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Lateglacial and Holocene environmental changes in the Southern Urals reflected in palynological, geochemical and diatom records from the Lake Syrytkul sediments

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ABSTRACT

A multi-proxy study including lithology, geochemistry, diatom analysis and palynology of the Lake Syrytkul sediments provides continuous environmental reconstruction of the Lateglacial and Holocene in the Southern Urals and make it possible to compare the role of natural and anthropogenic factors in lake history. The Lake Syrytkul sediment records reflect the main Lateglacial and Holocene paleoclimate changes. The Lateglacial–Holocene Transition (11,600–11,500 cal BP) expressed in all palaeorecords was followed by great limnological and vegetation changes. The climatic changes of ~7400 and ~4300 cal BP were fixed in all lake sediment records. Vegetation and lake ecosystem were less affected by global climate events: the Preboreal Oscillation (11,200–11,000 cal BP), 8.2 ka event and regional climate events: ~10,350 cal BP, ~9750 cal BP, ~9000 cal BP and ~2000 cal BP. As follows from lake sediment records, the environment deterioration after the Holocene climatic optimum started in different time in the range of 6300–5100 cal BP due to various sensitivities of different proxies to paleoclimate parameters. The climate events were the main drivers for the dynamics of the Southern Urals lake ecosystems during almost the entire lake history. The role of the human factor in the change of the lake ecosystem was critical since the beginning of the twentieth century. Despite the adjacent Karabash copper smelter as the source of considerable technogenic contamination, it was a dam constructed ~100 years ago that had the greatest impact on the lake system. This event is reflected in all sediment records, especially diatom and geochemical. Changes in the diatom species composition and sediments geochemistry of the shortest human impact period are comparable in magnitude to the response of the lake ecosystem to the Lateglacial–Holocene Transition.

1. Introduction

Currently, the Holocene and Lateglacial are considered in many papers. In Russia, most Holocene and Lateglacial records were obtained from Eastern Siberia (BDP, 2000; BDP-99, 2005; Goldberg et al., 2008; Fedotov et al., 2012; Bezrukova et al., 2014) and the Russian northwest (Subetto et al., 2002; Dolukhanov et al., 2010). The paleoreconstructions of the Ural environments provide a link between Europe and Asia paleorecords. Previous Holocene reconstructions from the Urals were mainly based on spore-pollen analysis of the peat deposits (Surova et al., 1975; Khotinsky, 1977; Panova, 1987; Jankovska et al., 2006; Panova and Antipina, 2013). Lake sediments have several advantages in comparison with peat deposits. For example, lake sediment pollen spectra are less influenced by the local component, which helps to distinguish zonal features of the pollen assemblage (Sladkov, 1967). Furthermore, peat deposits are generally studied by palynological and botanical analyses, whereas reconstructions from lake sediments are usually based on multi-proxy approach (Reinemann et al., 2009; Terasmaa et al., 2013). Prior to our investigations (Maslennikova et al., 2012, 2014) only a few Holocene and Lateglacial paleolimnological reconstructions were available from the Southern Urals, but most had no radiocarbon dating (Zhuze, 1939; Sukachev and Poplavskaya, 1946; Khomutova, 1978; Deryagin, 1999). Only one radiocarbon date, with a significant error in age determination (9720 ± 380 BP), was obtained for Lake Uvildy sediments (Khomutova et al., 1995).

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Prior to our research on sediment cores from lakes of the Southern Urals, natural changes in the lake ecosystem were studied separately from anthropogenic changes. Short sediment cores that were used for the study of anthropogenic impact were not informative enough to compare the influence of natural and anthropogenic factors on lake ecosystems (Udachin et al., 1998, 2009). Lake Syrytkul is located in the impact zone of the Karabash copper smelter built in 1910 AD. Since its opening, the smelter and refining plant have produced around 30 million tons of metallurgical slag and flotation wastes (Udachin et al., 1998). Previous investigations of the sediments from several lakes located near the Karabash copper smelter show increases in Cu, Zn, Pb, Cd, Tl, Se, Sn, Sb since 1910 AD (Udachin et al., 2009; Spiro et al., 2013). Additionally, it was observed that poorly-buffered lakes affected by acid deposition were characterized by changes in diatom assemblages due to the acidification effect (Maslennikova et al., 2012). Lakes well-buffered to the effects of acid deposition were investigated in relation to chironomids only. The chironomid fauna changes in most lakes were driven by trophic change, independent of the industrial activity (Brooks et al., 2005). The dam construction 100 years ago could also impact the lake ecosystem. The research of full sediment cores, including the period of human impact, makes it possible to compare the role of natural and anthropogenic factors in the history of the lakes.

Table 1
Coordinates and special characteristics of Lake Syrytkul.

Location and physical characteristics	Parameters	Water chemistry parameters	Surface water	Bottom water
Latitude	55°19′733″	pH	7.21	7.0
Longitude	60°15′233″	Eh, mV	335	334
Altitude, m.a.s.l.	358	Conductivity, μS cm^{-1}	171	173
Surface area, ha	60	Total hardness of water, mmol l^{-1}	1.79	1.82
Maximum water depth, m	6.5	HCO_3^-, mg l^{-1}	92.7	94.5
Average water depth, m	3.66	Cl, mg l^{-1}	3.37	3.72
Water volume, mn. m^3	2.18	SO_4^{2-}, mg l^{-1}	30.5	32.5
Capacity factor	0.57	N_{tot}, mg l^{-1}	3.40	5.4
Coring depth, m	5.24	Ca^{2+}, mg l^{-1}	25.9	25.1
Catchment area, ha	286	Mg^{2+}, mg l^{-1}	6.01	6.82
Average July air temperature,°C	+17	K^+, mg l^{-1}	2.51	2.58
Average January air temperature,°C	16	Na^+, mg l^{-1}	5.70	6.0
Annual precipitation, mm per year	500	Fe, mg l^{-1}	0.017	0.020
Mineralization, mg l^{-1}	170–176	Mn, mg l^{-1}	0.002	0.003

As the natural environmental changes in the Southern Urals and the human-induced impact have not been described in detail, we decided to provide an accurate palaeoenvironmental reconstructions from the Lateglacial and Holocene, including the industrial period, using the Lake Syrytkul sediments multi-proxy analysis and AMS ^{14}C dating. Substantial climate fluctuations in the Lateglacial and Holocene and human impact would have caused considerable changes in the lake ecosystems. Hence, the first investigation objective is to determine the main climate events reflected in Lake Syrytkul sediment records and their influence on the lake ecosystem. The second objective of our investigation is to study the way the anthropogenic factor is reflected in the records of Lake Syrytkul sediments and its role relative to other, natural factors.

2. Regional setting

Lake Syrytkul is situated on the eastern slope of the Southern Urals, in the intermountain area of the Ilmeny Ridge, 12 km south of the Karabash copper smelter (Fig. 1). The present-day climate is continental, with relatively low annual precipitation (Table 1). In winter months, the Southern Urals is influenced by the Siberian anticyclone. High-temperature and low-moisture tropical air is transferred in summer from Central Asia and Kazakhstan. The Atlantic cyclone brings warm and wet air masses into the Southern Urals (Andreeva, 1995). The Lake Syrytkul catchment area is covered by mixed South Ural taiga dominated by *Pinus sylvestris* L., *Betula pendula Roth*. and *Larix sibirica Ledeb*. Rocks occurring largely as nepheline-feldspar and quartz-feldspar migmatites, calcite-biotite, vermiculite rocks and granites make up the Ilmeny Mountain complex (Geologicheskaja karta, 1980). The lake basin is tectonic in origin. The natural surface area of the lake before the dam construction did not exceed 50 ha, with a water volume of 1 × 106 m^3. The dam increased the surface area to 60 ha and water volume to 2.18 × 106 m^3 (Deryagin et al., 2011).

3. Materials and methods

3.1. Field methods

A sediment core of 5.24 m long was taken from the central part of Lake Syrytkul at 5.2 m water depth using a gravity corer for surface sediments (30 cm) and a Russian corer (i.d. 8.0 cm, length 1 m) for the rest of the core. The cores were extracted in the field, sliced at 1 cm intervals from the surface to 30 cm depth, and 1–5 cm intervals to the core bottom. All of the samples were stored in plastic bags at 4 °C in the dark.

3.2. Chronology

The sediment core chronology is based on ^{210}Pb and AMS ^{14}C dating techniques. Four samples were selected for AMS ^{14}C dating at the Radiocarbon Dating Laboratory, University of Lund, Sweden (Table 2). ^{14}C years have been calibrated and age-depth modelled using the IntCal13 calibration curve (Reimer et al., 2013). Calibration and deposition model were obtained in OxCal 4.2 software (Bronk Ramsey, 2008) (Fig. 2). The ^{210}Pb analysis was applied for the upper sediments chronology. ^{210}Pb activities were measured using an Ortec HPGe GWL series well-type coaxial low background intrinsic germanium detector. Total ^{210}Pb were measured by γ-spectroscopy. The activity of $^{210}Pb_{supported}$ was estimated by measuring the activity of ^{210}Pb, while the activity of $^{210}Pb_{excess}$ was determined by the difference between the total and the supported ^{210}Pb. The upper sediment core was dated by applying the constant rate of supply (CRS) model to the ^{210}Pb profile (Appleby, 2001).

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