND THEIR INTERPRETATION

We present the obtained results by describing in parallel the lithologic–geochemical characteristics of the deposits and the composition of spore–pollen spectra. We believe that this is convenient for a better understanding of specific features of sedimentation and for a explanation of the origin of pollen and spores incorporated in sediments.

Late Glaciation Time

The lower part of the section at the depth of 6.2–10.3 m is mostly represented by gray and yellow–gray fine- to medium-grained sands with interbeds of coarse sand, gravel, and bluish loam (Fig. 2). Subhorizontal lamination (interbeds are about 1 cm thick) is characteristic of these deposits. The origin of gravel interbeds is of particular interest. The pre–Quaternary conglomerates at the base of the coastal cliffs may be regarded as their source. Changes in the granulometric composition of sediments throughout the section; alternation of sandy–gravel and loam beds; and a relatively high content of SO_4^{2-}, HCO_3^-, and Ca^{2+} ions in the extracted fluid suggest the continental genesis of the deposits. Konyakhin *et al.* (1991), who investigated the deposits in the 8–15-m-high terrace between the Baidara section and the Ngoyuyakha River mouth, arrived at the same conclusion. They consider the low content of easily soluble salts in the water extract (from 0.045% in sands to as much as 0.345% in clays) as evidence against the marine origin of grounds. Analyzing the diatom composition in samples collected from the lower part of the section, Z.V. Aleshinskaya (personal communication) suggested the alluvial origin of sediments.

Spore–pollen spectra in deposits at the depth of 6.2–10.3 m (Fig. 2) contain the rather abundant pollen of *Betula* sect. *Albae*, *Abies*, *Picea*, *Pinus* s/g *Haploxylon*, *Pinus* s/g *Diploxylon*, *Tilia*, *Corylus*, and *Juglans*. Spectra of a similar composition were detected in deposits of the Mikulino (Kazantsevo) time of the Pai

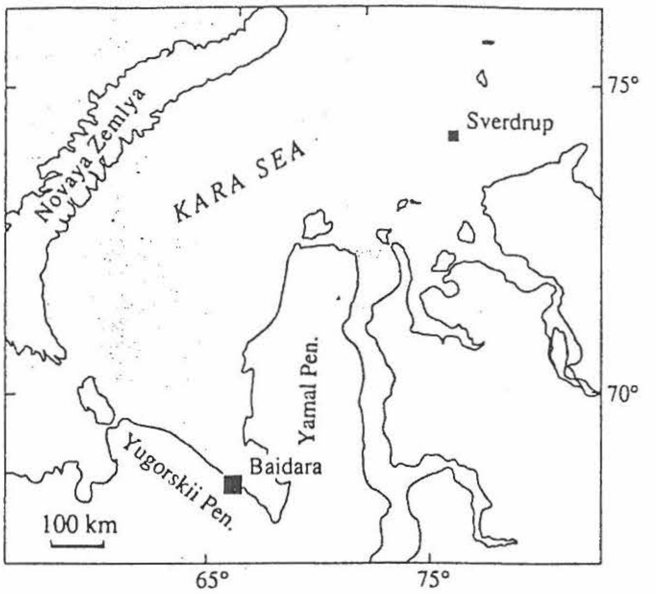

Fig. 1. Schematic map of the region with indicated localities of the Baidara and Sverdrup sections.

Khoi Ridge (Duryagina and Konovalenko, 1993); this may imply that a considerable part of spores and pollen was redeposited from older Pleistocene deposits. Some of pollen grains (*Juglans*, for example) may be pre-Quaternary in age. Contamination of glacial deposits with pollen of thermophylic plants redeposited from interglacial sediments was repeatedly mentioned in the literature, in particular, this is characteristic of the Russian plain (Chebotareva and Makarycheva, 1974). The criterion of identifying the redeposited pollen is its ecological incompatibility with pollen of local plants, such as dwarf birch, sedge, wormwood, grasses, heath, and of some others, regularly present in spectra in small amounts.

Opportunities for dating the above-described bed are relatively restricted. Konyakhin *et al.* (1991) dated the age of the 8–15 m terrace as late Pleistocene (Sartanian). The buried stratal ice at the base of the terrace is exposed along the shore for a considerable distance. The maximum thickness of the ice is 5 m, and its visual extension is 70–80 m. No ice sheets have been recovered at the Baidara section. This suggests a younger, late glacial age of the studied deposits.

The glaciation center that existed in the Pai Khoi Ridge and Polar Urals 18–20 ka ago and was the source area for glaciers spread up to the southwestern Yamal was suggested by many authors (*Razvitie landshaftov ...*, 1993). However, problems concerning the time of deglaciation and complete disappearance of the ice cover in the region still remain to be clarified.

In late glacial time (16–12 ka ago), the southeastern part of the Yugorskii Peninsula represented, most likely, an open landscape similar to recent arctic deserts. Under conditions of a severe climate, the very sparse

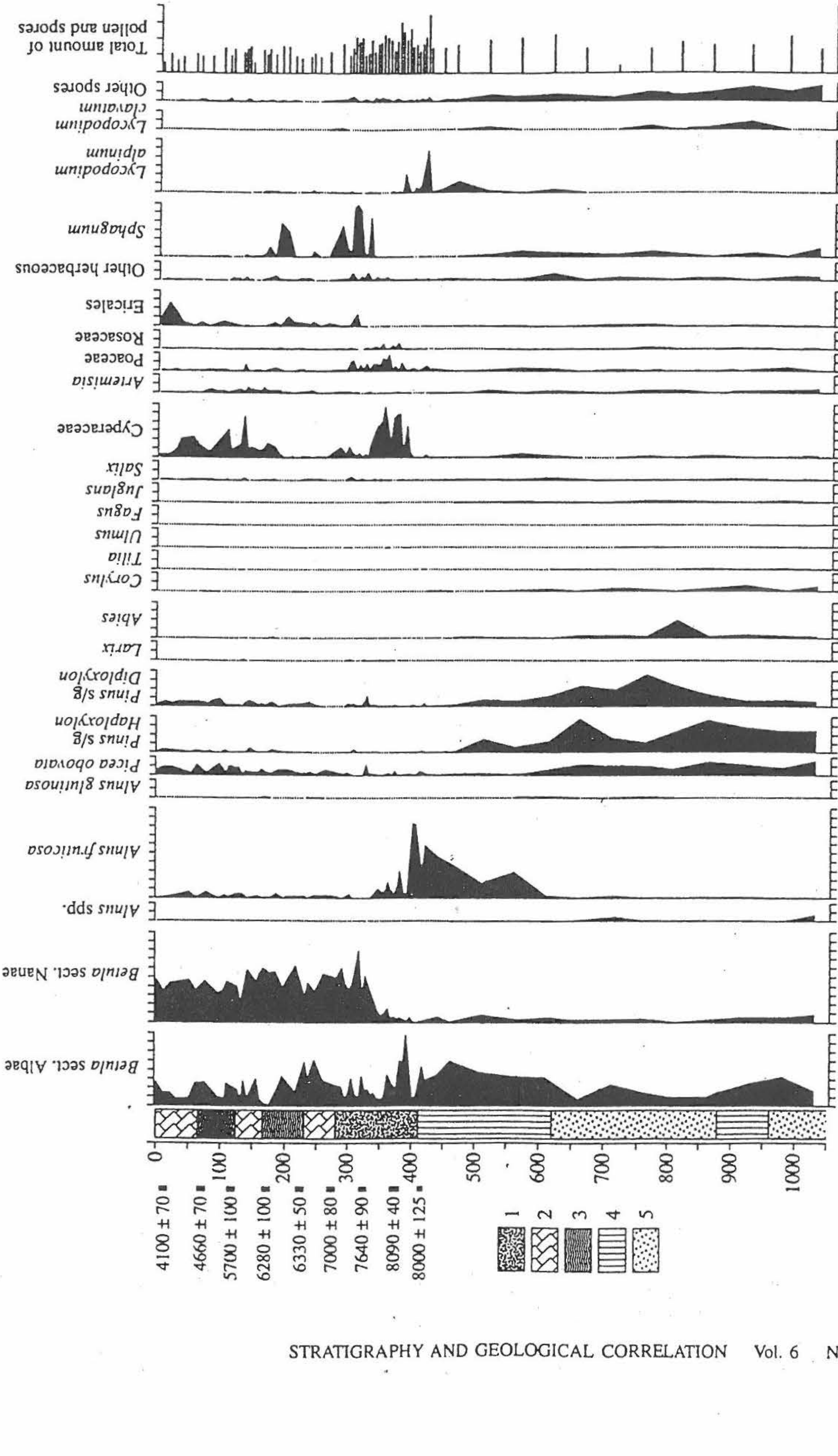

Fig. 2. Spore–pollen diagram for the Baidara section (percentages of pollen and spores are calculated relative to the total taxa amount in the spectrum: (1) sphagnum peat, (2) sedge–sphagnum peat, (3) sedge peat, (4) silty–pelitic sediments (loams and sandy loams), (5) sands with gravel interlayers.

vegetation did not produce an amount of pollen sufficient enough to be dominant in the spectra. Thawing of mountain glaciers intensified the river run-off, and the low sea level favored the erosion and redeposition of more ancient (pre-Quaternary including) sediments, as is evident from gravel interbeds and thermophylic pollen present in the section.

The Alleród Time

The silty-pelitic sediments occur higher in the section at the depth of 4.2–6.2 m. Their intense fragmentation and cryoturbation (wavy–lenticular cryostructure) suggest that they were accumulated under sufficiently severe climatic conditions.

The abundant pollen of *Alnus fruticosa* Rupr., arborescent birch, and spores of *Lycopodium alpinum* L. are characteristic of this interval. Simultaneously, the share of redeposited arboreal pollen and spores notably declines here (Fig. 2).

The upper horizon of the unit extending along a considerable part of the shore is represented by thin lenses of loam and sandy loam enriched in remains of alder stems and branches up to 4–6 cm in diameter. Their fragments are usually rounded in the course of fluvial reworking. Taking into account the abundance of alder pollen in deposits, we can hardly suggest redeposition of wood remains from older sediments. The radiocarbon analysis of a branch (about 6 cm in diameter), collected in 1991, yielded the age date of 10900 ± 120 years (MGU-1362). This implies that the silty–pelitic sedimentary unit can be attributed to the Allerod. The rough boundary with the overlying peat bed, marked by cryoturbation marks, suggests a hiatus in sedimentation in the past oxbow lake since the Younger Dryas. The hiatus may correspond to the time of local rearrangement in the hydrographic network and lake shoaling under conditions of climatic cooling and growing aridization combined with the low erosion base.

Our interpretation of spore–pollen spectra suggests that the thin birch forests of the forest–tundra type with a considerable alder admixture surrounded the studied locality in the Allerod time (about 12–11 ka ago). Dwarf birches (*Betula nana* L.) were also components of the vegetation cover. As was mentioned above, the present zone of arboreal vegetation is located farther to the south.

Holocene

The silty–pelitic member is overlain by a thick (0.0–4.2 m) peat bed. In coastal cliffs of the southwestern part of the Baidaratskaya Bay, the peat bed is discontinuous and consists of lenses extending for several dozens of meters. Radiocarbon dates for samples collected from the lower part of the peat are as follows: 80000 ± 125 years at the depth of 4.1–4.15 m (WAT-2924); and 8210 ± 110 (GIN-7862a), 8120 ± 90 (GIN-7862b), and 8090 ± 40 years (GIN-7862c) at the depth of 3.7–3.85 m. These dates suggest that the peat accumulation started about 8000–8200 years ago. Therefore, the recorded stratigraphic hiatus falls within the interval of 10900—8200 years ago.

In general, pollen spectra at a depth of 3.4–4.2 m resemble those of the Allerod time. The share of Cyperaceae, Poaceae, and Rosaceae is lower in this interval, where we detected simultaneously increased abundances of *Alnus fruticosa* pollen and *Lycopodium alpinum* spores.

The radiocarbon date of 7640 ± 90 years (GIN-7869) for the peat sample from the depth of 3.4–4.2 m corresponds to the end of the Boreal–early Atlantic period of the Holocene (about 8200–7700 years ago). The complete disappearance of alder pollen from the spectra is recorded at about 7700 years ago. According to palynological data, the vegetation of that time in the area under study was steadily dominated by birch forests of the forest–tundra type, but as compared with the Allerod time, the alder population considerably declined in them. This can be explained, apart from climatic reasons, by progradation of bogy landscapes in the area that was responsible for the accumulation of the lowland sedge peat. By the Atlantic time, the sea level rose up to the recent stand (Popov *et al.*, 1988) and, as a result, the erosion base and ground water level rose also. Moreover, the activation of peat-forming processes and an increase in the peat accumulation rates in the Atlantic period are characteristic of the entire northern Eurasia, which may be a result of the optimal ratio between the heat and humidity (Khotinskii, 1977).

From the depth of 3.40 m up to the surface of the section, the spectra are dominated by dwarf birch pollen and indicate the prevalence of fritucose coenoses in the peat bog landscape. The alder pollen is persistently present in spectra in small amounts, showing the insignificant role of these plants in the vegetation cover after 7700 years ago. Nevertheless, macroremains of alder discovered at a depth of 2.2–2.3 m from the peat bed 6330 ± 50 years old (GIN-7868) confirm its presence at the surface of the peat bog.

The content of arboreal birch pollen in the spore–pollen spectra periodically varies, declining up the section. The minimum content was recorded in the depth interval of 1.65–1.75 m marked by the radiocarbon date of 6280 ± 100 years (GIN-7860). We believe that variations in the content of arboreal birch taxa reflect the degree of their participation in the vegetation cover of the region that was mainly controlled by the temperature regime. Thus, the minimum content recorded 6300 years ago agrees well with the appreciable cooling that was typical of other regions of northern Eurasia, according to palynological evidence (Andreev *et al.*, 1989; Andreev and Klimanov, 1991). The abundance peaks of *Betula* sect. *Albae* pollen are recorded in peat layers that we refer to the last third of the Atlantic period of the Holocene (4500–6000 years ago). Radiocarbon dates of 5700 ± 100 years for the depth interval of 1.15–1.25 m (GIN-7867) and of 4660 ± 70 years for the depth interval of 0.65–0.75 m (GIN-7868) allow us to correlate the distinguished peaks with warming phases which occurred 6000, 5500, 5200, and 4600 years ago. A notable decrease in the abundance of *Betula* sect. *Albae* pollen is registered in the depth interval of 0.25–0.5 m. We correlate this level with a period of cooling that occurred about 4500 years ago (Khotinskii, 1977). Another warming marked by an increase in abundance of arboreal birch pollen took place 4000 years ago.

Changes in composition of herbaceous pollen and spores reflect the variability of coenoses at the peat bog surface. A high content of sphagnum spores in a depth interval of 1.75–3.40 m, associated with sedge and Ericaceae pollen, suggest an important contribution of sphagnum moss to the peat bed accumulation about 6300–7700 years ago. The final period of the Atlantic time is characterized by the nearly complete disappearance of sphagnum spores from the spectra predominantly enriched in sedge pollen. Sedge coenoses became widespread again at the peat bog surface 6300 years ago. The peak content of sedge pollen in the upper 20-cm-thick peat layer (4140 ± 70 years old in the depth interval of 0.15–0.2 m, WAT-2895) indicates another change in coenoses at the peat bog surface. It might have been associated with a transformation of the hydrological regime responsible for the bog desiccation and break in the peat accumulation about 4000 years ago.

The spruce pollen that is persistently present in spectra from peat layers increases in abundance during the last third of the Atlantic period. This indicates the northerly migration of the spruce distribution areas at that time.

Apparently, the vegetation cover around the peat bog in the middle Holocene consisted of thin birch forests and fruticose tundra areas alternating with open boggy landscapes.

A series of radiocarbon dates of 7000 ± 80 (GIN-7864), 6390 ± 50 (GIN-7865), 6280 ± 100 (GIN-7860), 5700 ± 100 (GIN-7867), 4660 ± 70 (GIN-7868), and 4140 ± 70 years (WAT-2895) was obtained for peat samples from different depth intervals. These dates indicate that peat accumulation continued during the entire Atlantic period with a rate of 1 mm/year and ceased about 4000 years ago.

Popov *et al.* (1988) distinguished a transgressive phase that occurred 6000–4500 years ago, when the sea level was presumably 2–3 m higher relative to the recent stand. The regressive phase took place 4500–2000 years ago. The conditions of a high sea-level stand and climatic warming of the Atlantic period were responsible for the expansion of boggy landscapes. The majority of bogs became dry as a result of sub-Boreal regression.

CONCLUSIONS

The palynological data obtained from the Baidara Section clearly indicate changes in vegetation of the southeastern part of the Yugorskii Peninsula at the end of the late Pleistocene and in the middle Holocene. Open landscapes with sparse vegetation (similar to modern arctic deserts) typical of the late glacial time were replaced during the Allerod by light birch forests of the forest–tundra type with a considerable admixture of alder and dwarf birch.

A hiatus in sedimentation in the interval between 10900 and 8200 years ago made it impossible to define the composition of vegetation at that time.

At the Boreal–Atlantic boundary (the Holocene), arboreal and fruticose birch taxa still prevailed in the vegetation, while the amount of alder notably declined. This presumably was associated with the increased development of bogs.

During the main part of the Atlantic and in the early sub-Boreal periods (7700–4000 years ago), vegetation was represented by birch tundra and light forests, alternating with open boggy areas mostly occupied by sedge and sphagnum assemblages.

Peat accumulation ceased about 4000 years ago, when the sub-Boreal regression of the Kara Sea started. At present, the studied locality is surrounded by typical tundra landscapes.

We think that the recognized changes in vegetation were controlled not only by the general evolution of the climate, but also by the position of sea level. The climatic warming of the Allerod time, when the sea level was rather low and the vast shelf areas of the Kara Sea represented the dry land, displaced the boundary of the arboreal–fruticose vegetation much further to the north than the warm Atlantic optimum, when the sea level was higher than now. Earlier we reported about similar events in the Sverdrup Island (the Kara Sea), which is now occupied by the sparse vegetation of the arctic desert. Palynological data obtained from the buried peat bog suggest that the island was covered with herbaceous and fruticose tundras 12–9.5 ka ago (Tarasov *et al.*, 1995).

As is evident from palynological data, the short-term climatic fluctuations (primarily, fluctuations of summer temperature under the sea cooling influence) were also characteristic of the middle Holocene. We distinguished and dated by the radiocarbon method the warming phases, which occurred about 6000, 5500, 5200, and 4000 years ago and were separated by cooling episodes.

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