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Geochemical indicators of climate changes in Southwestern Siberia (Russia) in the Holocene sediments of Lake Itkul

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ABSTRACT. We present the results of study the Holocene sediments of Itkul Lake, a shal low brackish lake with carbonate sedimentation, located in the eastern part of Baraba lowland (Southwestern Siberia, Novosibirsk Region). A 1.8 m thick core of the Holocene (7.9 ^{14}C yr) sediments of Itkul Lake has been studied. Based on the geochemical and lithostratigraphic properties of the bottom sediments, we have established the following stages of the lake evolution: (I) the beginning of sedimentation, 7.8–7.0 ^{14}C ka; (II) extreme shallowing with a probable complete drying, ~7.0–5.5 ^{14}C ka; (III) rise in the water level, ~5.5–4.3 ^{14}C ka; (IV) repeated shallowing, 4.3–2.8 14C ka; and (V) subsequent watering, 2.8–0 ^{14}C ka. At present, the lake again tends to shallowing.

Keywords: bottom sediments, geochemistry, XRD analysis, Holocene, paleoclimate

1. Introduction

One of the key sources of information about the climate changes in intracontinental regions is represented by the sections of bottom sediments from lakes characterized by different mineralization and trophicity. Lake basins are ubiquitous and abundant in the Siberian region, and their areas, salinity, and predominant sedimentation types vary in a wide range. However, it should be noted that different parts of the Siberian region are not equally studied in terms of both particular lakes and lake systems (Solotchina et al., 2021). Therefore, the respective research problem is to unravel in sediments the indicators of natural environments (in particular, temperature and degree of drying/wetting of the environment) in order to construct regional paleoclimatic records. The present work was aimed at obtaining the Holocene climate record from detailed mineralogical and crystallochemical studies of bottom sediments of Itkul Lake, one of the minor lakes in the southern West Siberian Plain.

2. Materials and methods

Lake Itkul lies 2.5 km from the Chulym, beyond its valley, and is separated from it by a linear hill (low ridge). Lake Itkul is located at the eastern edge of the area of an aeolian low ridge, in a lowland with Chany Lake at the center. The low-ridge strata are a bed of Late Glacial loess-like loams overlying all relief elements, except for river floodplains. These deposits are exposed along the Itkul Lake shores and are the main supplier of lacustrine sediments. Hollow Itkul Lake lies in the depression between low ridges and has a shallow bay in the west. The lake without a bay is 5.2 km in length (with a bay, 8.7 km), the maximum width is 3.7 km, the average depths in its central part are ~1.5–1.8 m (the maximum depth is 3 m), the water area is 15.1 km^2, and the drainage area is 124 km^2. Itkul Lake is a lake with a small watershed (the drainage factor is 8.2). The lake is fed with spring water and precipitation and is characterized by border overgrowing.

Two boreholes were drilled by the vibration method to depths of 1.8 and 1.9 m in the central part of the lake (55°03′54″N, 81°02′47″E), using a Livingstone piston sampler. The penetrated lacustrine sediments are ~1.6 m thick and are underlain by low-ridge rocks. The contents of Al, Ca, Mg, Sr, Na, K, Fe, and Mn, in bottom sediments were measured by ICP-AES. The mineral composition of the sediments was studied by XRD, using a DRON-4 diffractometer with CuKα radiation. The quantitative content of carbonates in the sediments was determined following the technique described by Vorobieva (1998). The content of total organic carbon (TOC) in the samples was evaluated by Tyurin's technique (Vorobieva, 1998). We estimated the contribution of terrigenous calcium (Ca_{ter}, %) to the sediments, taking Al as a reference element (the

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contents of Al and Ca in the upper continental crust are 7.74% and 2.94%) as follows (Maltsev et al., 2020):

$$Ca_{ter} = (Al_{samp} / Al_{cr}) \cdot Ca_{cr}$$

where Al_{samp} is the content of Al in the certain lacustrinesediment horizon, Al_{cr} is the content of Al in the upper continental crust, and Ca_{cr} is the content of Ca in the upper continental crust.

3. Results and discussion

Lake Itkul formed in the Middle Holocene at 7.8 ^{14}C ka (8.8 cal ka), under the influence of a rapid and drastic change of the cold arid climate by the warm humid one (Fig. 1). After the melting of a glacier, a lake began to form at the place of loess-like loams.

Stage I. At the initial stages of the lake formation (Fig. 1), at ~7.8–7.0 ^{14}C ka, silicate material (quartz, K-feldspar, mica, chlorite, and kaolinite) actively accumulated in the depth range 162–145 cm of the bottom sediments. This interval has the highest contents (%) of Al (5.6), Na (1.3) and K (2.0) supplied into the lake mostly with terrigenous products of destruction of Quaternary blanket deposits (Fig. 2). All this indicates the high standing of the lake and an active terrigenous supply from the drainage areas into the lake. At the high water level and low salinity of the lake, carbonates (calcites with a minimum impurity of Mg) poorly precipitated. A low intensity of carbonate sedimentation reflects the warm and humid climate dominated. It is at the stage of the Itkul Lake formation (depth range 162–145 cm), during the high level and low salinity, that the water lacked Mg-calcites and had low total contents of carbonates.

Stage II. At the stage of the lake shallowing (depth range 145–130 cm), ~7.0 ^{14}C ka, with a significant development of biota (mollusks), the contents of Mg-calcites and aragonites reached their maxima on the background of an increase in TOC content to 7.1% (Fig. 1, Fig. 2). The depth range 136–138 cm corresponds to the maximum shallowing of the lake throughout its evolution. This is confirmed by the highest contents of carbonates and by domination of aragonite over calcites and of Mg-calcite over $CaCO_3$ in this interval. Traces of gypsum indicated a strong shallowing of the lake and an increase in salinity. The maximum contents of Sr in the range 136–138 cm also reflect a strong shallowing of the lake. The Sr/Ca ratio (indicator of water salinity) increases in the range 138–136 cm, which indicates the maximum salinity of the lake water in the corresponding period. The contents of Mg in this range decrease less than the contents of Al, K, Na, and Fe, whereas the content of Ca drastically increases, which testifies to the active precipitation of Mg-calcites at the shallow-water stage of the lake evolution, when the produced chemogenic carbonates, mainly Mg-$CaCO_3$, contained most of the total Mg. The most active precipitation of carbonates in this range is evidenced by the maximum increase in the total contents of Ca.

The upper pat depth range 130–0 cm), we observe a tendency for a slow stepwise rise in the lake level and the lake freshening. This process was accompanied by periodical slight fluctuations from shallowing to watering of the lake.

Stage III. After the shallowing of the lake at ~7 ^{14}C ka, there was a rapid rise in its water level at 7.0–5.5 ^{14}C ka (depth range 130–125 cm) (Fig. 1). This range is characterized by a decrease in the contents of carbonates. A drastic drop in the contents of Ca and Sr in the range 130–120 cm on the background of an increase in the contents of Al and Fe indicates a rise in the lake water level. This rise is confirmed by higher contents of "Al group" elements, reflecting a more intense terrigenous input. The increase in the content of Ca_{ter} to 2.0% at a depth of 130 cm also confirms a rise in the lake water level (Fig. 2).

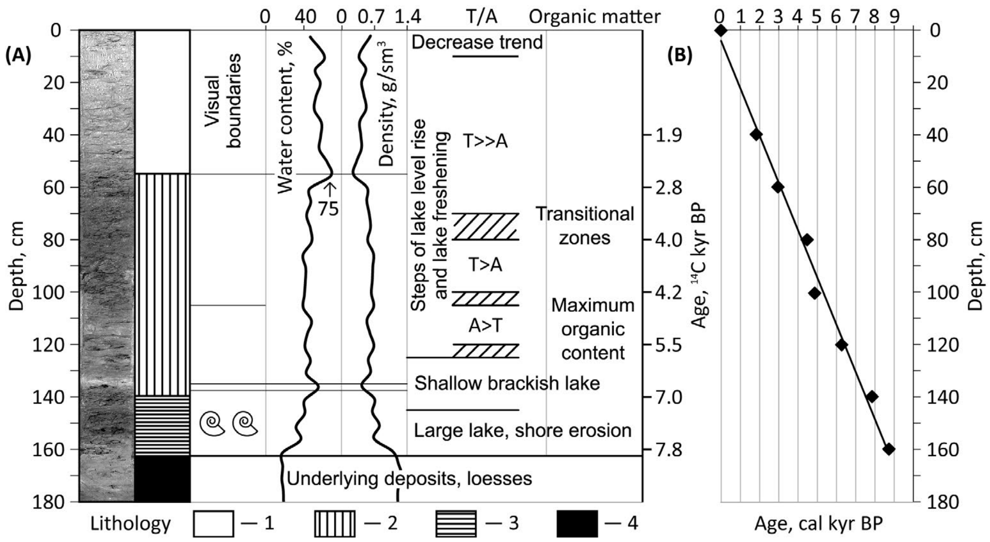

Fig.1. Structure of bottom sediments, changes in the depositional environment (A) and age model (B) of Itkul Lake. T — terrigenous fraction of the sediments; A — authigenic fraction of the sediments. Lithology: 1. 0–55 cm, light gray loam; 2. 55–138 cm, more compact dark gray loam, including darker clay with a sandy material (range 55–100 cm); 3. 138–162 cm, dark brown argillaceous material with fragments of mollusk shells; 4. 162–180 cm, underlying dark gray loess-like loams. The 14C age of the sediments was determined by accelerator mass spectrometry.

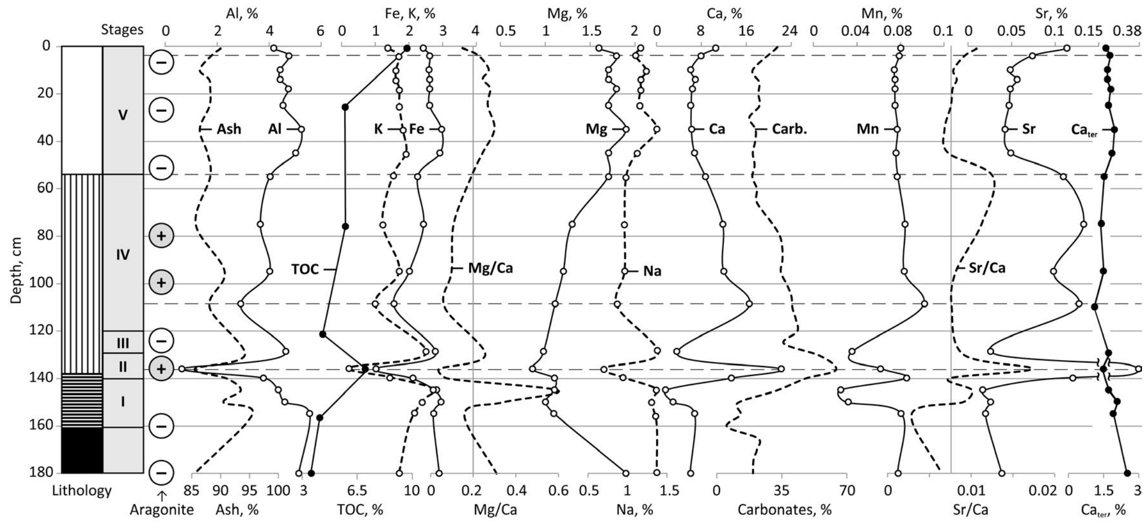

Fig.2. Distribution of ash content, carbonates (Carb.), total organic carbon (TOC), and chemical elements throughout the bottom sediment column. " + ", the presence of aragonite in the sediments (XRD data), "–", the absence of aragonite.

Stage IV. At ~5.5–2.8 ^{14}C ka, the lake water level fell (depth range 125–55 cm) as a result of the water evaporation and a less intense water inflow, which led to a higher lake salinity (Fig. 1). Thus, the conditions became favorable for the precipitation of carbonates; this was reflected in the increased contents of Ca in the sediments. Note that the depth range 120–100 cm (5.5–4.3 ^{14}C ka) is characterized by the maximum shallowing of the lake over the period 5.5–2.8 ^{14}C ka. The increase in the contents of Ca and Sr and the decrease in the contents of Mg and Al in the depth range 120–55 cm might indicate changes in the lake water parameters (salinity, carbonate alkalinity, pH, and temperature) and, hence, a more active chemogenic precipitation of calcium carbonates from the Mg-poor water. Chemogenic carbonates became enriched in Sr, which is confirmed by the significant Sr enrichment of this horizon as compared with the underlying ones. The Sr/Ca ratio increases in the middle depth range (100–55 cm) of the sedimentary strata which indicates the increases salinity of the lake water in this period (Fig. 2). The amount of Mg-calcites in it is smaller than that at the previous shallowing stage (depth range 140–130 cm). This indicates a smaller shallowing of the lake than that marked in the depth range 145–130 cm. The range 120–100 cm is characterized by the maximum (for this stage) drop in water level and an increase in water salinity: domination of Mg-$CaCO_3$ over $CaCO_3$, a drastic increase in the content of carbonates, and the absence of aragonite. The contents of Al and Fe significantly decrease on the background of the stable contents of Mg and a drastic increase in the contents of Ca and TOC.

Our colleagues (Solotchina et al., 2019) combine stages III and IV into one big stage III, which covers the core interval of 120–65 cm. Stage III was quite long, from about 5.5 to ~3.0 ^{14}C ka. Sediments formed during the Subboreal period the climate of which was colder and drier compared to the Atlantic one. This stage is characterized by a higher water level in the lake accompanied by its freshening (Solotchina et al., 2019).

Stage V. An increase in the lake water level and a decrease in water salinity (depth range 55–0 cm, 2.8–0 ^{14}C ka) strongly restrained carbonate formation (and, hence, led to a decrease in the content of Ca in the sediments) on the background of an intense inflow of terrigenous components (Al, K, Na, Fe) (Fig. 1, Fig. 2). At this stage of the lake watering, the contents of Ca and carbonates in the sediments decreased, which was expressed as a significant decrease in the portion of Mg-$CaCO_3$ and the absence of aragonite. A terrigenous input increased, as evidenced by much higher contents of Al, Fe, Mg, and Na (Fig. 2) and a higher content of Ca_{ter} as compared with the underlying sediment intervals.

The composition of sediments formed at the current stage of the lake evolution (10–0 cm, the last ~100 yr) shows an increase in water salinity and in the contents of Ca and Sr in the sediments and a slight increase in the amount of Mg-$CaCO_3$. There is a positive Sr/Ca trend in the uppermost sediment intervals (10–0 cm), which points to a current increase in water salinity. Hence, the lake tends for the next shallowing. Solotchina et al. (2019) identify this interval as a separate stage in the evolution of the Itkul Lake.

4. Conclusions

Based on the geochemical and lithostratigraphic properties of the bottom sediments, we have established the following stages of the Lake Itkul evolution: (I) the beginning of sedimentation, 7.8–7.0 ^{14}C ka; (II) extreme shallowing with a probable complete drying, ~7.0–5.5 ^{14}C ka; (III) rise in the water level, ~5.5–4.3 ^{14}C ka; (IV) repeated shallowing, 4.3–2.8 ^{14}C ka; and (V) subsequent watering, 2.8–0 ^{14}C ka. At present, the lake again tends to shallowing.

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Conflict of interest

The authors declare no conflict of interest.

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