Limnology and Freshwater Biology 2022 (4): 1503-1505 DOI:10.31951/2658-3518-2022-A-4-1503

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

Short communication

ISSN 2658-3518

LIMNOLOGY FRESHWATER BIOLOGY

www.limnolfwbiol.com

Lake Chistoye (northern Priokhotsk area, Russia) – the high resolution environmental archive for the Holocene

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ABSTRACT. Lake Chistoye in northeastern Russia provides one of the longest sequences of the Holocene sediments. Bottom surface and core sediments were analyzed using the complex method including rock magnetic, paleomagnetic, geochemical, mineralogical and radiocarbon dating. Two layers tephra with distinct individual petrophysical, geochemical and mineralogical characteristi were distinguished in the sediments. High-resolution secular variations of the geomagnetic field were constructed from the cores. According to radiocarbon dates, the lake was formed since the beginning of the Early Holocene. Synchronously, near the lake began an accumulation of marsh peats.

Keywords: Lake Chistoye, Holocene, rock magnetism, geochemistry, lake sediments, tephra

1. Introduction

Lakes of the North-East of Russia have different origins, age, physical and hydrological parameters, elevation, and composition of the surrounding rocks. Lakes of glacial, thermokarst, and tectonic origin are widespread in the continental part of the territory. The age of most lakes is relatively young and is limited by the end of the Pleistocene–the beginning of the Holocene. Lakes El'gygytgyn (67°30′ N; 172°05′ E.) and Grand (60°44' N, 151°53' E) are among the ancient lakes, whose sediments began to form in the Late Pliocene (3.6 Ma) and the Late Pleistocene (60 ka), respectively (Melles et al., 2012; Minyuk and Subbotnikova, 2021). The lakes are differed rates of sedimentation and sediment composition. The thickness of Holocene sediments varies from several tens of centimeters to several meters. Among the studies lakes the maximum thickness of Holocene sediments is in Lake Chistoye (945 cm). The sediments from this lake are a unique material for obtaining detailed data about changes in the Holocene environment.

2. Materials and methods

Lake Chistoye (59.543850 °N, 151.800185 °E) is one of the largest in the Northeast. Its length is 8.8 km, width – 6.5 km, maximum depth – 6.6 m (Fig.). About 30 tributaries with various lengths inflow into the lake. The lake is located in the Lankov Cenozoic depression of the Northern Priokhotye, on the left bank of the Lankovaya River (a tributary of the Ola River). The depression is filled by Cenozoic sediments. Holocene marsh peats containing layers of tephra are common on the southern and northern shores. The eastern, southern and western hills surrounding the lake are composed of basalts, andesites and their tuffs of the Lower Cretaceous P'yagin formation. Late Cretaceous tuffs of acid composition, tuff sandstones are located in the north of the lake. Chemical and physical weathering products from these rocks comprise the majority of the clastic deposits in the lake.

Nine sediment cores were sampled during winter from 2016 to the present.

The core sediments were split into 1-cm segments (945 samples) for various types of analyses, including petrophysical, mineralogical, geochemical, granulometric, palynological and diatomic. The organic matter was selected for radiocarbon dating. The sediments from the longest core 9 and 6 were continuously sampled for paleomagnetic investigations with plastic boxes 2 × 2 × 2 cm; yielding a collection of 439 and 286 specimens, respectively.

3. Results and discussion

The lake water is ultra-fresh with total mineralization 32.15–53.76 mg/l, total hardness is 0.14–0.46 mg-eq/l, pH = 4.8–6.6.

Surface sediments

In summer 2021, a set of 71 surface sediment samples was collected from the floor of Lake Chistoye.

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Received: May 30, 2022; ***Accepted:*** July 28, 2022;
Available online: September 02, 2022

The surface sediments of lake consist of gravel, sand and silt (clay). The spatial distribution of the sediments shows coarse-grained material in the western and southern edges of the lake whereas silt is dominated in the central and eastern parts of the lake.

Geochemical and petrophysical parameters of sediments were followed the lithology. In the western part, where sand is dominant, sediments are more magnetic, also increased values of magnetic (MS) saturation magnetization (Js) and remanent saturation magnetization (Jrs). Hysteresis data of the silt sediments shows a finer magnetic granulometry.

According to geochemical data, the coarse-grained sediments are less chemically altered. They are enriched with mobile elements – SiO_2, Na_2O, CaO, K_2O. Silt and clay shows the high content of Al_2O_3, Fe_2O_3, MgO, and TiO_2.

Magnetic minerals are represented by a wide range of titanomagnetites with a titanium content from several percent to 26%. The Curie points of magnetic minerals range from 540-580°C (low-titanium titanomagnetites) to 100°C (high-titanium titamagnetites). Typical impurities are manganese, silicon, aluminum, chromium.

Grains of titanomagnetites have abundant shrinkage cracks, which provide clear evidence for low-temperature oxidation (maghemitization). Maghemite (titanomaghemite) is fixed on thermomagnetic curves during its transition to hematite at T 400–425° C. Some heating curves show an increasing magnetic susceptibility at T = 235–254 °C, followed by a decrease during further heating to 580 °C indicating the transformation of lepidocrocite into maghemite–hematite (Gehring and Hofmeister, 1994; Gendler et al., 2005). Thus, surface sediments data have a direct impact on the interpretation of the environmental record derived from sediment cores of Lake Chistoye.

Core sediments

The core sediments are mainly consist of silt and clay. Sand and gravel deposits are located at the base of the cores. The sediments thickness is 577 cm (core 1), 599 cm (core 2), 223 cm (core 5), 635 cm (core 6), 945 cm (core 7). Two tephra layers with distinct individual petrophysical, geochemical and mineralogical characteristic are found in the sections. The lower tephra (KO) is acidic composition, weakly magnetic, and is correlated with the tephra of the Kuril Lake caldera in Kamchatka, which is 7,600 years old (Ponomareva et al., 2004). According to the mineralogical data of 29 grains, two groups of titanomagnetites are clearly distinguished in magnetic extract from tephra. The group of high-titanium titanomagnetites shows the titanium content between 24.26–28.01 wt% (average 25.54 wt %). In the second group of titanomagnetites, titanium concentrations are 0.35–16.87 wt% (average 6.48 wt%).

KO tephra are found at depths of 373–377 cm (core 1), 360–364 cm (core 2), 190–193 cm (core4) .185–189 cm (core 4a), 184–188 cm (core 4b), 182–186 cm (core 4b), 433–435 cm (core 6), 625.5–626.5 cm (core 7).

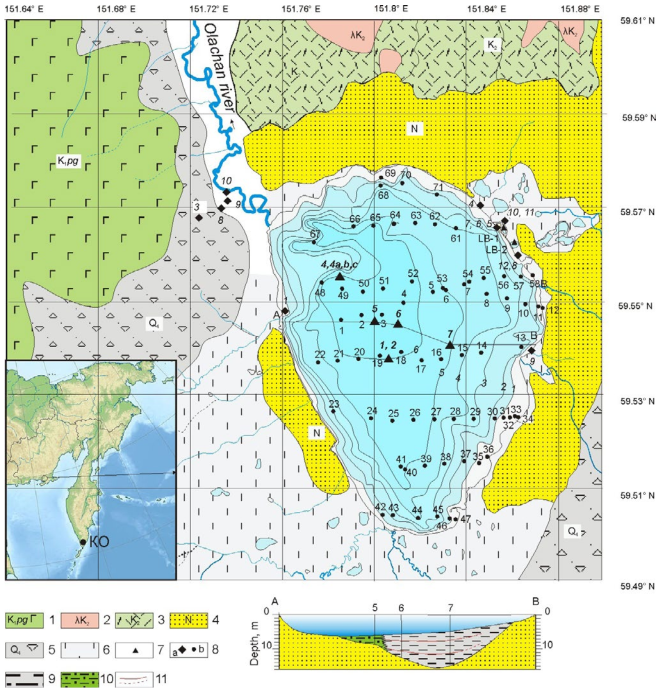

Fig. Location, geological map of the Chistoye Lake area and cross-section of the lake. 1 – Lower Cretaceous P'yagin formation; 2 – Upper Cretaceous intrusive; 3 – Upper Cretaceous volcanic rocks; 4 – Neogene sediments; 5 – slope sediments; 6 – Holocene marsh peat; 7 – core sites; 8 – slope sediments sitese (a) and surface bottom samples (b); 9 – silt lake sediments; 10 – sand sake sediments; 11 – tephra depth based on core measurements; KO – Kurile Lake caldera.

The upper tephra was recognized at depths of 86–88 cm (core 1), 77–80 cm (core 2), 36–38.5 cm (core 4), 35.5–37 cm (core 4a), 31–34 cm (core 4b), 36.5–37 cm (core 4b), 162.0–166.0 cm (core6), 237.0–249.0 cm (core 7). Visually, tephra is difficult to find in the sediments, but can be easily distinguished by the maximum values of magnetic susceptibility. The shards have in average SiO_2 content of 64.65 wt%, the sum of K_2O+Na_2O is 7.57 wt% in average, indicating the dacite composition.

Magnetic minerals of the upper tephra, according to the study of 28 grains, are compose of low-titanium magnetites with an average titanium content of 2.7 wt%. Vivianite is found everywhere along the sections in the sediments of the lake.

The radiocarbon age of organic matter from core 1 is 8815 ± 36 years (depth 524 cm) and 5349 ± 33 years (depth 266 cm). Based on the radiocarbon dates and assuming that the sedimentation rates are approximately the same in the core the interpolated age of the upper tephra is 1350–1590 years in the core 1. The sediments of the lake include diatoms, organic remains their study will allow reconstructing the natural environment of the Holocene. The petromagnetic parameters of sediments vary significantly along sections, reflecting changes in sedimentation conditions. The values of magnetic susceptibility in core 7 are (-0.4–1.8) $\times 10^{-6}$ m^3/kg (average = 0.4). Magnetic susceptibility, hysteresis parameters and the tephra layers are used as tools for the correlation between different sediment cores. The shift of petromagnetic characteristics is at 500 cm in the longest core 7. High-resolution secular variations of the geomagnetic field were constructed from the core 6 and 7. Cores 7 and 6 were correlated using both secular variations and rock magnetic features and can be correlated with the Holocene secular variation records from the other regions.

The maximal sedimentation rate is in core 7, where they are approximately 1 cm/10 years. According to radiocarbon dates, the lake was formed since the beginning of the Early Holocene. Synchronously, near the lake began an accumulation of marsh peat having a radiocarbon age of 9725 ± 250 years.

Acknowledgements

The authors acknowledge M.A. Morozova and M.I. Makarov for assistance in fieldwork and sampling. This research was funded by the Russian Science Foundation (research project no 22–27–00444).

Conflict of interest

The authors declare no conflict of interest.

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