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GEOGRAPHY

Glacial Refugium of *Pinus pumila* (Pall.) Regel in Northeastern Siberia

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One of the most glowing representatives of the Kolyma flora [1], *Pinus pumila* (Pall.) Regel (Japanese stone pine), is a typical shrub in larch forests of the northern Okhotsk region, basins of the Kolyma and Indigirka rivers, and high-shrub tundra of the Chukchi Peninsula. It also forms a pine belt in mountains above the forest boundary, which gives way to the grass–underbrush mountain tundra and bald mountains. In the southern Chukchi Peninsula, *Pinus pumila* along with *Duschekia fruticosa* (Rupr.) Pouzar and *Betula middendorffii* Trautv. et C. A. Mey form trailing forests transitional between tundra and taiga [2]. *Pinus pumila* pollen, usually predominating in subfossil spore-and-pollen spectra of northeastern Siberia, is found as single grains or a subordinate component (up 2–3%, rarely 10%) in spectra of lacustrine deposits formed during the last glacial stage (isotope stage 2) in the Preboreal and Boreal times of the Holocene. Sometimes, its content increases to 15–22% in spectra of lacustrine deposits synchronous to the last glacial stage near the northern coast of the Sea of Okhotsk [3], evidently indicating the proximity of Japanese stone pine thickets.

The pollen record of glacial lake sediments in the Kalgan Massif, which separates the Sea of Okhotsk basin and the southeastern Kolyma River basin, exhibits for the first time the considerable participation of *Pinus pumila* in local vegetation during the last glacial stage. The lake (arbitrarily named Julietta), 450 m long and 250 m wide, is located in a very wide valley (61°12′15″ N, 153°56′20″ E, altitude 880 m) on the poorly defined flat watershed between the upper reaches of creeks running into the Levaya Dzhugadzhaka and Pravaya Ivan'ya rivers of the Kolyma River system (Fig. 1). The lake bottom is even and gradually sinks toward the center to a depth of 635 cm. Larch forests (*Larix dahurica* Turcz. ex Trautv.) with undergrowth consisting of *Pinus pumila, Betula middendorffii*, and *Duschekia fruticosa* grow on moraines surrounding the lake. A sedge–hummocky tundra with willow shrubs is developed on the lake shores.

A 443-cm-long core recovered form the lake center characterizes the following complete lacustrine sequence (from top to bottom): (0–36 cm) light gray silt with a high water content; (36–116 cm) dark gray plastic silt with dissemination of black organic material; (116–128.6 cm) gray horizontally laminated silt; (128.6–128.8 cm) whitish gray volcanic ash; (128.8–168 cm) dark gray plastic silt; (168–278 cm) gray silt with fine horizontal lamination and numerous interlayers of black organic material (from 1–5 mm to 1–2 cm thick); (278–411 cm) bluish gray dense thin-laminated silt with interlayers of hydrophilic plants (0.5–2 mm thick); (411–441 cm) bluish gray fine-grained dense sand.

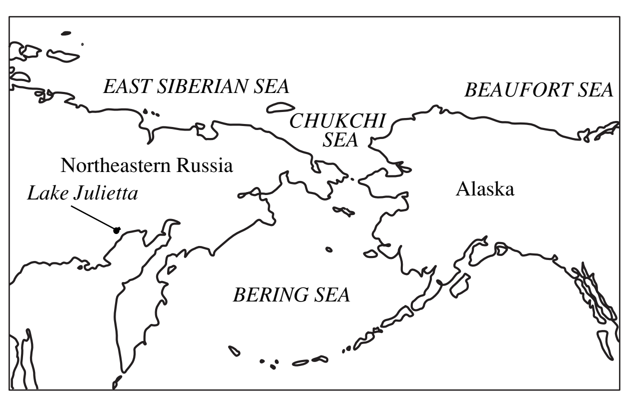

Fig. 1. Geographical position of Lake Julietta.

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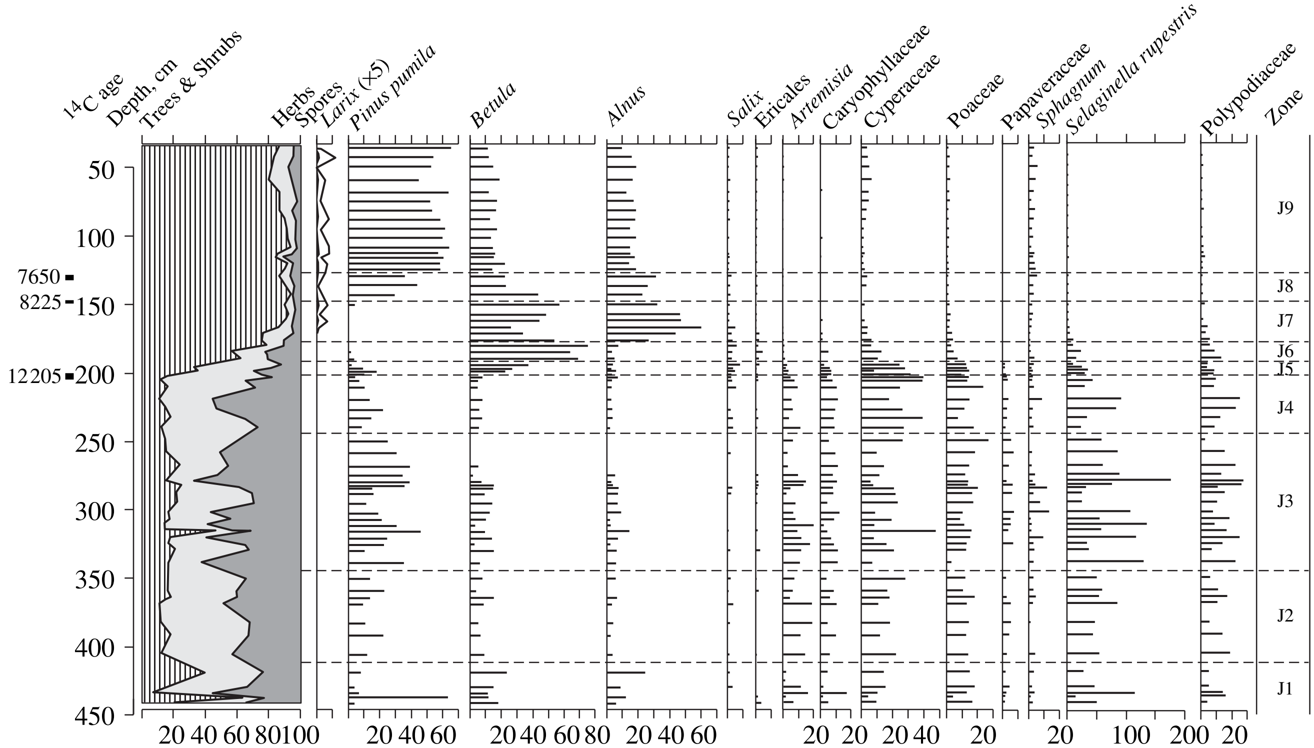

Fig. 2. Spore-and-pollen diagram of sediments from Lake Julietta (see text for explanations).

The radiocarbon dates reported in [3] are as follows: 8225 ± 35 yr B.P. (CAMS103332) established for a wood sample from the depth of 145 cm, 12205 ± 40 yr B.P. (CAMS103339) for a shrub branch fragment and hydrophilic plants from the depth of 200 cm, and 7650 ± 50 yr B.P. for a volcanic ash interlayer. These dates show the timing of extreme rearrangements of vegetation related to climate variations in the Pleistocene–Holocene transitional period, and the Boreal and Atlantic times of the Holocene. Computer-based extrapolation of the dates (Fig. 2) indicates that the pollen record of sediments from Lake Julietta spans the period from 2.3 to 26 ka B.P. (with allowance made for their compaction at depth). Based on changes in the ratio of principal pollen-and-spore taxons, the record is subdivided into nine pollen zones. The participation of each pollen taxon is expressed as a percentage from the sum total of all pollen grains, and the relative content of spores in the sum total of pollen grains is given separately for each spore taxon.

Spore-and-pollen spectra of four lower zones (J1–J4) are similar to spectra of grass pollen zones reflecting the vegetation of Late Pleistocene glacial stages in northeastern Siberia [3]. They are also characterized by high contents of Poaceae, Cyperaceae, *Artemisia*, Papaveraceae, and Caryophyllaceae pollen and especially *Selaginella rupestris* spores. Unlike spectra of the typical herb pollen zone, spectra of zones J1–J4 comprise a noticeable percentage of pollen of Middendorff's birch (up to 15–20%) and alder grove (up to 14–23%). However, their contents are substantially less than those in spectra of the Late Pleistocene Interstadial (isotopic stage 3) [3]. The main distinctive feature of spectra of zones J1–J4 is the constant presence of *Pinus pumila* pollen, the maximum amount (40–45%) of which was established in Zone J3 (about 14.5–20.5 ka B.P.). *Larix* pollen is missing from spectra of zones J1–J6. The upper boundary of larch forests probably did not reach the level of the glacial valley of Lake Julietta. Thin forest communities occupied the most favorable areas in deep valleys near the Kolyma River channel. Based on data of pollen zones J1–J5, the regional vegetation represented a patchwork of different communities ranging from an intermittent cover of wormwood, different herbs, and Siberian lycopod on dry stony slopes to humid and moderately humid sedge, sedge–gramineous communities on low slopes and lake shores. Development of stony areas is emphasized by the association of spores of Polypodiaceae and *Selaginella rupestris*. The pollen spectra suggest that mountain slopes were covered with abundant *Pinus pumila*, which is susceptible to seasonal thawing and freezing. This fact indicates the development of a thick snow cover that should form from early autumn to mid-autumn when daily temperatures begin to fall. Consequently, the "traditionally dry" month of January in the Kolyma region and northern Okhotsk area had no adverse effect on *Pinus pumila*.

Rearrangement of vegetation caused by climate warming about 12.2 ka B.P. is confirmed by spore-and-pollen spectra of Zone J5. A sharp increase in the percentage of *Betula* pollen (up to 75%) in spectra of Zone J6 (11.0–10.6 ka B.P.) indicates that herbaceous tundra and the belt of Japanese stone pine predominating in the Younger Dryas were replaced by dwarf birch tundra. Hence, as in other pollen records of lacustrine sediments in the upper reaches of the Kolyma River and northern Okhotsk region, spectra of sediments of Lake Julietta do not reflect climatic cooling in the late Dryas [3].

Zone J7 characterizes the vegetation of the Boreal time of the Holocene. The prevalence of *Alnus* and *Betula* pollen in spectra of the zone indicates wide development of birch–alder communities. *Larix* pollen appears in this zone for the first time, suggesting the distribution of larch forests with a rich undergrowth of *Duschekia fruticosa, Betula middendorffii*, and *Salix* sp. in the Lake Julietta valley. The upper boundary of Zone J7 coincides with the first Holocene peak of *Pinus* pollen (Zone J8) dated at 8.0 ka B.P. Maximums of *Pinus pumila* pollen are characteristic of Zone J9, the lower boundary of which coincides with the boundary of the Boreal and Atlantic times of the Holocene. Zone J9 spans the Atlantic and Subboreal time intervals. A constant and relatively high (up to 5%) content of *Larix* pollen in the spectra of this zone reflects the distribution of larch forests (with a close stand) in river valleys and thinner larch forests on mountain slopes, which give way to the belt of Japanese stone pine.

Thus, the first palynological data on evolution of the Late Pleistocene vegetation of the Kalgan Massif indicate that the Japanese stone pine continued to grow in northeastern Siberia during the glacial stage and did not "migrate" from southerly regions because of climatic warming. Spectra of zones J1–J4 also show that Middendorff's birch and alder grove formed sparse populations in the glacial stage. Hence, northeastern Siberia in the Last Glacial Maximum was a refugium not only for Arctic herbs and underbrush, but also for Boreal trees and shrubs, including not only the main forest-forming species *Larix dahurica* Turcz. ex Trautv., but also arboreal species, such as *Picea obovata* Ledeb., *Chosenia arbutifolia* (Pall.) A. Skvorts., *Populus suaveolens* Fisch., *P. tremula* L., *Alnus hirsuta* (Spach) Turcz. ex Rupr., *Betula lanata* (Regel) V. Vassil., *B. platyphylla* Sukacz., and *B. cajanderi* Sukacz., which grow in the region at present. New data reported in the present communication may be of prime importance for understanding the evolution of the Beringia environment, which played a crucial role in the formation of Arctic and Boreal climates and biota.

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