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GEOGRAPHY

First Lake Record of Holocene Climate and Vegetation Change of the Northern Kuril Islands

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Abstract—Investigation of Pernatoe Lake sediments in the south of Paramushir Island has enabled us to obtain the first continuous pollen record of climate and vegetation changes in the north of the Kurile archipelago during the Holocene. Series of radiocarbon datings of between 10 000 ± 40 and 2180 ± 40 years ago are evidence that the beginning of sediments accumulation, found after borehole development, is related to the Early Holocene. Diatom analysis has shown several stages in the lake development: raised bog on the border of the Pleistocene and Holocene, lagoon formation resulting from the sea level rise over 9–6 ky, and freshwater lake formation 6 ky and up to the present. Climate warming during the period attributed to the boreal and Atlantic periods of the Holocene is reflected by the dominance of *Pinus pumila* and *Alnus serrulata* assemblages in vegetation cover. Wide dune fields were formed in the Sea of Okhotsk and the Pacific shores of Paramushir Island 5–4 ky. Strengthening of atmogenic processes is related to cooling of the climate and drying of some areas of the underwater slope.

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The territory covering Northeast Siberia, the lower Amur, Far East Maritime Territory, Sakhalin Island, and Kurile archipelago determines the key climatic and biogeographic relations between the Arctic and Subarctic, Temperate and Tropical zones. Palynological and diatom analyses and radiocarbon dating of Holocene sediments forming the sea, lake, and river terraces and peat swamps in the Southern Kuriles are evidence for complicated changes in the natural environment of Kunashir and Iturup islands during the time period corresponding to the Atlantic, Subboreal, and Subatlantic stages [1, 2].

The first continuous pollen record of climate and vegetation changes in the north of Kurile archipelago in the Holocene was obtained while studying the Pernatoe Lake sediments on Paramushir Island. Pernatoe Lake is situated near the shore of the Sea of Okhotsk, on Vasil'ev Peninsula (50°02′ N, 155°23′ E; altitude is 20 m), which is the southern end of Paramushir Island. The lake is divided from the seashore with a belt of sandy dunes up to 15–20 m height. The length of the lake is 1400 m, the width is 800 m, and the depth does not exceed 2 m. In the central part of the lake, boreholes were driven, and the following sediments were found with summarized thickness of 695 cm: 0–427 cm is gray siltstone with a varied complex of freshwater diatoms, a higher content of multigrained sand, and horizontal interlayers (15–30 cm) of fine grained back sand; 427–669 cm is dark gray, to black, siltstone with assemblages of mesohalob euryhaline diatoms, tephra interlayers (535, 560–561 cm), and there is an admixture of brown peat in the lower part of the layer; 669–695 cm is black peat. Peat in the base of the section was dated by radiocarbon at 10000 ± 40 years (CAMS-133389). The datings for siltstone, which overlies the peat, are the following: 8790 ± 50 years ago (CAMS-133392) at the depth of 667–668 cm, 8160 ± 40 years ago (CAMS-133390) at the depth of 646–646.5 cm, 7325 ± 30 years ago (CAMS-137384) at the depth of 584–586 cm. The upper layers of gray siltstone have datings at 2760 ± 35 years ago (CAMS-137160) at the depth of 80 cm and 2180 ± 40 years ago (CAMS-133391) at the depth of 37 cm.

Thus, radiocarbon dating shows that accumulation of sediments found by boreholes from Pernatoe Lake began in the Early Holocene. Palynological analysis of sediments enables us to distinguish five pollen zones (Fig. 1). A higher content of Cyperaceae pollen and *Sphagnum* spores in the sporo-pollen spectra of peat (pollen zone P1) reflects the local condition of a sedge-sphagnum bog. The simultaneous presence of *Sphagnum* spores and Ericaceae pollen in the spectra shows the evident role of heather assemblages in the vegetation cover. Shrub assemblages of *Pinus pumila* and birch trees were, most probably, very rare and included wormseed associations in dry areas of mountain slopes. Pollen of *Pinus pumila* is found as single

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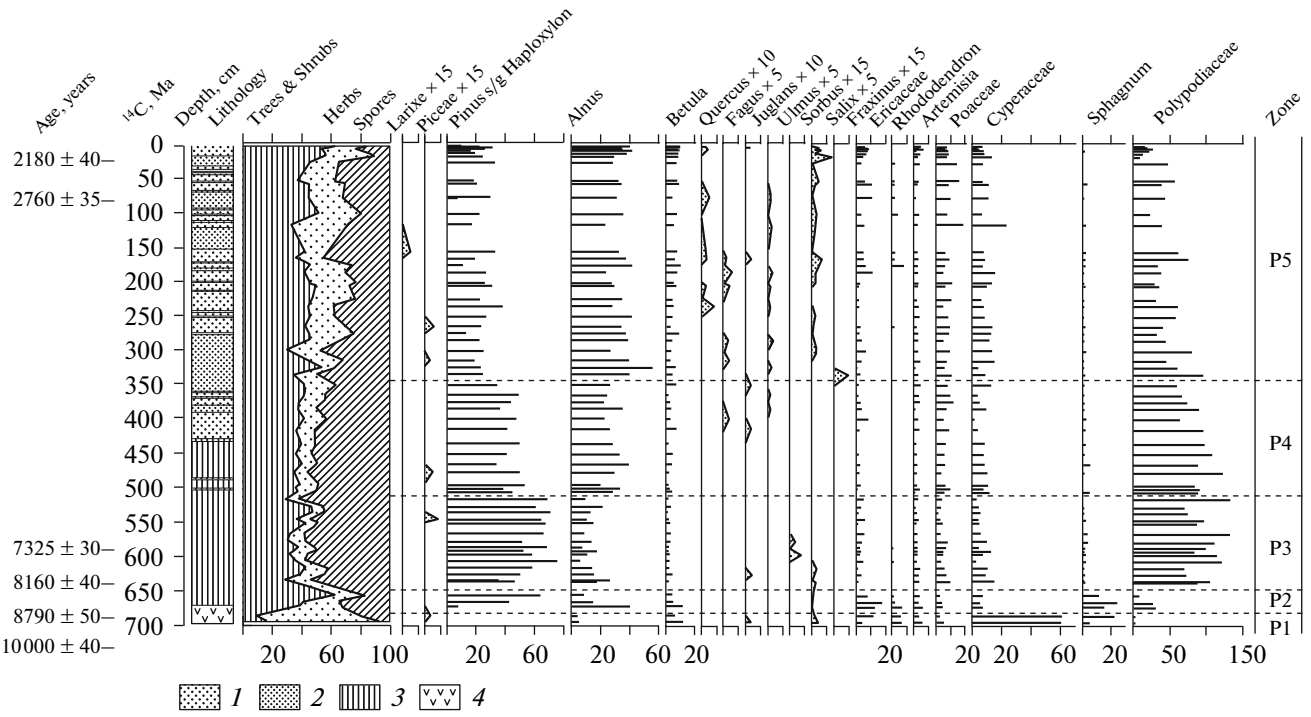

Fig. 1. Percentages of vegetation groups and the main pollen and spore taxons in spectra of Pernatoe Lake sediments (the percentages of pollen taxons is shown from the sum of all pollen grains; spore content is relative value from the total quantity of pollen separately for every spore taxon). Cytological characteristics: (*1*) gray siltstone with sand, (*2*) interlayers of black sand, (*3*) dark gray siltstone with tephra interlayers, (*4*) peat.

grains or is entirely absent, which is typically characteristic also for pollen spectra of vegetation corresponding to the stage that is transitional from the Pleistocene to the Holocene in Beringia [3]. The development of a raised bog is stressed by an abundance of *Pinnularia divergentissima* (Grun.) Cl. and *Eunotia exigua* (Bréb.) Rabenh., as well as by a sufficient participation of *Navicula soehrensis* Krasske and *Eunotia fallax* A.Cl. var. *fallax* in diatom palaeoassemblages.

In the period corresponding to the Boreal and Atlantic stages of the Holocene, the sea level rose and a lagoon formed. An active sea incursion is evidenced by the ultimate change in the ecological structure of the diatom complex with domination of *Melosira nummuloides*, (Dillw.) Ag., *Cocconeis scutellum* Ehr. var. *Scutellum, Paralia sulcata* (Ehr.) Cl. etc. Black siltstones, formed in the lagoon, are characterized by sporo-pollen spectra belonging to the three pollen zones (Fig. 1). Pollen zone P2 with radiocarbon dating of 8790–8160 years ago shows the first peaks of *Pinus pumila* and *Alnus serrulata* pollen, and reflects vegetation that developed during a substantial climate warming in the northern Kuriles in the Early Holocene. Such an abrupt increase in *Pinus pumila* pollen quantity for the sporo-pollen spectra of about 9 ky is also established for pollen records from lakes of Northern Okhotsk Region and the upper Kolyma River [3].

The spectra of the P3 zone stress a wide development of *Pinus pumila* brushwood on mountain slopes descending to the lagoon (the maximum of *Pinus pumila* pollen is 77%). A substantial role in vegetation cover was played also by *Alnus serrulata* and the Polypodiaceae family. Radiocarbon datings and vegetation cover reconstructions, indicative of a further climate warming, allow us to consider that this zone corresponded to the Atlantic stage of the Holocene.

The content of *Alnus serrulata* pollen is appreciably increases (40%) in spectra pollen of the P4 zone; however, dominance in spectra belongs to *Pinus pumila* pollen and Polypodiaceae spores (Fig. 1). These spectra, which reflect the dominance of *Pinus pumila* and *Alnus serrulata* shrub assemblages in the vegetation cover, characterize the upper layers of lagoon sediments and gray sandy siltstones from the depths of 427–344 cm.

The upper boundary of lagoon sediments at the depth of 427 cm corresponds to the maximal rise in sea level of the Holocene. By the radiocarbon dating of wood remains from coastal pebblestones of the 10-m terrace, located on the southwestern coast of Karaginskii Island, the transgression had its maximum at about 6370 ± 50 years ago (GIN-7778) [4]. The same age of the transgression maximum is established in more southern regions of Kamchatka's eastern shore (Kamchatka Peninsula, mouth of the Kamchatka

River) [5]. Carbon dates of 6390 ± 50 and 6000 ± 130 years ago characterize the maximal rise of the sea level in the Holocene (South Maritime transgression) in the southeast Maritime Region [6]. According to the data presented, the boundary of the lagoon and gray sandy siltstones in the sediment section of Pernatoe Lake is an age reference point, marking the beginning of freshwater lake formation in the place of the lagoon. The levels dated in lake gray siltstones show that the average rate of sediment formation in the lake, taking into account sediment consolidation at a depth and a wind sand-drift, was 0.8–0.9 mm per year. It allows us to date the boundary of the P4 and P5 pollen zones at about 5200–5100 years ago; i.e., it is close to the border of the Atlantic and Subboreal stages of the Holocene and corresponds to a drop in the sea level, recorded for southern parts of the Far East [3, 6, 7].

Sporo-pollen spectra of pollen zone P5, corresponding to the Subboreal and Subatlantic periods of the Holocene, are similar to the modern pollen (Fig. 1). In comparison with P1–P4 pollen zones, in spectra of the P5 zone, the content of *Alnus serrulata* pollen (55%) increases, but the content of *Pinus pumila* pollen decreased substantially (15–30%). Most probably, a more sufficient role in vegetation cover is played by *Betula fruticosa* Pall., along with the families Poaceae, Cyperaceae, and Ericaceae.

The ecological structure of the freshwater lake formed at the end of the Atlantic stage was substantially influenced by small water sources, determining the species and quantitative composition of diatoms to a great degree. The freshwater species *Staurosira construens* var. *Venter, Epithemia adnata*, and *Cocconeis placentula* var. *euglypta* (Ehr.) Cl. are dominant in palaeoassemblages. There are various small-valvate forms. Excluding *S. construens*, the complex is formed by *Staurosirella pinnata*, *Pseudostaurosira brevistriata*, *Fragilaria neoproducta*, etc. The presence of the Surirella genus is evidence for the small depths and sufficient warming of the water column.

A substantial admixture of sand in gray lake siltstones is a reflection of relatively wide dune fields formed in the Sea of Okhotsk and along the Pacific shores of Paramushir Island at about 5–4 ky. Strengthening of atmogenic processes as a result of drying of underwater slope areas can also be evidenced by interlayers of black fine-grained sand, similar to inwash sand on the modern beach of Pernatoe Lake. Most probably, the lake area was changed many times. The lowest levels of the lake are reflected by sand interlayers in the ranges of 152–120 and 30–15 cm, i.e., in periods corresponding to the end of the Subboreal and the middle of the Subatlantic stages of the Holocene, and caused by climate cooling and its greater dryness.

Thus, a complex study of Pernatoe Lake sediments has shown cyclicity in its development, caused by climate changes. The climatic optimum of the Holocene coincides with sea level rise and lagoon formation. Climate cooling at the boundary of the Atlantic and Subboreal stages of the Holocene is related to drying of underwater slope areas and activation of atmogenic processes.

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