Limnology and Freshwater Biology 2022 (4): 1417-1420 DOI:10.31951/2658-3518-2022-A-4-1417

SI: «The 5th International Conference Paleolimnology of Northern Eurasia»

Short communication

ISSN 2658-3518
LIMNOLOGY FRESHWATER BIOLOGY
www.limnolfwbiol.com

Lake Chukhlomskoe in the Late Pleistocene and Holocene (Kostroma region, Russia)

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ABSTRACT. The article discusses the first results of geomorphological and paleolimnological study of Lake Chukhlomskoe (Kostroma region). We analyzed the topography of the lake bottom using new bathymetric data from 2021 fieldwork. The structure of the lake basin slopes was studied using hand drilling. Analytical characteristics of the bottom sediments core (grain size distribution, loss on ignition, magnetic susceptibility, AMS-dating and palynological data) are presented. The distribution of organic matter, carbonates and particle size by depth allow us to correlate the bottom sediments of Lake Chukhlomskoe with the sediments of other well-studied large lakes (Belaya Struga, Galichskoe and Seliger).

Keywords: paleolimnology, paleoarchives, relief, lake deposits, Lake Chukhlomskoe

1. Introduction

Lake Chukhlomskoe is located in the northern part of the Kostroma region, on the elevated Galich-Chukhloma ridge (the watershed of the Kostroma and Unzha rivers). It is one of the largest and most ancient lakes in the center of the East European Plain, along with lakes Pleshcheevo, Nero and Galichskoe. Their location south of the boundary of the last Valdai glaciation (Map of Quaternary..., 1972) suggests that the age of lake sediments may exceed 130 thousand years.

Lake Chukhlomskoe has a relatively small catchment and compact size – its area is about 48.7 km^2 with a maximum length from NW to SE of 8.8 km and a maximum width from SW to NE of 7.6 km. All tributaries are small rivers. According to the rate of external water exchange, the lake belongs to medium- and low-flow, autochthonous processes prevail in it. The removal of solid runoff, nutrients and pollutants are difficult. The lake is highly trophic. There is a process of active eutrophication of the lake (Timofeeva and Yukhno, 2019). In 1963, on the Veksa River, flowing out of the lake, a sill overflow dam was built (upper pool height 150 m asl, lower pool height 148 m asl). It was renovated in the 2010s.

The lake's geomorphological position and its basin's morphometric characteristics create the prerequisites for stable and continuous sedimentation, which is very important for environmental paleoreconstructions since the loss of information from such a paleoarchive is minimized.

Until now, there was no reliable data on the age and composition of the sediments of the Chukhlomskoe lake basin, which makes it the least studied among the other mentioned lakes.

The history of the study of Chukhlomskoe lake includes several stages: 1) in the 1920-30s, gyttja deposits were evaluated, but the results were published only in small descriptive articles (Chernov, 1930; Shturm, 1932). Since the 1980s, the works have been mainly devoted to the lake's ecology and fishery problems (Baranov and Tereshin, 1981; Cherednichenko, 1987). In 1993 there was one more gyttja deposits study (Gurin, 1993) without any multi-proxy analytics and publications. There are few modern studies, and they are mainly devoted to the lake's ecology (Sirotina and Vorontsova, 2016; Timofeeva and Yukhno, 2019).

2. Materials and methods

Three fieldwork expeditions were carried out to study the basin and bottom sediments of Lake Chukhlomskoe. In winter 2021, we verified the archival map of 1927-28 by manual lotting and drilled

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Received: June 01, 2022; ***Accepted:*** June 24, 2022;
Available online: September 02, 2022

two boreholes (using the Livingston Piston Sampler) at different depths: Chu13A (7 m long) at a depth of 4.5 m and Chu7A (9 m long) at a depth of 2.6 m. Also, for Chu13A borehole, the upper weakly consolidated part of the sediment was selected according to the method of E.A. Konstantinov (2019).

In summer 2021, a bathymetric survey of the entire water area of the lake was carried out using a motor boat and two echo sounders – Deeper Pro+ and Lowrance HDS 9. We obtained more than 50000 depth measurement points, which allowed us to make the first reliable Chukhlomskoe lake's bottom relief model. Also, two drilling profiles were made on the slopes of the lake basin: 14 boreholes with an Eijkelkamp hand drill with a depth of 1.4 to 3.6 m and one pit with a depth of 1.76 m.

In winter 2022, we made 54 points with probe drilling, and as a result two boreholes were drilled: 13.65 m long on the background surface with the depth of 2.6 m (Chu22-39A) and 5.1 m long on the transverse profile near the area of the Veksa river head (Chu22-16A, which reveals loamy deposits with gravel inclusions). Also, presumably gas outlets were found on the ice surface.

The samples of the bottom sediments were analyzed at the Laboratory of Paleoarchives of the Natural Environment of the Institute of Geography RAS. Samples for AMS-dating was prepared at the Center for Collective Use, 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 particle size distribution of the deposits (with a step of 5 cm) was performed on a Malvern Mastersizer 3000 laser diffractometer. Loss on ignition (LOI) was measured according to the method proposed by O. Heiri et al. (2001). Mass magnetic susceptibility (MS) was measured using a ZH Instruments SM 150 L instrument at low frequency (500 Hz). Samples were also taken for diatom and palynological analysis to characterize paleoecological and paleoclimatic conditions. These parameters are currently being processed (except for four palynological samples of Chu13A core). Analysis for the content of radioactive isotopes (137Cs, 210Pb) was made at the Radiochemistry Division of the Chemistry Department of the Moscow State University.

3. Results

Our bathymetric map analysis results showed that the deepest zone has the shape of two hollows, diverging from the center of the lake towards the city of Chukhloma (to the southeast). The maximum depth in this zone (and the entire lake) reaches 5.44 m. The lake's average depth is 2.38 m (median – 2.26 m, modal – 2.24 m). Depths of 2.1-2.3 m occupy 37% of the area and depths of 1.9-2.6 m – 66.33%. According to the depth distribution histogram, it can be seen that there are two steps – 2.0-2.4 m and 1.5-1.8 m. The hollows have morphological features of fluvial forms: smooth bends and sustained width. At the same time, these forms are enclosed – i.e. they are interrupted, which is impossible for normal channel forms. In the bottom topography, there are no signs of overdeepening (hollows) in the northern part of the lake, where the Veksa River flows out of it. In the structure of the sides of the Chukhloma lake basin, there are no signs of a level rise above the present level during the Upper Pleistocene and Holocene. The upper layer of the bottom strata is organic silt (gyttja) of brown-olive color with a thickness from 2 to 5 m. Unstratified gray mineral silt (loam) lies below.

Chu13A core (4.5-11.45 m) was fully investigated by laboratory and analytical methods. Curves of changes in the material composition make it possible to identify the stages of changes under the conditions of sedimentation. From a depth of 6.4 m upsection, an increase in the content of organic matter (LOI 550) begins, then there is a slight decrease, and again a sharp increase from a depth of 5.4-5.5 m. Magnetic susceptibility decreases with an increase in the amount of organic matter in the sediment. The carbonate content clearly shows a peak at a depth of 5.4-5.7 m, which is preceded by a stage of increasing sediment size at a depth of 5.9-6.1 m. Four samples have palynological characteristic. The lower samples from a depth of 8 and 10 m characterize the conditions of the late pleniglacial (after LGM) – periglacial steppe with the participation of a few cold-resistant tree species in minimal numbers. This is confirmed by AMS-dating from depths of 8.1 and 9.85 m (22320 ± 60 cal BP and 23110 ± 110 cal BP, respectively). A sample from a depth of 6 m characterizes the conditions of the late glacial period – birch periglacial forest-steppe with spruce and has an age of 18000 ± 90 cal BP. A sample of the upper layer from a depth of 5 m characterizes the middle Holocene – forest, spruce, and broad-leaved species (mainly oak) with a lot of birch pollen (between 5110 ± 110 and 5130 ± 100 cal BP). The core bottom at a depth of 11.4 m has been dated as 25460 ± 110 cal BP. The pattern of the curves of analytical characteristics in the remaining boreholes below 4.5 m is identical to Chu13A. But there is a large thickness of organic gyttja at the upper part, which indicates that in the Chu13a borehole, which was drilled in a hollow, the upper part of the sediment was eroded. The result of the assessment of the content of radioactive isotopes 137Cs and 210Pb showed low rates of modern sedimentation. All the cores have layers with porous material which means that there is a process of gas production in the sediment.

4. Discussion and conclusions

The hollows were developed in Holocene; its probable mechanism of origin is erosion due to the bottom current resulting from the release of gases/springs with the participation of wind surge in case of strong winds and the fact that the natural depth of the basin was at least 1 m less before the dam's construction. The lake is a potentially good archive for studying Late Pleistocene and Holocene sediments with a small catchment area and a slow flow of material brought by rivers which suggests to find regional signal of landscape and climate change. A sharp peak in the content of carbonates at the end of the Late Glacial (interval 5.45–5.69 m in Chu13A core) and the peak in the content of the sandy fraction preceding it mark the regional patterns of sedimentation for lakes in the center of the Russian Plain (Konstantinov et al., 2021). The results of analyzes for all cores are comparable to each other, the results are reproducible. There is a good potential for correlation with the NGRIP oxygen isotope curve.

Acknowledgments

The fieldwork was funded by the Megagrant project (agreement № 075-15-2021-599, 8.06.2021). Laboratory analytics was carried out within the framework of the State Assignment of the Institute of Geography, Russian Academy of Sciences FMWS-2019-0008.

Conflict of interest

The authors declare no conflict of interest.

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