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Paleolimnological reconstructions for Lake Arakhley (Central Transbaikalia, Russia) inferred from high-resolution reflection seismic data

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ABSTRACT. High-resolution seismic data (65 km profiles) have been used to study the sedimentary infill of Ivan-Arakhley lake system (Lakes Arakhley, Ivan and Shakshinskoe). It found that full limnological cycle bears only sediment cover of Lake Arakhley. Total sediment infill of Lake Arakhley is 6-7 m, and it was be divided into three sequences. The uppermost ~2.5 m of sediment cover was presented by a normal lacustrine filling. Lacustrine sediments began to form *ca.* 21 cal. ka BP. The lake was almost dried during the regression occurred between *ca.* 3 and 2.6 cal. ka BP.

Keywords: high-resolution seismic data, Ivan-Arakhley lake system, Transbaikalia, LGM, Holocene

1. Introduction

In present, there still is gap about structures of sediments cover of small lakes from Transbaikalia. Lake Arakhlei belongs to the Ivan-Arakhley lake system (6 lakes), an is located on 955 m a.s.l. This area is 59 km^2, and 11x6.7 km in size. The lake is the largest freshwater body of Transbaikalia, however, knowledge about its limnology evolution is still rare. In our study, based on the analysis of high-resolution seismic data on the sedimentary infill of three lakes from the Ivan-Arakhley lake system, we attempt to reconstruct the evolution of the lakes as regional climate and geology proxy the Late Pleistocene-Holocene.

2. Materials and methods

Seismic data were collected using a Frequency Modulated (FM) sub-bottom profiler consisted of tree transducers that receive and radiate FM signal (frequency 1-10 kHz). Seven and 35 km of seismic profiled were obtained on Lake Arakhley, and 30 km of seismic profiled were obtained on Lakes Ivan and Shakshinskoe, in 2022. The FM profiler enables to study stratification of sedimentary layers with a resolution of up to 10 cm. For conversion of the acoustic travel time into depth, we assumed velocity of 1.45 m/ms in water and 1.5-1.6 m/ms for the uppermost unconsolidated sediments.

3. Results and discussion

3.1. Seismostratigraphic facies and subdivisions

Illuminated sediment cover is approximately 6-7 m and below seismic signal damped. According to characteristic of seismic signals, bulk sediment can be divided into three sequences. Thus from down to up, a lower part – the basement is chaotic unstructured high-amplitude reflections, acoustically un- or poorly stratified (Fig. 1). Thickness is approximately 1.5-2 m (deeper, seismic signal damped). It is most likely that reworked fluvial and eolian sediments represent these sediments. It is notable that there are two clear, high amplitude reflectors into the basement sequence. These reflectors are likely attributed with gaps in fluvial sedimentation.

The upper sequences indicate about a transition from a shallow to modern lake condition. Thus, the basement was overlapped by high-amplitude sub-parallel reflections in middle or hummock at distal part of the lake. This sequence can be related with shallow lake sediments (pLS) at began filling of the lake. The mean thickness of pLS is 1 m. There are packets of chaotic low-amplitude reflections embedded into packets of parallel reflections can be associated with a silty sand-rich mudslide, sandslide or river fan.

The upper sediment sequence (~2.5 m thickness) is thinly and regularly stratified, with good lateral

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continuity (longitudinal and transverse) (Fig. 2). This sequence are represented by low and high-amplitude sub-parallel reflections. However, the sequence (LS) can be divided into three units (Fig. 1). The unit-1 is characterised by high-amplitude reflectors, that it likely indicates about to enrich of sediments by coarse clastic materials. In contrast, the unit -2 is presented by low-amplitude reflectors and “transparent” in seismic records. We assume that the unit-2 is a high water-saturated lake sediment. The uppermost layer (the unit -3, ~20-30 cm thickness) is characterised by high-amplitude reflectors. It is notable, the upper parts of units 1 and 2 were eroded, and the unit 3 overlap this erode surface (Fig. 3). The drop of lake level was approximately by 12-12.5 m relative to the modern. The lake was practically full dried, and 1-3 m depth along the axial part, during this lowstand.

In general, this reflection pattern of sequence – LS can be interpreted as normal lacustrine filling, and its thinning seems to show that the lake depths gradually increased.

Seismic patterns of Lakes Ivan and Shakshinskoe are presented by chaotic unstructured high-amplitude reflections. Reflectors related with lacustrine sediments were not found. Lacustrine sediments likely was denudated during the regression marked in Lake Arakhley by the unit 3. However, in records form Lake Shiksha, there are two reflectors similar to those from the basement of Lake Arakhlei.

3.2. Paleo-reconstructions

Age estimation and regional pale-reconstruction based on investigation of bottom sediment Lake Arakhley are still rare. Our interpretation of seismic pattern and age estimations based on Reshetova et al. (2013) and Solotchina et al. (2018). The uppermost 1.27 m from lateral part of the lake was dated by 15 cal. ka BP (Solotchina et al., 2018). There are the pollen record and radiocarbon age estimation for the core located near discussed seismic profile showed in figure 2, the uppermost 1.44 m of the LS was formed during 13 cal. ka (Reshetova et al., 2013). In addition, this core was sampled from the part of lake with lacustrine condition during the regression described above. Thus, the depth-age is practically line, and it can be evidence of the absence of a gap in sedimentation between the unit-3 and 2.

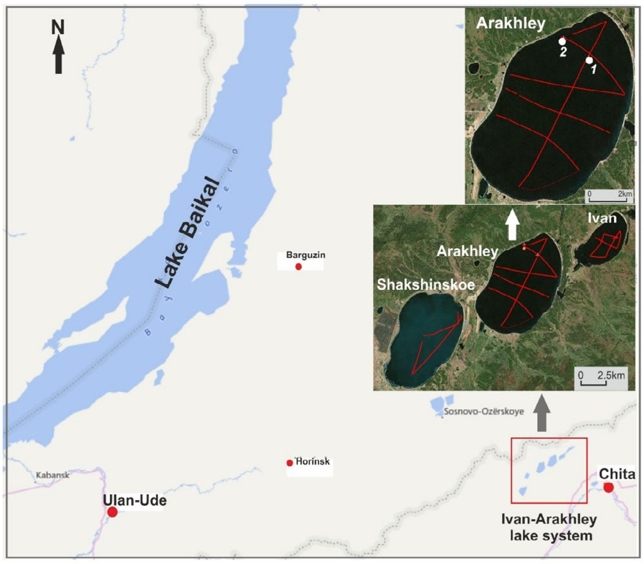

Fig.1. Location of studied lakes. *Red lines* - seismic profiles, *white circles 1* - the core from Solotchina et al. (2018), 2 - the core from Reshetova et al. (2013).

If the line depth-age model is correct then the unit-2 and 3 likely began to form ca. 13.4 and 2.6 cal. ka BP, respectively. The extrapolated age for the boundary between the pLS and unit-1 (~2.5 m below sediment surface, bss) is *ca.* 21 cal. ka BP. However, actual age of this boundary may by somewhat younger, because the unit-1 was composited more coarse sediment compare to the unit-2a and sediment rates likely were higher. Thus, the unit-1 formed during the Late Glacial Maximum of Pleistocene (LGM). The pollen data from 1.4-1.6m layers also indicated about cold and dry air condition related with the LGM (Reshetova et al., 2013).

It is surprised, that lacustrine conditions (the pLS and unit-1) were during the LGM. In addition, lacustrine sediments dated by *ca.* 15 cal. ka BP have been reported by Solotchina et al. (2018). For instance, significant climate changes in Baikal region happened ca. 22 and 17.5 ka BP and small lakes dramatically reduced or dried (Chensky et al., 2020). It seems that Lakes Ivan and Shakshinskoe were dray at the LGM, because there are no lacustrine sediments. Air condition of the LGM was characterized as dray, however, high content of Caryx-Poaceae assemblages in pollen record can be attributed with water-saturated soil due to season

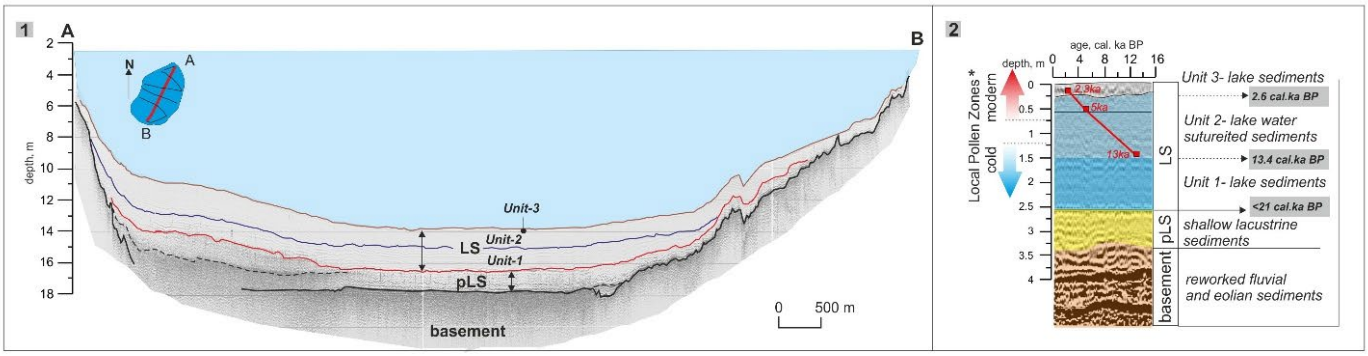

Fig.2. Seismic stratigraphy of Lake Arakhley. *1* - axial profile along sediment fill of Lake Arakhley. *2* – facial interpretation of seismic sequences, local pollen zones and depth-age model from Reshetova et al. (2013).

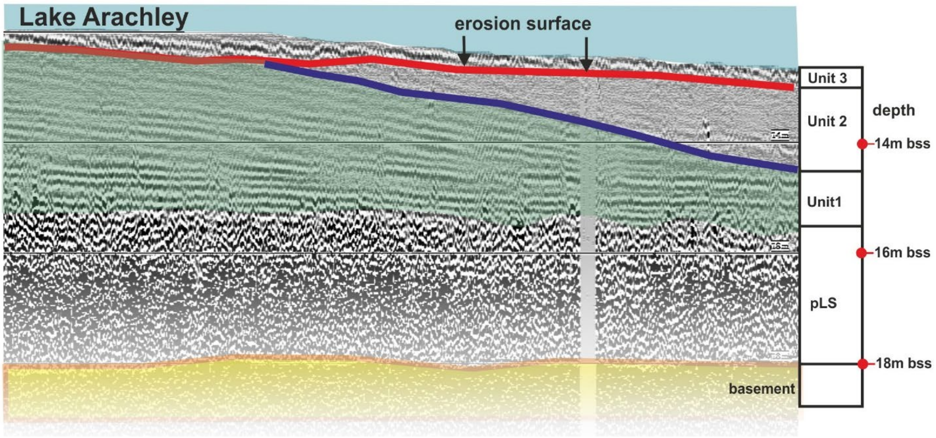

Fig.3. The example of the lowstand of Lake Arakhley occurred between 3 and 2.6 cal. ka BP.

thawing of active layer of permafrost (Reshetova et al., 2013). It is possible, a positive water regime of Lake Arakhley was due to supply of the thawing water into the lake during LGM. In addition, lake ice cover could not be completely break due to a short summer, as a result, evaporation from the lake was insignificant, and lake was stable by thawing water.

The modern regional climate and landscape features are forming since *ca.* 6.5 cal. ka BP (0.7 m bss) (Reshetova et al., 2013). Episode of the lowstand of lake occurred before 2.6 cal. ka BP likely was short because there are no deep erosion cuts and thickness of eroded part of the unit 2 was about 20-cm. Regional oxygen isotope records marked change at ca. 3-2.5 ka BP (Kostrova et al., 2013). We assume that the lowstand happened between 3 and 2.6 cal. ka BP.

There are no bodies of a silty sand-rich mudslide, sandslide or river fan that evidence bout high inflow of suspended material into the lake after the lowstand. In this reason, acoustical “hard” reflectors of the unit-3 can not be explained by a high content of allochthonic clastic material. We assume, that these acoustic features of the sediment indicate low rate of rise up to modern of the lake level.

4. Conclusions

The sedimentary infill of Lakes Arakhley, Ivan and Shakshinskoe were studied based on 65 km profiles of high-resolution seismic data. It was found that sediment records of Lake Arakhley contents sediment sequences from the beginning lacustrine condition to modern status. However, there are no representative lacustrine sediments in Lakes Ivan and Shakshinskoe. Found thickness of sediment cover of Lake Arakhley is 6-7m. The uppermost ~2.5 m of sediment cover was presented by a normal lacustrine filling showing gradually increase of lake level. Estimate age of the beginning is ca. 21 cal. ka BP. Lake level dramatically dropped by 12-12.5 m relative to the modern, between *ca.* 3 and 2.6 cal. ka BP.

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Conflict of interest

The authors declare no conflict of interest.

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