

Lake Gusinoe (the southern part of East Siberia, Russia): sedimentary history inferred from high-resolution reflection seismic data

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ABSTRACT. This paper studies the formation of the sediment cover in Lake Gusinoe. For this purpose, we used high-resolution seismic data. Depression of Lake Gusinoe has a tectonic origin; however, there is no evidence of recent tectonic activity. Sediment thickness in Lake Gusinoe is less than 9 m, and its history is short (< 35-45 ka). In addition, seismic stratigraphy records contain three contrasting episodes when the lake level dramatically decreased. It is very likely that there were also other shorter episodes of low-level stands. Thus, seismic structures of lakes Gusinoe and Kotokel have a strong resemblance, and it is most likely that their history began at the same time, ca. 40 ka BP.

Keywords: High-resolution seismic data, Lake Gusinoe, East Siberia

1. Introduction

The southern part of East Siberia is characterised by a variety of landscapes, from steppe to mountain zones, and, according to paleorecords from this region, can be very sensitive to climate changes. There are paleorecords from small lakes of this region, however, these records are often until only the Holocene-Bølling-Allerød (e.g. Shichi et al., 2009; Bezrukova et al., 2010; Fedotov et al., 2012; 2013; Solotchina et al., 2014). For example, according to records from Lake Kotokel, intensive warming of the region was during 11.8-9.5 ka BP; regional climate was most likely moderately cold and humid from 9.5 to 7 kyr BP; from 7 to 6 kyr BP there was a trend to drying, the climate pattern at 5.8-1.5 ky BP was very unstable when there were episodes of abrupt cooling by the backdrop of the warm climate (Fedotov et al., 2012)

The climate in this region of East Siberia is continental, which is reflected in the large differences in the mean January (-30 °C) and July (15 °C) temperatures. Annual precipitation is relatively low, ranging from 220 to 590 mm (NOAA data set <ftp://ftp.ncdc.noaa.gov/pub/data>). Lake Gusinoe is located in approximately 60 km to the south of Lake Baikal (Fig. 1). The lake is situated at 551 m above sea level. It is approximately 24 km long and 8.4 km wide, with a maximum depth of 26 m. For this reason, this sediment cover may contain long paleorecords.

However, there are probably hiatuses in the

paleorecords from Lake Gusinoe due to erosion of sediment cover at the lowest lake levels. Thus, according to historical records, there were two lakes on the place of Lake Gusinoe in 1728, and it is very likely that similar changes also happened before.

In our study, based on the analysis of high-resolution seismic data on the sedimentary infill of Lake Gusinoe, we attempt to reconstruct the evolution of the lake.

2. 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). The operation is based on the transducer radiating an acoustic signal directed vertically downwards. An acoustic signal reflects from a bottom, reflecting horizons of sub-bottom sedimentary layer, and proceeds back in a transducer. In the receiving channel of the device, amplification, coordinated filtration and digitization of analogue signals amplification are produced. In data array records, data required for the bottom surface mapping and profiles of sub-bottom, namely, acoustic signals from the transducer and current coordinates are received from GPS receiver. Forty-five kilometers of seismic profiled were obtained in 2018 (Fig. 1). The FM profiler enables to study stratification of sedimentary layers with a resolution of up to 10 cm. For conversion

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of the acoustic travel time into depth, we assumed velocity of 1.45 m/ms in water and 1.6-1.7 m/ms for the uppermost unconsolidated sediments.

In 2019, a sediment core was taken from the northwestern part of Lake Gusinoe N 51°14.720, E 106°25.161 (Fig. 1) using a Uwitec Corer sampler. The water depth was 20 m at the core-sampling site. The core was 80 cm long, but the core sampler cannot penetrate deeper due to a high density of bottom sediments.

Depth-age model based on AMS-technic was performed in Budker Institute of Nuclear Physics (Novosibirsk, Russia). Chemical pre-treatment and graphitization of samples were carried out in Laboratory of Radiocarbon Methods of Analysis at Novosibirsk State University using laboratory installation (Lysikov et al., 2018). Six sediment layers were dated. Calendar date was evaluated from the radiocarbon one by CalPal ver.1.5.

3. Results and Discussion

3.1. Seismic units

Seismic profiles clearly distinguish a two-part subdivision of the stratigraphic section from the sedimentary infill: - a lower part, acoustically un- or poorly stratified; - an upper part, thinly and regularly stratified, with good lateral continuity (longitudinal and transverse). Both can be subdivided with more details as follows.

A lower part – the basement is chaotic unstructured low-amplitude reflections (Fig. 2). Thickness is approximately 2-3 m (deeper, seismic signal damped). It is most likely that reworked fluvial and eolian sediments represent these sediments.

Unit -1 is characterized by sub-parallel, discontinuous coarse high-amplitude reflections. It can indicate that the ratio of sand is high. The lower boundary parallels covered basement. Thickness varied from 1.5 to 3 m. The lithology of this unit is probably coarse-grained sediments, which formed under shallow lacustrine condition. Position of the upper boundary of the unit indicates that the lake can have a depth of approximately 15 m. However, the upper boundary was eroded (erosion level-1).

Unit-2 in the lower part is represented by low-amplitude sub-parallel reflections. High-amplitude of reflectors and a distinct thinning of its rhythmic pattern is increased towards the upper boundary of the unit. Sediment thickness is approximately 1.5-3 m. In general, this reflection pattern can be interpreted as normal lacustrine filling, and its thinning seems to show that the lake depth gradually increased. However, the 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 (van Rensbergen et al., 1999). The upper boundary also was eroded (erosion level-2) at slope parts of the depression.

Unit -3 is characterized by sub-parallel, distinct coarse high-amplitude reflections with thinning rhythmic pattern. Sediment thickness is ca. 1-2 m. This

unit is enriched with lenses or mound-shape geometry bodies with chaotic high-amplitude reflections. These bodies are associated with silty sand-rich sediments. A cross breadth of some bodies is up to 2.5 km (Fig. 3), and it is most likely that these bodies are related to river fan.

A boundary between unit- 3 and 4 is very strong erosion surface (erosion level-3). This erosion denudated distal parts of units 1, 2, and 3 (Fig. 2, Fig. 3). Unit - 4 consists of packages of high-amplitude reflections parallel to discontinuous reflections with packages of seismically semitransparent reflection in the upper part (0-1 m bss). Unit 4 becomes thicker in deep parts of the axial part of the lake, attaining a maximum thickness of approximately 2 m.

3.2 Interpretation

The relief and configuration of the acoustic basement beneath Lake Gusinoe strongly suggest that the lake has a tectonic origin due to the presence of a deep fault. Thus, the morphological structure of the lake is represented by two depressions (southern and northern) restricted by faults (Fig. 3). At the beginning of forming unit-1, the basement of the southern depression was lower than that of the northern depression by ca. 10 m. The southern depression is approximately 9 km long.

Due to this morphological asymmetry, the northern depression was completely dried when erosion levels -1-3 were formed. However, deeps of a paleo-lake in the southern depression were approximately 2-5 m during events of erosion levels-2 and 3. In addition, it is most likely that the southern depression was also completely dried at events of erosion level-1, as the upper boundary of unit-1 was eroded. In general, there are no erosion cuts along erosion levels 2 and 3. For this reason, it is most likely that the duration of low lake levels was not long. To confirm this assumption, the total thickness of sediment covers in the southern and northern depressions are approximately 9 and 7 m, respectively (Fig. 3). Hence, ca. 2 m of total sediment cover in the northern depression can be denudated at a time when the erosion levels were formed.

High content of bodies enriched with sand materials into unit-3 can evidence high activity of tributaries or floods at that time. These bodies are

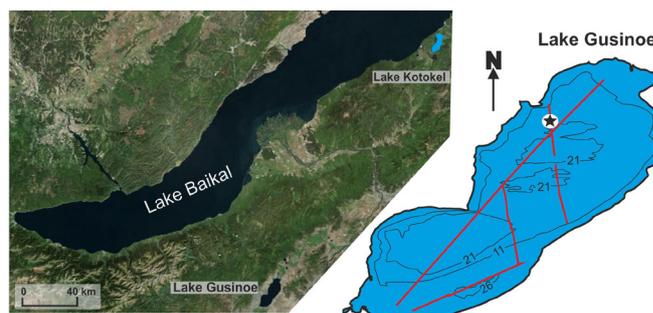


Fig.1. Location of Lake Gusinoe: red lines - seismic profiles, asterisk – point of the core sampling

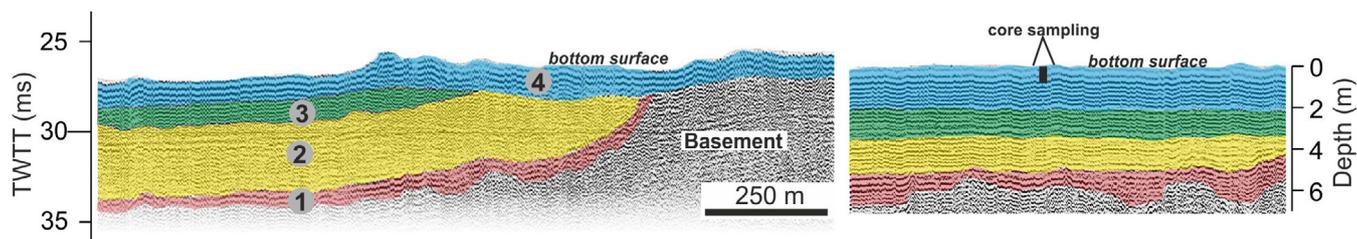


Fig.2. Seismic stratigraphy of Lake Gusinoe, *number* - seismic units

more abundant in the southern depression. At present, all tributaries flow in the lake along the west coastline, and the Khamar-Daban Ridge can be a source for these streams. Hence, it seems that this period had maximum moisture in the region.

The sediment core was composed of fine, light grey and black silty clay in the upper part (0-25 cm bss) as well as olive-green firm silty clay (25-80 cm bss). Interval of 25-80 cm was enriched with shells of ostracods and gastropods. Thus, these sediments formed under lacustrine conditions; however, it was a shallow lake. AMS dating indicates that the layer of 79-80 cm likely deposited ca. 5 cal. ka BP, and a change in sedimentation (approximately 25 cm bss) occurred ca. 1.5-2 cal. ka BP (Fig. 4). According to this age estimation, the mean sediment rate for the upper 0-0.8 m bss was approximately 1 cm/71 yr. If this sediment rate is linearly extrapolated to the layer of the erosion level-3 (approximately 2 m bss), in this case, the unit-4 began to accumulate after 14-15 ka BP. For this reason, it seems that the erosion level-3 can be formed during the Last Glacial Maximum. The results of pollen analysis and pollen-based biome reconstruction from bottom sediments of Lake Kotokel show that steppe and tundra vegetation composed of grasses and various herbs dominated ca. 26.8-19.1 cal. ka BP, and a lake level was low compared to the present (Müller et al., 2014).

The level of Lake Baikal, being by 50 m deeper than the modern lake, as well as a low and irregular discharge of the Selenga River are evidence of high regional aridity in the LGM (Urabe et al., 2004; Osipov and Khlystov, 2010). Hence, the level of Lake Gusinoe most probably was also dramatically low under this LGM-condition.

The seismic pattern indicates that units 2-4 were formed during one limnological cycle, whereas the unit - 1 can be a remnant of other older cycle.

Coarse age estimation for units 2-4 based on the sediment rate for the upper 0-0.8 m shows that these units can deposit approximately 35-45 ka BP. However, this estimation does not take into account the duration of low-levels (erosion levels 2 and 3) and layers of sandslides or turbidities. Nevertheless, it seems that 35-45 ka is most likely the highest possible age for the bottom layer of the unit-2. Moreover, the seismic profiles of Lake Kotokel indicate that the three depositional units were distributed over the entire lake basin (Zhang et al., 2013). Age estimation of these units was the present-15, 15-25 and >32 ka BP (Zhang et al., 2013). The bottom unit in Lake Kotokel is represented by densely-spaced reflections, occurring as chaotic and occasionally hummocky structure, partly alternating with reflections of low contrast. The seismic pattern of this unit is very similar to those of unit 1 and basement from Lake Gusinoe. Thus, seismic structures of Lake Gusinoe and Kotokel have similarity, and it is most likely that their history began at the same time, ca. 40 ka BP.

4. Conclusions

We have studied sediment cover of Lake Gusinoe based on high-resolution seismic data. Morphology of the lake basement evidences a tectonic origin of this lake. Two depressions (southern and northern) represent the structure of the lake floor. The thickness of lacustrine sediments cover is only 9-6 m, and this cover was divided into four seismic units. Boundaries of these units are three erosion surfaces. The northern

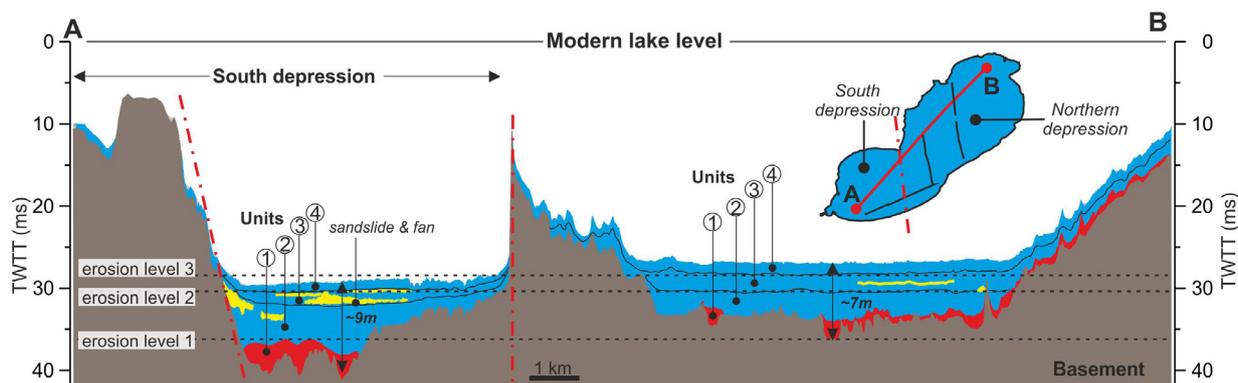


Fig.3. Axial structure of sediment filling of Lake Gusinoe: *dashed redlines* – faults, *yellow lenses* – sediment bodies enriched with sand

depression completely dried in periods when formed erosion levels-2 and 3, and the entire lake was dried at the period of the erosion level-1. According to radiocarbon dating of the short sediment core from the northern depression, approximate age of the erosion level-3 and lacustrine sedimentations are 14 and 35-45 ka BP, respectively. There is also evidence of high fluvial activity towards the southern depression.

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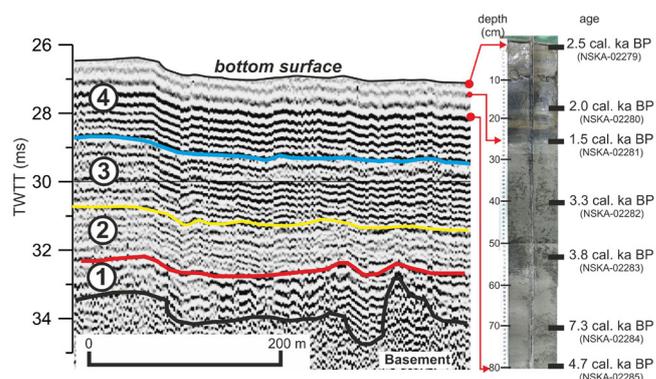


Fig.4. Seismic stratigraphy and the core image, ^{14}C age-dates were converted into calendar ages until present (cal. BP)

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