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Evolution of Lake Paleolotos (the south of the Russian Far East) in the Middle Pleistocene

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ABSTRACT

This paper presents recently obtained palebotanical data regarding the evolution of Lake Paleolotos in the Middle Pleistocene. Its evolution was more complicated than the development of the adjacent lakes in the coast of Peter the Great Bay (the Sea of Japan). The Middle Pleistocene lacustrine sediments accumulated in the downstream of the Tumannaya River (the most southwestern area of Primorye, Russia Far East) were studied using diatom and pollen analytical methods. We found that the Lake Paleolotos arose during Marine Isotope Stage 11 (MIS 11) and disappeared during MIS 6. For more than half of its existence (MIS 11–8), it was a freshwater oligotrophic basin with a depth of at least 20 m, with clear waters and poor organic matter content. The lake occupied most of the modern accumulative plain on the left bank of the Tumannaya River, reaching a size of at least 10–12 km across. During MIS 7–6 Lake Paleolotos turned into a shallow-water basin (its depth most likely did not exceed 1–3 m) of a eutrophic type with turbid waters rich in organic matter. Palynological data suggest that during MIS 11, 9 and 7 the area adjacent to the Lake was covered with coniferous/broad-leaved forests with presence of some thermophilic plants of North China and North Korea Flora (*Castanea*, *Celtis*, *Magnolia*, *Tsuga* and Cupressaceae). This indicates that vegetation zones were displaced by about 500–700 km to the north relative to their present position. During periods of cooling they were replaced by coniferous/small-leaved forests with the participation of shrub species of birch and alder (MIS 10) and coniferous/small-leaved forests consisted of pine, birch, and spruce with the participation of elm and oak (MIS 8 and 6).

1. Introduction

In spite of the fact that the paleobotanical data obtained from different boreholes complement each other, lacustrine sediments, when interpreted paleogeographically, provide more reliable representation about the evolution of the natural enveronment

The evolution of the Middle Pleistocene (MIS 11–6) lakes is most interesting and poorly studied in the Quaternary history. Lacustrine sediments are a reliable source of paleogeographic and paleobotanical information and preserve detailed records, which fix the natural evolution of ecosystems not only of a particular lake and its drainage basin, but also of larger areas of a regional scale. They provide the continuous registration of the changes in the structure of the diatom and pollen records. In spite of the fact that the paleobotanical data obtained from different boreholes complement each other, lacustrine sediments, when interpreted paleogeographically, provide more reliable representation about the evolution of the coastal lakes. The diatom studies of lacustrine and alluvial-lagoon sediments help in our understanding of the Quaternary evolution of the costal lakes.

Middle Pleistocene lacustrine sediments have very limited distribution in the south of the Russian Far East. Their thickest of strata is present in the sediments of the shelf of the Peter the Great Bay (Mechetin et al., 1983; Khershberg et al., 2010) and in the Prikhankayskaya depression (Muratova et al., 1978; Korotky et al., 2002, 2007). Later the Hydrogeological Expedition of Primorgeologia has carried out the large volumes of drilling. As a result it was determined that the accumulative plain in the mouth of the Tumannaya River was composed of thick strata of lacustrine sediments (Pavlyutkin and Belyanina, 2002). However, they were studied only by the method of spore-pollen analysis (Belyanina and Belyanin, 2014), and one of the most informative paleobotanical groups – diatoms remained outside the field of research. In this article we reconstruct the evolution of Lake Paleolotos based on the diatom studies of lacustrine and alluvial-lagoon sediments and correlate the obtained data with climatic fluctuations, which are well reflected in

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the previously obtained pollen records.

2. Materials and methods

2.1. Study area

Modern Lake Lotos is a small freshwater lake in the extreme south of the Russian Far East. It is located at the mouth of the Tumannaya River (at 42°25′ N, 130°39′ E) at the distance of 8.8 km to the west of the coast of Peter the Great Bay (the Sea of Japan) (Fig. 1). The water surface area of Lake Lotos is about 12.3 km^2, its depth does not exceed 1.4–2 m, and the water surface of the lake is located at a height of about 2 m above the sea level. The catchments' area of the lake is 16.9 $кM^2$. The lake has a periodically operating channel, which flows into the sea. The lake is surrounded from the north, the west, and the east by the low hills with swampy small valleys. In the south, the lake is framed by a low riverbed swell, up to 2 m, behind which an accumulative plain of the Tumannaya River, is located. The lake appeared in the Late Holocene, no more than two thousand years ago (Mikishin et al., 2008). It is not related to the Middle Pleistocene paleolake.

The climatic conditions of the modern basin of Lake Lotos and the accumulative plain at the mouth of the Tumannaya River depend on the geographical location and local natural features. Chernye Mountains protect the area from the north winds, leaving it open to warm south and southeastern air currents. In summer the sea and air masses are warmed by the East Korean Current (Chubar, 2000). This explains the favorable conditions for the development of vegetation: the high positive (3021 °C) and low negative (657 °C) sums of temperatures, the high average annual air temperature (6 °C), and a long growing season (eight months). Annual precipitation ranges from 680 to 1080 mm, and most of it falls in summer. Fogs are frequent in spring and in summer (Agroclimatic …, 1960). Besides, this area is located in the zone of influence of waves of dry and warm air such as dry winds, periodically penetrating in late spring – early summer from northeastern China (Sokolov, 1958).

The Lake Lotos basin is located in the contact zone with the Manchurian and North China floristic provinces (Komarov, 1908). This area is known for its significant vegetation diversity (Valova, 1964; Chubar, 2000). Many plants grow there on the northern border of their ranges; therefore they are sensitive to even weak abiotic changes.

Moist and wet reed-grass, sedge, and forbs-reed-grass meadows, and grass mires occupy the shores of Lake Lotos and the accumulative plain in the Tumannaya River mouth. The water surface of the lake is partially covered with thickets of *Nelumbo komarovii*, the light forests from *Quercus dentata* and *Quercus mongolica*, with small participation of *Fraxinus rhynchophylla*, *Tilia amurensis,* and *Tilia taquetii* (Valova, 1964; Chubar, 2000).

2.2. Drilling and sampling

Boreholes 26, 28, and 31 were drilled on the accumulative plain in the lower reaches of the Tumannaya River (Fig. 2, Tables 1–4). The samples of the sediments were taken from the boreholes at the intervals

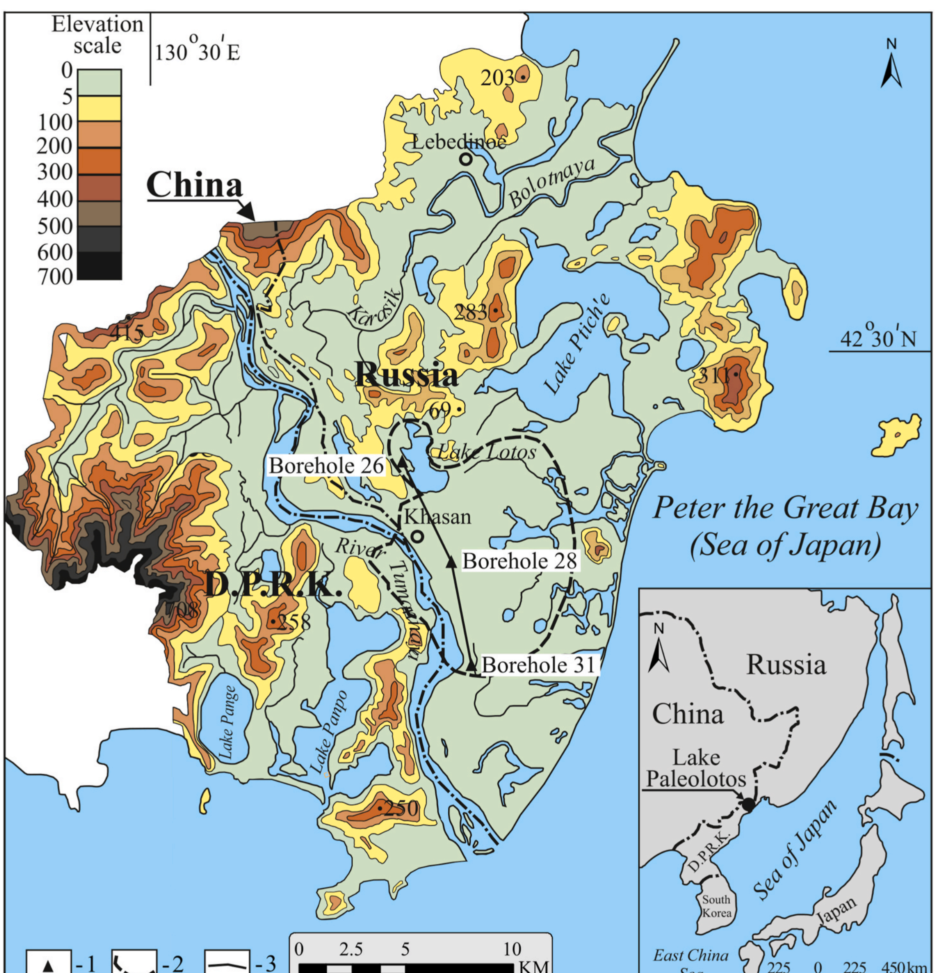

Fig. 1. The map of location of modern Lake Lotos and the accumulative plain at the mouth of the Tumannaya River. 1 – studied boreholes, 2 – the estimated position of the coastline of Lake Paleolotos in the Middle Pleistocene, 3 – longitudinal profile.

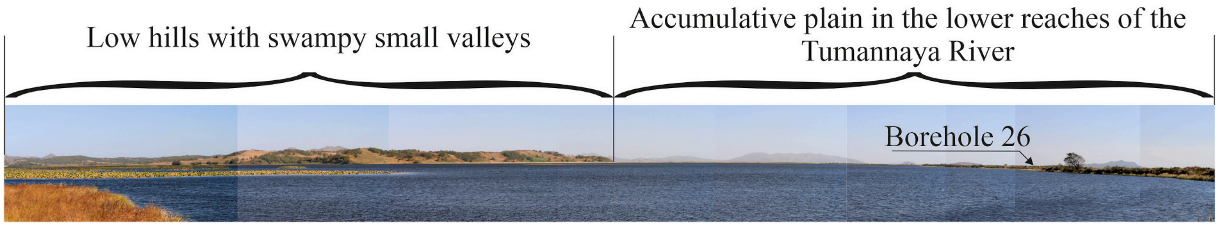

Fig. 2. Field photo of the southern and eastern coast of modern Lake Lotos.

Table 1
The location of boreholes in the mouth of the Tumannaya River.

Boreholes	Location	Total length of the boreholes (m)	Altitude (m a.s.l.)
26	42°26′16″74.4 N, 130°39′07.13″ E	86.6	2.0
28	42°25′41″87.6 N, 130°39′19.82″ E	97.0	2.4
31	42°22′33″11.1 N, 130°40′44.45″ E	70.0	5.0

Table 2
Lithology of the sediments from borehole 26.

Lithology	Range, m
The fragments of weakly rounded pebbles	86.6–76.2
Greenish-gray loam with admixture of coarse sand	76.2–73.8
Interlacing of gray sandy loam and gray and greenish-gray loam. At the base of the layer there is an accumulation of grains of vivianite and plant detritus	73.8–62.0
Fine-grained gray sand	62.0–61.1
Greenish-gray loam, horizontally layered, with mica and vivianite grains. At the base of the layer – sandy loam	61.1–56.2
Sandy loam with thin layers of greenish-gray loam with vivianite grains	56.2–55.1
Sand, greenish gray, fine to medium grained	55.1–54.6
Greenish-gray sandy loam, thin-layered with mica	54.6–50.9
Thin-layered of greenish-gray loams and sandy loam with vivianite grains	50.9–39.3
Gravel, pebbles with mixed-grained sand	39.3–37.3
Greenish-gray loam, silty, with fine horizontal stratification. At the bottom of the layer is replaced by gray sandy loam	37.3–33.9
Pebbles, gravel with sand and fine gravel	33.9–32.4
Interlacing of gray sand and loam	32.4–27.9
Interlacing of gray loam and sandy loam	27.9–21.9
Dark gray loam with layers sandy loam with shell detritus	21.9–10.9
Dark gray sandy loam with plant detritus, wood remains and shells	10.9–6.9
Yellow gray sand	6.9–1.6
Loam	1.6–0.0

Table 3
Lithology of the sediments from borehole 28.

Lithology	Range, m
Andesite porphyrites, weathered	98.0–76.0
Loam yellowish brown	76.0–62.0
Sandy loam, greenish-gray, with weathered andesites and porphyrites	62.0–55.0
Gray-greenish loam, with horizontal stratification, with thin interlayers of gray mica sandy loam, with grains of vivianite	55.0–29.0
Gray loam, micaceous	29.0–28.0
Sand, gray, fine-medium-grained, polymictic, micaceous	28.0–22.5
Gray loam, micaceous, with interlayers of gray sandy loam	22.5–21.0
The sand is fine-medium-grained, brownish-yellow, polymictic	21.0–12.0
Fine-medium-grained sand, polymictic, gray	12.0–4.0
Fine-medium-grained brownish-yellow sand, micaceous, with interlayers of bluish-gray micaceous loam	4.0–2.0
Brownish-gray loam with horizontally layering, with a thin (0.1 m) sand interlayer	2.0–0

Table 4
Lithology of the sediments from borehole 31.

Lithology	Range, m
Pebbles and small andesite boulders with sand	66.0–70.0
Dark gray mica sand	66.0–65.0
Black loam, horizontally layered	65.0–64.0
Dark gray sand, with grains of vivianite	64.0–62.0
Dark gray sandy loam, micaceous, with vivianite grains, plant detritus and fragments of mollusk shells	62.0–54.0
Dark gray sandy loam, mica, with vivianite; at a depth of 54 m - small remains of wood, plant detritus and seeds	54.0–49.0
Dark gray sandy loam, horizontally layered. The layering is thin, in the interval 38–39 m - sand and vivianite grains	49.0–36.0
Dark gray sandy loam, horizontally layered, micaceous, with mollusk shells	36.0–30.0
Gray sandy loam, with poorly expressed horizontal stratification, with grains of vivianite and shells of mollusks. At a depth of 26 m - shells of mollusks and wood remains	30.0–24.0
Dark gray mica sand with vivianite and mollusk shells	24.0–23.0
Dark gray silty loam, micaceous, with vivianite and accumulation of mollusk shells	23.0–18.0
Dark gray sandy loam, mica, with rare grains of vivianite and fragments of shells of mollusks	18.0–12.0
Silty sandy loam, bluish-gray, mica	12.0–10.0
Interlayering of yellow-brown sandy loam, mica and fine-medium-grained sand	10.0–6.0
Yellow-brown sandy loam, micaceous, with interlayers of fine-grained sand, with a thin oblique layering	0–6.0 M

of 5–10 cm. Sampling and the lithological description of drill cores were carried out by B.I. Pavlyutkin (Far Eastern Geological Institute FEB RAS), and a palynological analysis was carried out by L.P. Karaulova (Primorgeology) and N.I. Belyanina (Pacific Geographical Institute of FEB RAS). A diatom analysis was carried out by Yu.A. Mikishin (Far Eastern Geological Institute FEB RAS).

2.3. Diatom analysis

Sixty one samples were studied from boreholes 26, 28, and 31. Diatom samples were prepared using the standard procedures (Proshkina-Lavrenko, 1950, 1974; Gleser et al., 1974). The species composition of diatoms was determined in permanent slides using an Axioscop microscope at 1 200× magnification. More than 250–300 frustules were counted in each slide. The number of diatom frustules per 1 g of air-dried sediment was counted. Diatom species were identified following (Krammer, 1988; Krammer and Lange-Bertalot, 1986); Krammer, 1991; Gleser et al., 1974; Gleser and Makarova, 1992). The percentage content was calculated from the number of taxa. The ecological data given by the above-mentioned authors enabled most taxa to be grouped according to their habitat, salinity, pH, and biogeography. The distribution of dominant and subdominant species was used to infer diatom assemblages. The results of the diatom analysis are plotted in diagrams using Tilia v. 2–0–41 software (Grimm, 2004).

2.4. Correlation

The paleobotanical data were correlated using the General

Stratigraphic Scale of the Quaternary System (Borisov, 2009). The age division of the Pleistocene is given in accordance with Marine Isotope Stages (MIS) (Bassinot et al., 1994).

3. Results

3.1. The lithology features of sediments

A significant amount of drilling work made it possible to establish that under the layer of the Upper Pleistocene-Holocene estuarine sediments a stratum of greenish-gray thin-layered fine-sandy-silty rocks was exposed (Tables 2–4). The layering character is clearly seasonal: microlayers consist of two elements – fine sandy and silty. The microrhythm thickness does not exceed 1–2 mm. At the base they are underlain by weakly rounded pebbles, crushed stones and porphyrites, cemented by sandy loam. They are overlapped by the layers of the Late Pleistocene sediments of alluvial-marine genesis and the Holocene sediments – sands, sandy loams, and loams.

3.2. Borehole 26

The most complete and representative data on diatom diversity were obtained from borehole 26 (Fig. 3). According to the ratio of ecological groups of diatoms in borehole 26, two diatoms assemblages are distinguished.

3.2.1. Lower diatom assemblage (interval 76.2–47.4 m from the surface)

Freshwater planktonic species dominate among diatoms. These are *Aulacosira alpigena*, *Aulacosira granulata*, *Stephanodiscus niagarae* var. *insuetus*. Less often *Aulacosira distans*, *Discostellastelligera*, and *Fragilaria rumpens* are noted. Some of the discovered species of the genus *Aulacoseira* are extinct now. Of the epiphytic diatoms, *Pinnularia borealis*, *Pinnularia viridis*, *Pinnularia borealis, Fragilaria rumpens*, *Stauroneis acuta*, *Synedra balthica*, *Gyrosigma acuminatum* var. *gallicum*, *Gyrosigma kuetzingii*, *Epithemia gibba*, *Encyonema ventricosum*, *Navicula cryptocephala,* and *Luticola mutica* are more common than others. Most of the species are typically freshwater – indifferents. Mesohalobic diatoms are found in small quantities, represented mainly by *Diploneis smithii*. Inhabitants of mires – *Pinnularia viridis* and *Eunotia* species are present.

In relation to pH, the prevailing number of flaps belongs to alkaliphilic diatoms, and by the geographic location – to the boreal and north-boreal species (the number of the latter exceeds 50%). By belonging to saprobic groups, the flaps of xenosaprobic (26–51%) and oligosaprobic (20–45%) diatoms, inhabiting clean waters with a small

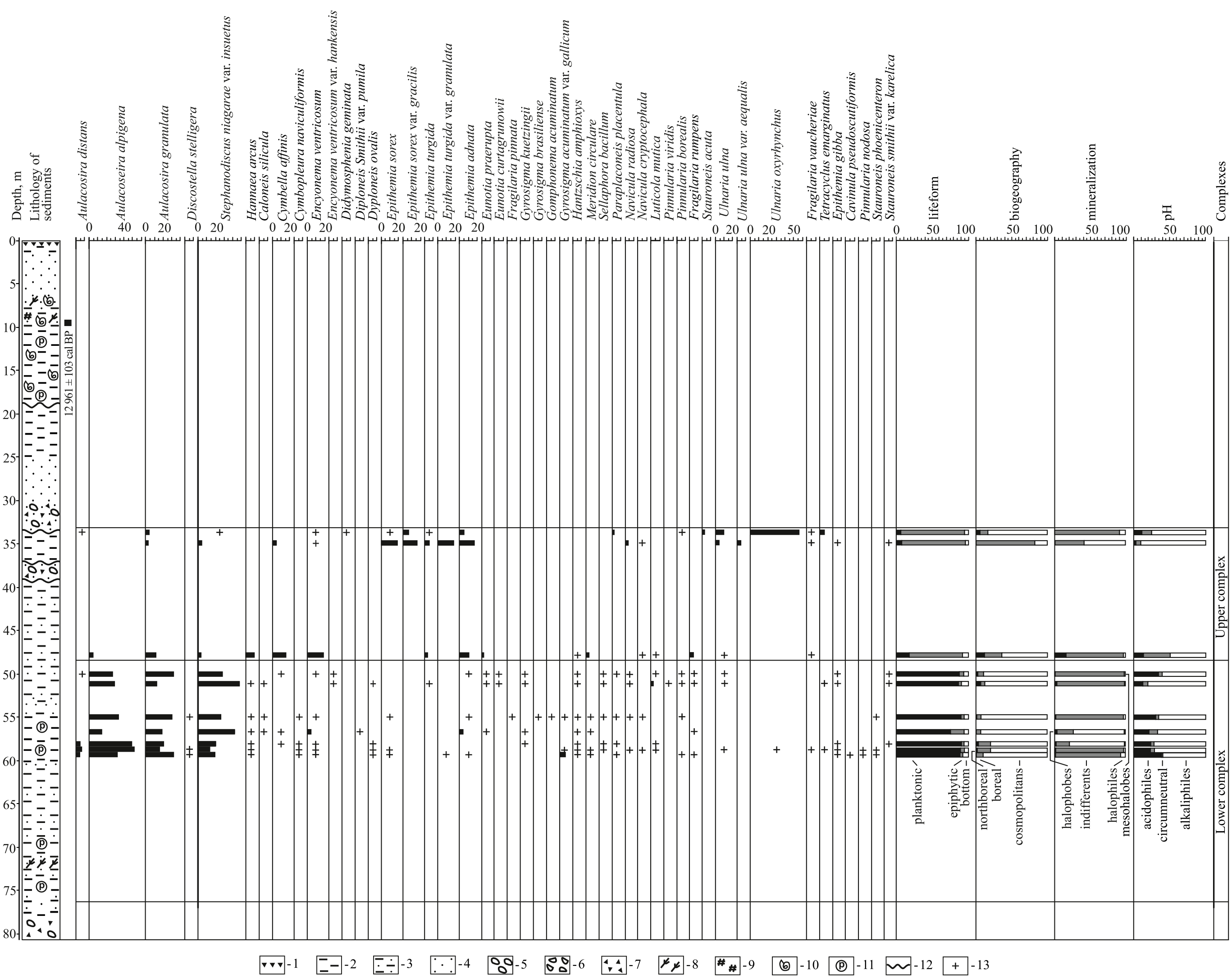

Fig. 3. The diatom diagram of the lacustrine sediments of Lake Paleolotos, borehole 26. 1 – modern soil, 2 – loam, 3 – sandy loam, 4 – sand, 5 – pebbles, 6 – fragments of poorly rounded pebbles, 7 – rubble, 8 – plant detritus, 9 – wood remains, 10 – shells of mollusks, 11 – microconcretions of vivianite, 12 – break in sedimentation, 13 – taxa present in the assemblage in amounts less than 3%.

amount of organic matter, predominate. The sediments of the paleolake were poor in organic substance ($C_{org.}$ content averaging 0.68%) and biogenic calcium ($CaCO_3$ – 0.08–1.08%).

The percentage of northern and north-alpine species, which are massively found in cold freshwater reservoirs of high latitudes and mountainous regions is 28–53%. However, they predominate only in the samples from the depths of 58.0 and 57.8 m. This is connected with the intensive development of the cold-water diatoms *Aulacoseira alpigena, Pinnularia nodosa, Stauroneis smithii* var. *karelica, Stauroneis phoenicenteron,* and *Tetracyclus emarginatus*. At a depth of 54.8 m the diatom *Gomphonema brasiliense* typical of Lake Baikal was also found.

Being ecologically similar, diatom assemblage was identified in borehole 28 at a depth of 56.0–29.2 m, and in borehole 31 at a depth of 62.0–26.0 m. It is characterized by freshwater species, with a small proportion of halophytes, mesohalobic, and single marine diatoms. Epiphytic forms predominate; there are few planktonic species.

3.2.2. *The upper diatom assemblage (interval 47.4–33.2 m from the surface)*

It is characterized by a significant reduction in the proportion of planktonic diatoms, among which the proportion of *Aulacosira granulata* (3.8–11.8%) and *Stephanodiscus niagarae* var. *insuetus* (0.6–4.8%) is still high. The diatom assemblage is dominated by epiphytic diatoms – 64.0–88.0%. *Encyonema ventricosum* (0.6–18.6%), *Epithemia sorex* (0.0–18.7%), *Epithemia sorex* var. *gracilis* (0.0–16.0%), *Epithemia turgida* var. *granulata* (0.0–18.2%), and *Epithemia adnata* 5.0–17.1%) dominate among them. They are noted much more often than in the lower layer of the rheophytic diatoms flaps, which live exclusively in flowing waters: *Hannaea arcus* and *Meridion circulare*. This testifies to nearness of the mouth of the river or the channel connecting the paleolake with the river. Alkaliphiles diatoms dominate in relation to pH, while the cosmopolitan and boreal species geographically dominate.

Most of the species found in the sediments are typical freshwater indifferent species, according to Kolbe's classification with additions (Gleser and Makarova, 1992). Oligohalobes, which usually live in freshwater, but reach the greatest development at salinity of 0.4–0.5‰, make up 0.4–7.3% of the number of all diatom flaps.

Exception is the sample from the depth of 33.9 m. The content of halophiles in it increases due to the development of some species of genus Epithemia. Oligohalobes, the inhabitants of the low-mineralized waters (up to 0.02‰), do not reach high development. Their share usually does not exceed 1.5–2.0% of the total number of the diatom flaps. Mesohalobes, the brackish water species, were recorded only in very small quantities (0.8–2.3% of diatom flaps) at depths of 54.8, 58.0, and 58.8 m.

Most of the registered diatom taxa in relation to pH are alkaliphiles, preferring an alkaline reaction of water (pH $>$ 7). Their proportion is 81–92% of all diatoms. Alkaliphiles include the following species: Aulacosira alpigena, Stephanodiscus niagarae var. insuetus, Epithemia sorex et var. gracilis, Epithemia turgida var. granulata, Epithemia adnata, which are abundant in sediments. Indifferents developing at pH values, close to neutral, are encountered less and take the second place in the number of diatom flaps – from 3 to 12%, reaching 38% at a depth of 47.4 m. Acidophiles, inhabitants of acidic bog waters (pH $<$ 7), are rare. By geographical distribution diatoms-cosmopolitans, the inhabitants of the freshwater of all natural zones of the Earth (51–78%), dominate in most of the samples.

The proportion of boreal diatoms characteristic of temperate latitudes is 10–20%. They dominate only at a depth of 33.9 m. The percentage of northern and north-alpine species, which are massively found in the cold freshwater reservoirs of high latitudes and mountainous regions, is 2–14%.

Similar ecology is reflected by the diatom assemblage from borehole 28 in the depth interval 29.0–28.45 m. It is dominated by the epiphytic genuses *Epithemia*, *Cymbella*, and *Gomphonema*; from semi-planktonic – *Ulnaria ulna*, from planktonic – *Stephanodiscus niagarae* and representatives of the genus *Aulacosira*.

4. Discussion

4.1. *Middle Pleistocene evolution of Lake Paleolotos*

Lacustrine sediments are well diagnosed in the borehole 26 at a depth of 76.2–33.2 m, borehole 28 at a depth of 56.0–29.2 m, and in borehole 31 at a depth of 62.0–26.0 m (Fig. 4). The lacustrine setting of sedimentation is emphasized by the lithological features of the deposits formed by interlayering of horizontally layered sandy loams and greenish-gray loams, with a layer thickness of less than 1 mm (Fig. 5). Loams have aleurite-pelitic composition, with a predominance of particles <0.1 mm in size.

Diatom assemblages obtained from the lower layers of the boreholes 26, 28, and 31 (Fig. 4) indicate accumulation of these sediments in a deep freshwater lake. Diatom assemblages have the features typical of clear and cold lakes with a neutral-weakly alkaline water reaction pH 7.0–7.8 (Gleser et al., 1974). Lake Paleolotos, an oligotrophic freshwater reservoir, was more extensive than at present. The water area of the paleolake covered part of the modern accumulative plain in the mouth of the Tumannaya River and extended to the village of Khasan and further, to the present position of the sea coast. The top of the lower layer in nearby boreholes indicates that the depth of the lake was at least 20 m. It is possible that found single mesohalobic flaps of diatoms were brought by wind, birds or fish going to spawn.

The diatom assemblage obtained from the upper layers in the boreholes 26 and 28 indicates accumulation of these sediments in a shallow eutrophic lake with swampy shores. Predominance of beta-mesosaprobic diatoms, the inhabitants of waters with a large amount of organic substances, is evidence of this. Lake Paleolotos was most likely connected by a channel with the Tumannaya River, but salt water did not penetrate into it through the river-channel system. But such a phenomenon has not been observed. On the contrary, in the sample obtained from a depth of 33.9 m, the content of freshwater diatoms is 58.3% while the marine and brackish water diatoms have not been found. Nevertheless, the sediments from borehole 31 in the depth of 26.0–23.0 m are alluvium and lagoon sediments. Their accumulation of these sediments occurred in the delta or estuary of the Tumannaya River under conditions of periodic exposure to sea waters. They probably penetrated into the bottom layers of fresh water during high tides.

4.2. *The Middle Pleistocene evolution of vegetation in the Lake Paleolotos basin*

The palynological results obtained from boreholes 26, 28, and 31 (Belyanina and Belyanin, 2014) indicate the significant climatic fluctuations during the Middle Pleistocene. They caused the change in the structure of vegetation in the basin of Lake Paleolotos (Table 5).

Broad-leaved and needle-leaved forests of assemblage composition were the main components of vegetation elements in MIS 11, 9, and 7. Such taxa of the North China and Manchurian floristic provinces, as genuses of *Castanea, Celtis, Magnolia, Tsuga*, *Quercus*, *Ulmus*, *Tilia*, *Juglans*, *Phellodendron*, *Carpinus*, and family of Cupressaceae were present among the broadleaf plants. The species of *Pinus* subgen. *Haploxylon*, and *Pinus* subgen. *Diploxylon* and *Picea* were present among the needle-leaved plants. There were also spread of plants, which are now common only in the Northern China Floristic Province (Ohwi, 1965; Pavlov, 1965). They were represented by the species of genuses *Castanea*, *Celtis*, *Magnolia*, *Tsuga*, and Cupressaceae family (Ohwi, 1965; Pavlov, 1965). Probably, many families and genus were represented by greater species diversity than now. In this case, the shift of the vegetation zones to the northern direction relative to their present position could reach 5–7°.

Similar global climatic fluctuations, which caused the restructuring of vegetation in the Middle Pleistocene, are also noted for more northern

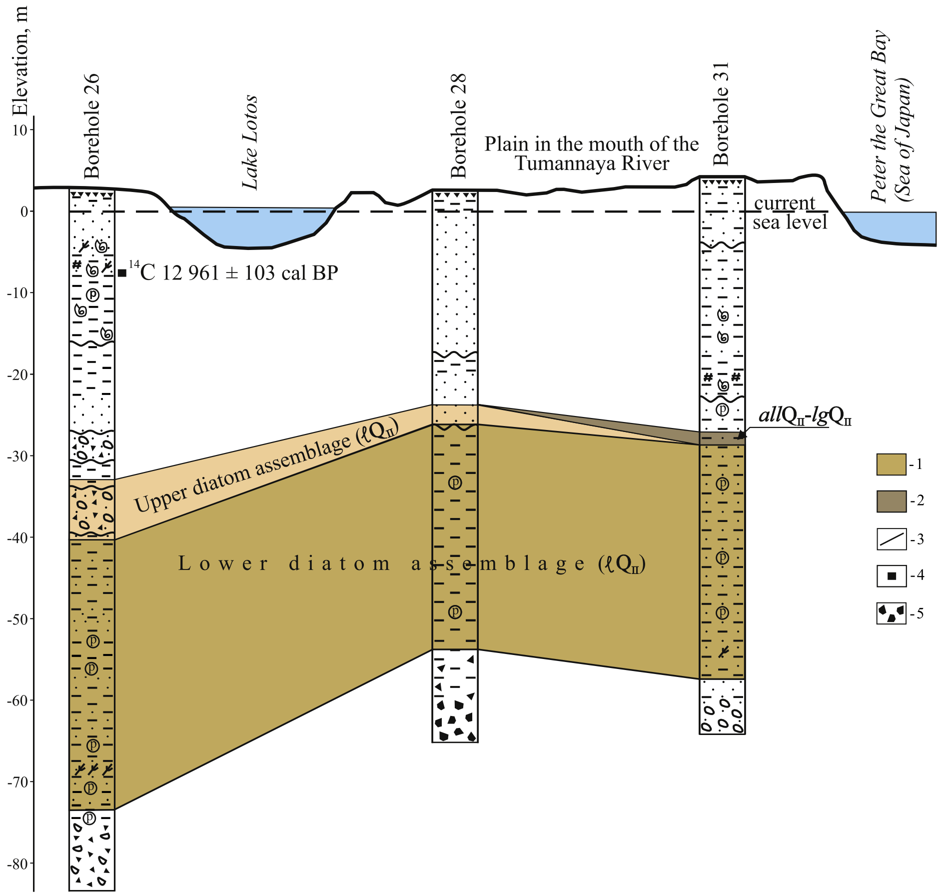

Fig. 4. Correlation of the Middle Pleistocene lacustrine sediments recovered by boreholes 26, 28 and 31 on the accumulative plain in the mouth of the Tumannaya River. 1 – the Middle Pleistocene lacustrine sediments, 2 – the Middle Pleistocene alluvial-lagoon sediments, 3 – the boundary between the Pleistocene and Holocene sediments, 4 – radiocarbon dates, 5 – porphyry debris.

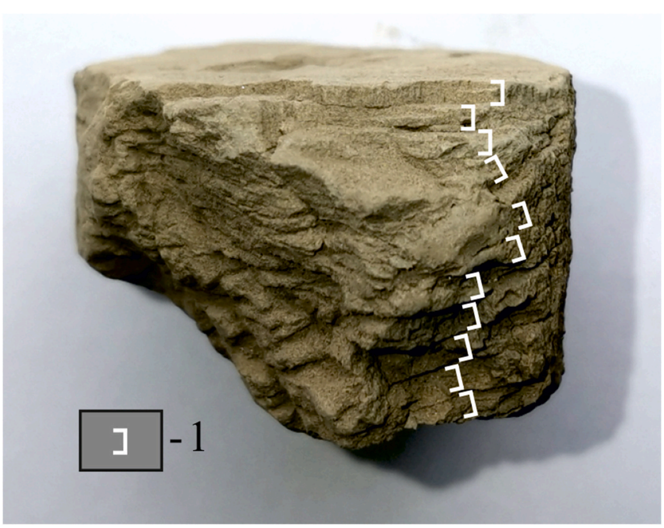

Fig. 5. Photo of horizontal layers of silty-pelitic loam. Sample from a depth of 71.8 m, borehole 26. 1 – layers of silty-pelitic loams with thickness of less than 1 mm.

regions of Russia (Troickij, 1982). Thus, in Chukotka, in MIS 11, 9 and 7, there were repeated changes of herbaceous-birch shrub tundra with herbaceous or herbaceous-alder-birch tundra (Lozhkin, 2007). At the same time, in the lower reaches of the Irtysh, the average annual temperature was 8–10° higher than the current one, and the northern border

Table 5
Phases evolution of the Lake Paleolotos and vegetation in its basin.

Paleolake evolution phase	MIS	Depth	Characteristic of vegetation in the Paleolake Paleolotos basin (Belyanina and Belyanin, 2014)
Deep freshwater reservoir with clear and cold water with a neutral-weakly alkaline reaction	11	75.7–67.6	Oak-pine forests with the presence of thermophilic components of the North Chinese flora – *Tsuga diversifolia*, *Carpinus cordata*, *Fagus japonica*, *Castanea crenata* and species of the genus *Magnolia*
	10	67.6–60.3	Pine-birch forests with shrub birches (*Betula* sp. and *Betula* sect. *Nanae*)
	9	60.3–51.9	Elm-spruce-pine forests with *Tsuga diversifolia*, *Fagus japonica*, and *Carpinus cordata* and species of the Cupressaceae family
	8	51.9–50.3	Coniferous-small-leaved forests with Duschekia, *Picea* and *Pinus* subgen. *Haploxylon*, *Betula* sect. *Nanae*
A shallow freshwater lake with swampy shores	7	50.3–34.8	Broadleaved-pine forests with beech (*Fagus japonica*)
	6	34.8–33.9	Fir-pine-birch forests with *Quercus mongolica* and species of the genus *Ulmus*

of broad-leaved and needle-leaved forests and the steppe shifted to the north by 1000–1300 km (Volkova, 2008).

In the colder climatic conditions, during MIS 10 by coniferous/small-leaved forests with the predominance of *Betula* sect. *Nanae*, *Betula* sp., Duschekia, *Picea*, *Pinus* subgen. *Haploxylon*, and *Pinus* subgen. *Diploxylon*, *Ulmus* and *Quercus* were wide-spread.

During MIS 8, Duschekia, *Picea* and *Pinus* subgen. *Haploxylon* became widespread in the vegetation. The lakeside plains were dominated by *Sphagnum* mires with *Betula* sect. *Nanae*.

Under a later cooling, comparable to MIS 6, fir-pine-birch forests with the participation of *Quercus* and *Ulmus* spread. Vegetation similar in composition is reflected in the palynospectrum from the modern soil, which we studied at the foot of the Baitoushan volcano (42°03′ N, 128°03′ E), at an altitude of about 600 m. The pollen assemblage is also dominated by the pollen of needle-leaved plants of the Manchurian flora, i.e. *Picea*, *Abies*, and *Pinus* subgen. *Haploxylon* dominates in them. Pollen by *Quercus* and *Ulmus* is present in the group of broadleaf plants (Belyanina and Belyanin, 2014).

5. Conclusions

Thus, the obtained paleobotanical and lithological data indicate that in the Middle Pleistocene (MIS 11–6) on the coast of Peter the Great Bay, along with the shallow lakes, there were the deep ones of the oligotrophic type. Lake Paleolotos was one of these lakes.

The sediments exposed by a series of boreholes in the mouth of the Tumannaya River have the main features typical of the lacustrine sediments in temperate regions – good sorting of material, thin horizontal stratification, and characteristic lithological features. The sediments are so specific that they are easily identified in all boreholes. According to ecology of diatoms, they are clearly subdivided into two layers. Sedimentation of the lower layer took place in a deep lake during MIS 11–8. In MIS 7–6, the lake became shallow, turning into a eutrophic reservoir. Lake Paleolotos covered most of the modern accumulative plain in the mouth of the Tumannaya River. Its water area extended to the south, up to the Khasan village, and to the east, most likely, it reached the low-mountain rock Golubiny Utes, which now lies on the coast of the Sea of Japan.

The identified phases of the evolution of Lake Paleolotos are in good agreement with the palynological data (Belyanina and Belyanin, 2014). It has been found out that in the warm epochs, correlated with MIS 11, 9, and 7, diverse broad-leaved and needle-leaved forests dominated in the paleolake basin. During periods of cooling, the Lake Paleototos basin was dominated by coniferous/small-leaved forests with the participation of shrub species of birch and alder (MIS 10) and coniferous/small-leaved forests consisted of pine, birch, and spruce with the participation of elm and oak (MIS 8 and 6).

Author contributions

Pavel S. Belyanin – statement of a scientific problem, formal analysis, data curation, writing – original draft, writing – review and editing, preparation, visualization preparation. Yuri A. Mikishin – statement of a scientific problem, participated in the fieldwork, conducted diatom analysis, conceptualization, methodology, formal analysis. Nina I. Belyanina – investigation, conceptualization, resources, Investigation, methodology, formal analysis.

Data availability

All data are available upon request from the corresponding author P. S. Belyanin.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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