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Geochemical indication of the Holocene climatic changes in sediments of Bolshoi Bagan Lake, Southern West Siberia

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ABSTRACT. Our study of the Holocene sediments of shallow saline Lake Bolshoy Bagan located revealed the following stages of the lake evolution: (I) Appearance and maturing of the lake 9.1–5.8 ka BP; (II) rise in water level 5.8–2.3 ka BP; and (III) shallowed lake 2.3–0 ka BP.

Keywords: bottom sediments, geochemistry, saline lake, Holocene, paleoclimate

1. Introduction

Despite a noticeable increase in paleoclimatic research in recent years, there is still an acute shortage of reliable data on the climate of the past, including for the inland regions of the largest Asian continent. (Sklyarov et al., 2010; Solotchina et al., 2019). Thus, with a large number of paleoclimatic studies for the steppe biome of the European part of Russia, the vast territory of the south of Western Siberia is a “blank spot” in our understanding of the evolution of lake systems and climate dynamics in the Holocene. Studies of the sediments of small lakes in the south of Western Siberia for the purpose of carrying out paleoclimatic reconstructions are not numerous and are based mainly on data from palynological and diatom analyzes and the distribution of macro- and microelements (Blyakharchuk, 2003; Andreev et al., 2004; Zhdanova et al., 2019). The most informative are the bottom sediments of small salt lakes, which, due to their small size, are exceptionally sensitive to climate change (Last, 2002). Unlike large water bodies, they are less conservative under external influences, since their small size causes their instability depending on climate change (Sklyarov et al., 2010). Therefore, it is small lakes that can provide high-resolution climate records.

2. Materials and methods

Mineral Lake Bolshoi Bagan is located in the south-west part of the Baraba forest-steppe, Novosibirsk Region, near the Kazakhstan boundary. The our days (2019) lake has linear size 4×2 km, area 5.6 km^2, and depth 0.65 m. A sign of the modern drying of the lake is the salt plain in its southern part, the former bay. On the slopes of the basin of the lake there are dozens of coastlines, indicating that the lake was 10 meters higher than it is now. The lines continue on the slopes of the neighboring basins, which means that there was a much larger lake at the maximum level ascent. We drilled a well in the central part of the lake (N 53.89804°, E 77.12836°) by a Livingston-type piston probe to a depth of 3.75 m. The lake sediments are 2.84 m thick coarsely laminated silts, and the underlying sediments derive from Quaternary sands typical for the area.

The age of the lake sediments is determined by 15 radiocarbon dates (Fig. 1). We investigated the mineralogy and geochemistry of the lake sediments and the composition of their pore waters. The concentrations of anions in the pore water were determined by titrimetry (HCO_3^-) and capillary zone electrophoresis. The total dissolved organic carbon (DOC) in pore water was determined on an *Analytik Jena AG Multi N/C 2100S* analyzer. The contents of chemical elements in bottom sediments and pore water were determined by ICP-AES. The mineral composition of the sediments was studied by XRD, using a *DRON-4* diffractometer with CuKα radiation. The total organic carbon (TOC) in bottom sediments was evaluated by Tyurin’s method. The grain size of the sediment was measured on Analysette 22 MicroTec.

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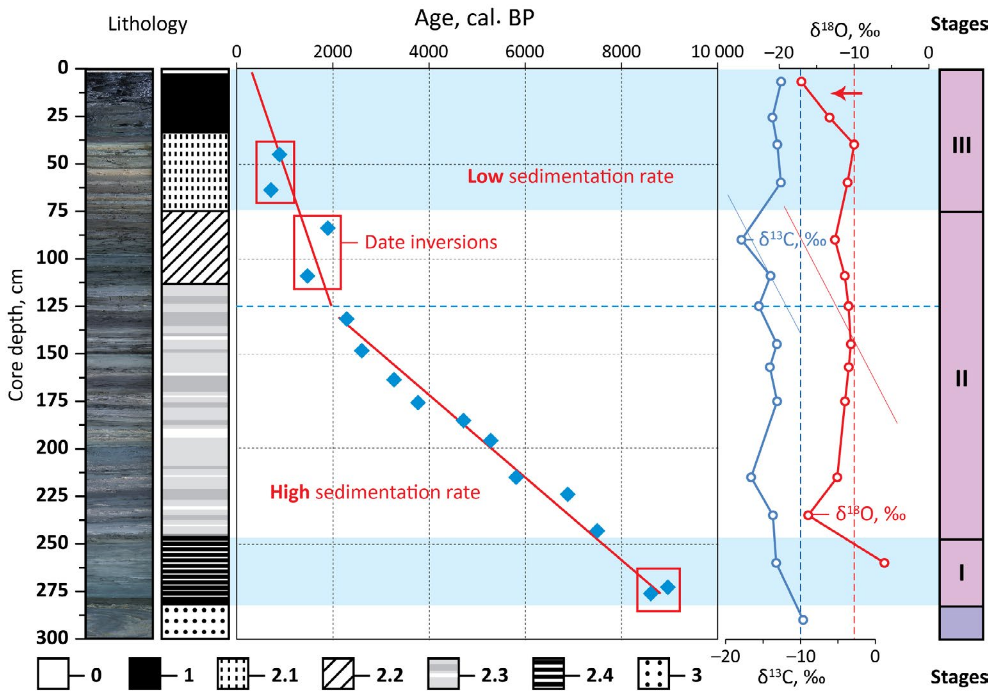

Fig.1. Radiocarbon age of the Bagan Lake sediments and lithology of the core. 0. salt; 1. black watered silt: 2.1. grayish and greenish laminated watered silts, 2.2. denser dark-gray silts, 2.3. denser laminated grayish and brownish silts, 2.4. light-grayish and bluish silts; 3. underlying sands.

3. Results and discussion

The underlying substrate is geochemically different from the lake sediments (Fig. 2). It showed the highest portion of terrigenous minerals: quartz and plagioclase. The presence of halite indicates salinization of the substrate. Its chemical composition indicates high Si and lowered Ca and Mg in comparison with the lake sediments. We recognize two layers of the substrata; the upper (310–280 cm) is indicative by sharp decrease in Al, increase in Sr and in Na and Ti/Al ratios. We suggest soil origin of this blackish color layer and low part of clay in it.

For lake sediments we envisage the following stages of development.

Stage I (~9.1–5.8 cal ka BP). The initial stage shows lowered terrigenous component of the sediment due to increase in calcite, chlorite and mica. The radiocarbon-based age model indicates the lowest sedimentation rate, while the arithmetic mean particle diameter (AMD) 50.6 μm in this interval is the largest for the whole lake part of the core. Therefore we suggest that the lake had rather high water level during this stage. The stage shows increase of Al, Fe, and Ni, which suggests an increase in the flow of aluminosilicate minerals into the lake. The increase in TOC indicates an increase in bioproductivity. We suggest low salinity of the lake water, which contributed to the active deposition of gypsum against the lowest halite content. However, the lake was gradually salinized. This is illustrated by increase of the proportion of Mg-carbonates and by changes in ionic composition of the sediment pore waters.

Stage II (5.8–2.3 cal ka BP). Transportation of terrigenous minerals was low in the first half of the stage and considerably increased in the second. By authigenic minerals, it was a gypsum stage with sharp increase in proportion of halite in the second half. The succession of precipitation of minerals infers the bottom-to-top increase of alkalinity and salinity of the lake. The concentrations of Na^{+}, Cl^{-}, SO_4^{2-} increase, and Ca^{2+} decrease in the pore waters, which confirms the trend to salinization. The low Ca and Mg carbonate content in the interval of 230–160 cm can be an indicator of a higher level of water in the lake. This is indicated by the drop of halite and terrigenous minerals—mica, quartz, and chlorite. In the subsequent part of Stage II, interval 160–110 cm, the lake geochemistry abruptly changed: gypsum sharply decreased and halite and calcite became the dominated authigenic minerals. At the same time, the portions of mica, quartz, and chlorite also increased. The higher Ca and Mg and decreased Al, Fe, and Si, also confirm a sharp change of the lake geochemistry: salinization and high terrestrial input.

Stage III (2.3–0 cal ka BP). The maximal contents of halite and calcite suggest the highest salinity of the lake. The grain size of the sediments is the lowest (AMD = 17.5 μm) and the portion of clay minerals (chlorite) and mica increases. General Ca decreases as well. This means a significant lowering and salinization of the lake with the maxima 0.7–0.4 cal ka BP reflected in an increased portion of halite and decreased calcite. Maximum of carbonates is characteristic for the recent time of the lake development. The presence of aragonite, dolomite and high-Mg calcite reflects a negative water balance, which leads to further salinization of the lake.

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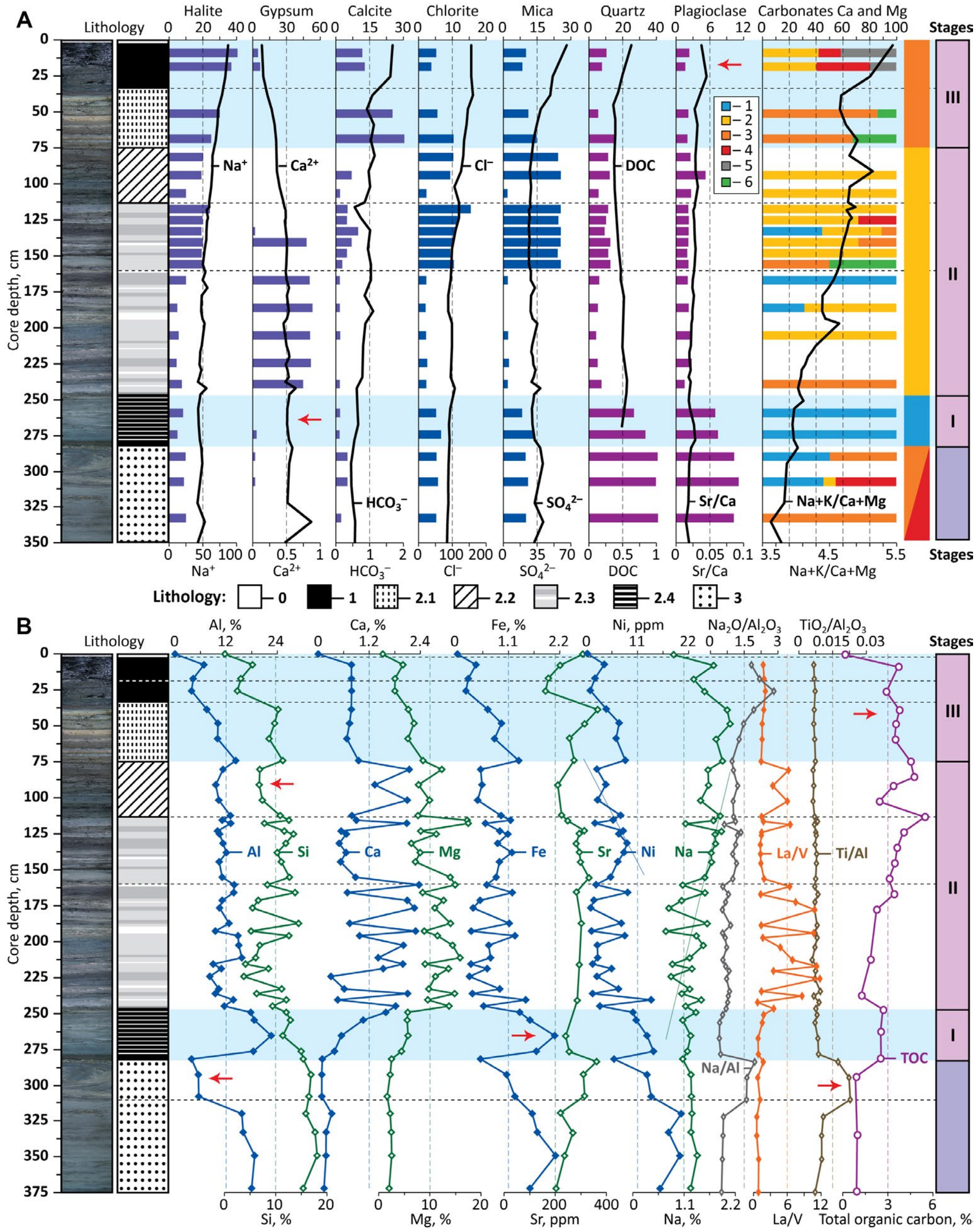

Fig.2. Mineralogical and geochemical data. (a) Mineral composition and carbonate mineralogy: 1. calcite, 2. low-Mg-calcite (about 5% Mg), 3. medium-Mg-calcite (10–12% Mg), 4. high-Mg-calcite (40–45% Mg), 5. aragonite, 6. dolomite. (b) Distribution of chemical elements and geochemical indicators of sedimentation (La/V, sodium module Na_2O/Al_2O_3 and titanium module TiO_2/Al_2O_3).

performed at the Analytical Center for Multi-element and Isotope Studies of IGM SB RAS.

Conflict of interest

The authors declare no conflict of interest.

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