Short communication

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History of the Belye Lakes (the Tsars' valley, Tuva Republic, Russia) in the Late Pleistocene and Holocene

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ABSTRACT. According to the study of bottom sediments, the Belye Lakes (near the famous mound Arzhaan-2) begun to exist about 16.5 ka. The lakes formed in a local depression at the site of the alluvial fans of temporary rivers, which is marked by red sands in cores. A three-meter lacustrine stratum overlies the sands, in some places with interbeds of peat, with a variable content of organic matter and carbonates along the section. Lithological, diatom and pollen analyzes show that the lake has always been shallow. The minimum flowability of the lake, indicating drier conditions, existed 10.0-4.2 ka and for the last 2.0 ka. During the middle of the Holocene (between 8.3-4.2 ka) it could dry up temporarily.

Keywords: sedimentary paleoarchives, climate change, Holocene, pollen analysis, diatom analysis

1.Introduction

There is a 2.5-2.8 ka large complex of Scythian burial mounds known as the "Tsars' Valley" in the Turan-Uyuk basin. In the northern part of the basin there are two groups of lakes located in the closed and semi-closed depressions: the Belye Lakes and the Kislyye Lakes. In the south part of basin the Uyuk River is located. One of the burial mounds, Arzhaan-2, is located about 1 km northwest of the Belye Lakes. Previous studies of the sediments of the Belye Lakes were carried out by Dirksen and Chugunov (2007), however, the coastal core was probably not complete. The aim of the study was to reconstruct the conditions of sedimentation and development of landscapes in the Turano-Uyuk basin in the Holocene by study of the deposits of the Belye Lakes.

2. Materials and methods

The core BEL-20-4 was obtained from the central part of the northern waters of the Belye Lakes by Livingstone piston sampler. Total length of the core is 340 cm. The content of organic matter and carbonates in the bottom sediment was determined by loss on ignition. The grain size analysis was performed by the laser diffractometry method. The magnetic susceptibility was measured by ZH Instruments SM 150L at a magnetic field strength of 320 A/m and with a low frequency of 500 Hz. The radiocarbon age of 10 samples was prepared at the Laboratory of Radiocarbon Dating and Electronic Microscopy, Institute of Geography RAS and measured at the Center for Applied Isotope Studies, University of Georgia (USA). The age-depth model was constructed by Bacon software in R (Blaauw and Christen, 2011). Diatom analysis was performed to reconstruct the ecological characteristics of the lake. Pollen analysis and analysis of non-pollen palynomorphs (NPP) were performed to reconstruct the climatic changes in the Tsars' Valley.

3. Results

Seven layers were identified in the BEL-20-4 core based on the lithological description and variations in analytical characteristics.

Layer 1 (3.40 - 3.15 m, formed until 16.5 ka). The content of organic matter varies from 1.0 to 1.6%, the content of carbonates is about 6 - 7%, the content of terrigenic deposits is about 91-93%. Sand dominates (33-66%), silt varies from 23 to 48%, clay varies from 11 to 19%. Values of magnetic susceptibility are high (0.45-0.85*1e-6 m^3/kg). No diatom valves were found in this layer.

Layer 2 (3.15 - 2.50 m, 16.5-12.0 ka). The content of organic matter varies is about 2 - 4 %, the content of carbonates varies from 6 to 11%, the content of terrigenic deposits varies from 86 to 90 %. Silt dominates (52-73%), clay varies from 21 to 30 %, sand varies from 8 to 26%. Values of magnetic susceptibility are very high (0.2-1.00*1e-6 m^3/kg). The content of

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benthic diatoms is about 90%, the content of periphytic and planktonic diatoms is a few percent.

Layer 3 (2.50 - 2.30 m, 12.0-10.0 ka). The content of organic matter is 9%, the content of carbonates is 28%, the content of terrigenic deposits is 63%. Silt is 69%, clay is 28%, sand is 4%. Values of magnetic susceptibility are average (0.18-0.20*1e-6 m^3/kg). No diatom valves were found in this layer.

Layer 4 (2.30 - 2.10 m, 10.0-8.3 ka). The content of organic matter varies from 9 to 22%, the content of carbonates varies from 57 to 64%, the content of terrigenic deposits varies from 20 to 34%. Silt predominates, its content varies from 64 to 74%, clay varies from 16 to 29%, sand varies from 7 to 19%. Values of magnetic susceptibility are extremely low (0.0-0.02*1e-6 m^3/kg). The benthic diatom species (about 54%) dominate in the diatom assemblage. The content of periphytic species is slightly more than 30%, planktonic species content is about 10%. Slightly more than half of the valves are represented by mesohalobic species (*Iconella hibernica* and *Tabularia fasciculat*e dominate), the content of freshwater species is 35%, the content of indifferent species is about 10%. The diatoms concentration is over 100000 valves/cm^3.

Layer 5 (2.10 - 1.40 m, 8.3- 4.2 ka). The content of organic matter varies from 18 to 52%, the content of carbonates varies from 6 to 68%, the content of terrigenic deposits varies from 15 to 42%. Silt dominates (65-76%), clay varies from 7 to 28%, sand varies from 4 to 20%. Values of magnetic susceptibility are extremely low (almost zero). More than 90% valves relate to bentic oligohalobic species, about 75% of them relate to halophobe species (*Cymbella subhimalaspera* dominates), the content of halophile species is about 3-5%, the content of indifferent species varies from 20 to 30%. The diatoms concentration decreased from 28000 to 10000 valves/cm^3 toward to the bottom of the layer.

Layer 6 (1.40 - 0.45 m, 4.22.0 ka). Interlayers with a higher (7-14%) and lower (4-6%) content of organic matter are distinguished. The content of carbonates varies from 4 to 18%, the maximum content relates to the bottom of the layer. The content of terrigenic deposits varies from 67 to 91%. Silt predominates (57-78%), clay content varies from 17 to 38%, sand content varies from 0.3 to 12%. Values of magnetic susceptibility is moderately high (0.15-0.35 *1e-6 m^3/kg), peak values are located at depths 0.55 and 1.1 m. This layer relates to the formation of an "empty diatom zone" (although there are single valves).

Layer 7 (0.45 - 0.00 m, 2.0 – 0.0 ka). The content of organic matter varies from 6 to 12%, the content of carbonates varies from 3 to 20%, the content of terrigenic matter varies from 45 to 55%. Silt predominates, sand varies from 3 to 17%. Values of magnetic susceptibility are low (about 0.1*1e-6 m^3/ kg). About 80-90% of diatom valves relate to bentic mesohalobic species (*I. hibernica* and *Anomoeoneis costata* dominate). The diatoms concentration increases from 20000 to 100000 valves/cm^3 toward to the upper part of the layer.

There are three local pollen zones (LPZ) in the section. In the lower part of the section (LPZ 1, 320–240 cm) the content of tree and shrub pollen does not exceed 30% of the spectra. Pollen of forest-forming trees is represented mainly by pollen of spruce (*Picea*), Scots pine (*Pinus sylvestris*) and Siberian pine (*Pinus sibirica*) is present in approximately equal amounts (up to 15%). The proportion of non-arboreal pollen reaches 75% of the pollen spectra. Among the herbaceous plants, the pollen of haze (Chenopodiaceae), wormwood (*Artemisia*) and grasses (Poaceae) dominates; there is a large amount of pollen from the daisy (Asteraceae) and buckwheat (Polygonaceae) families. The total pollen concentration in LPZ 1 at the bottom of the section does not exceed 15000 pollen grains/cm^3.

The content of tree and shrub pollen in LPZ 2 (240-120 cm) increases up the section from 25 to 65%. The pollen of Poaceae is about 15%. The content of Chenopodiaceae pollen in LPZ 2 decreases from 25 to 3-5% of pollen spectra. Pollen from coastal (*Sparganium*, *Alisma*) and aquatic (*Hydrocharis, Myriophyllum*) plants and numerous leaf spines of hornwort (*Ceratophyllum*) were found in LPZ 2. A huge number of sponge spicules is noted in the lowest sample from LPZ-2. The total concentration of pollen reaches more than 550000 grains/cm^3.

In LPZ 3 (120–0 cm) the content of tree and shrub pollen decreases from 80% (the maximum along the section) to 40–50% of the pollen spectra. Among tree pollen, pine pollen dominates, and its content decreases from 40% at the bottom of LPZ 3 to 17% in the surface sediment sample. The content of Poaceae pollen remains at the same level (about 15% of the pollen spectra). There were found the aquatic plants pollen in LPZ 3 – the pollen of water milfoil (*Myriophyllum*) and pondweed (*Potamogeton*). The total pollen concentration generally does not exceed 250000 grains/cm^3.

4. Discussion

The lithological composition of layer 1 likely indicates a highly dynamic sedimentation environment (a water flow). At the end of the Late Pleistocene (from 16.5 ka) and the beginning of the Early Holocene (up to 10.0 ka) the moderately shallow lake with highly flowing conditions and low bioproductivity (probably due to the cold climate) existed. At the end of the Early Holocene the water exchange of the lake decreased, and as a result the water salinity increased. In the middle Holocene, the water body desalinates, its level becomes unstable - probably, it could dry up completely in some extremely dry years. At the same time, the relatively warm climate contributed to high bioproductivity, the development of macrophytes and molluscs. In the first half of the Late Holocene (4.2-2.0 ka), the Belye Lakes were a shallow flowing reservoir with medium mineralization and moderate bioproductivity. The relatively high degree of flowability may be associated with increased of fresh water inflow at this stage. In the last 2.0 ka, the mineralization of the lake has increased,

which indicates a decrease in fluvial activity. The composition of pollen spectra and fossil flora in LPZ 1 allows us to conclude that during the Late Glacial, the dominant landscape in the Turano-Uyuk depression was grass-wormwood desert steppes having a sparse, open herbaceous cover. The associated development of erosion processes is confirmed by the findings of various glomus fungi spores (*Glomus spp*.).

Analysis of NPP showed that over time, the composition of green colonial algae *Pediastrum spp*. and cyanobacteria and the aquatic fauna became richer. The composition of pollen spectra and fossil flora in LPZ 2, which approximately corresponds to the Middle Holocene, reflects further climate amelioration, apparently expressed not so much in general warming as in a decrease in continentality and an increase in precipitation compared with the Late Glacial and the beginning of the Holocene. The productivity of the lake itself increased dramatically during this period - this is indicated by the abundance of colonial green algae (*Botryococcus, Pediastrum*) and the growing diversity of aquatic fauna. Findings of sponge spicules in LPZ 2 indicate the inflow of flood waters into the lake from the river Uyuk. Changes in the composition of sediments, pollen spectra and pollen concentrations of the main taxa in LPZ 3 can be explained by simultaneous cooling (increase in continentality) and aridization of the climate over the past 3000–4000 years.

5. Conclusions

The results of core study show that the lake sediments are underlain by red sands of the alluvial fans. The formation of the Belye Lakes began about 16.5 ka, which is marked by mineral loam at the base of core. Above, there is a three-meter layer of lacustrine sediments with significant variations in composition: lacustrine loam in the lower and upper parts of the core, and peaty gyttia and lacustrine lime in the central part. In the time intervals 16.5-10.0 and 4.0-2.0 ka, the lake is characterized by moderate and high-flow conditions. The minimum flowability is typical for the periods 10.0-4.2 ka and in the last 2.0-0.0 ka. The lake has always been shallow, in the interval of 8.3–2.0 ka it could dry up periodically.

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Conflict of interest

The authors declare no conflict of interest.

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