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Oxygen isotope composition of diatoms from sediments of Lake Kotokel (*Buryatia*)

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Abstract

This is a summary of new oxygen isotope record of diatoms from Lake Kotokel sediments, with implications for responses of the lake system and its environment to global change over the past 46 kyr. Fossil diatoms in all samples are free from visible contamination signatures and contain no more than 2.5% Al_2O_3, which ensures reliable reconstructions. The $\delta^{18}O$ values in diatoms vary between +23.7 and +31.2‰ over the record. The results present mainly diatom assemblages of summer blooming periods, except for the time span between 36 and 32 kyr, when the isotopic signal records mainly a shift from summer to spring blooming conditions. Possible water temperature changes only partly explain the changes in the isotopic record. The observed isotopic patterns are produced mainly by isotope changes in lake water in response to variations in air temperature, hydrology, and atmospheric circulation in the region. During Marine Isotope Stage (MIS) 2 (Last Glacial maximum), high $\delta^{18}O_{diatom}$ resulted from rapid evaporation and low fluvial inputs. The high $\delta^{18}O_{diatom}$ values of about +29 to +30‰ during the first half of MIS 1 (Holocene interglacial) suggest an increased share of summer rainfalls associated with southern/southeastern air transport. The $\delta^{18}O_{diatom}$ decrease to +24‰ during the second half of MIS 1 is due to the overall hemispheric cooling and increased moisture supply to the area by the Atlantic air masses. The record of Lake Kotokel sediments provides an example of complex interplay among several climatic/environmental controls of $\delta^{18}O_{diatom}$ during the Late Pleistocene and the Holocene.

Keywords: isotope analysis; lacustrine sediments; biogenic silica; climate changes; hydrologic variation; southern Siberia

Introduction

Lithology, mineralogy, and chemistry of bottom sediments have important implications for the history of lakes, sediment provenance, and responses of lake systems to global change (Kuzmin et al., 2014; Sklyarov et al., 2010). Variations in oxygen isotope composition ($\delta^{18}O$) of limnic fossils found in sediments, such as foraminifera, ostracods, or gastropods, bear information on their environments, and can be used as a climate proxy (Faure, 1986). Isotopic records of diatom silica have been intensively studied in the past decade (Leng and Barker, 2006; Leng and Henderson, 2013; Swann and Leng, 2009). Diatom algae (Bacillariophyta) are essential constituents of many limnic ecosystems. When die, they sink to the bottom and become part of lake sediments representative of the respective deposition environments. $\delta^{18}O_{diatom}$ curves may reflect variations in temperatures and oxygen isotope composition of water (Labeyrie, 1974). The values of $\delta^{18}O_w$, in turn, depend on lake hydrology and $\delta^{18}O$ of regional atmospheric precipitation ($\delta^{18}O_{atm}$) (Leng and Barker, 2006).

Although being yet few, oxygen isotope archives available from Russia (Chapligin et al., 2012a; Jones et al., 2004; Meyer et al., 2015; Swann et al., 2010) extend the knowledge of global change, lake hydrology, and atmospheric circulation that controls moisture transport. Specifically, $\delta^{18}O_{diatom}$ data from Lake Baikal revealed general trends in the system responses to global climate change (Kalmychkov et al., 2007; Mackay et al., 2008, 2011, 2013; Morley et al., 2005). However, detailed climate reconstructions for the last glacial-interglacial cycle are impeded by poor age constraints (Kalmy-

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chkov et al., 2007) and low temporal resolution (Mackay et al., 2011; Morley et al., 2005) of the records. On the other hand, the diatom isotopic signal from Lake Baikal with its basin and catchment area of Lake Baikal is strongly averaged while high contamination with nondiatom silicates (up to 60%) of diatom samples deposited during the Late Glacial reduce the record quality (Mackay et al., 2011; Morley et al., 2005).

According to interdisciplinary results (Bezrukova et al., 2010; Müller et al., 2010, 2014; Sklyarov et al., 2010), bottom sediments of small lakes provide valuable information for reconstructions of Late Pleistocene climates and environments on different scales. Specifically, the ecosystem of Lake Kotokel located at the taiga/steppe boundary (Fig. 1) was proven (Bezrukova et al., 2008, 2010, 2011; Fedotov et al., 2012; Müller et al., 2014; Shichi et al., 2009; Tarasov et al., 2009) to be highly sensitive to heat and moisture variations. High contents of total organic carbon (TOC) and the absence of the reservoir effect allowed reliable dating of the lake sediments (Bezrukova et al., 2010). The Holocene $\delta^{18}O_{diatom}$ record of the Kotokel sediments at an average resolution of 150 yr (Kostrova et al., 2013a,b) satisfactory images the general climate history of the Northern Hemisphere. In this paper we synthesize partly published (Kostrova et al., 2013a,b, 2014) and recently obtained unpublished oxygen isotope data from the longest and most representative Kotokel core KTK2 (Bezrukova et al., 2010); describe the analytical methods; and discuss the responses of the lake system to global change for the past 46 kyr (hereafter the ages are quoted as calibrated using the *CalPal* online radiocarbon calibration software (http://www.calpal-online.de). The results are compared with

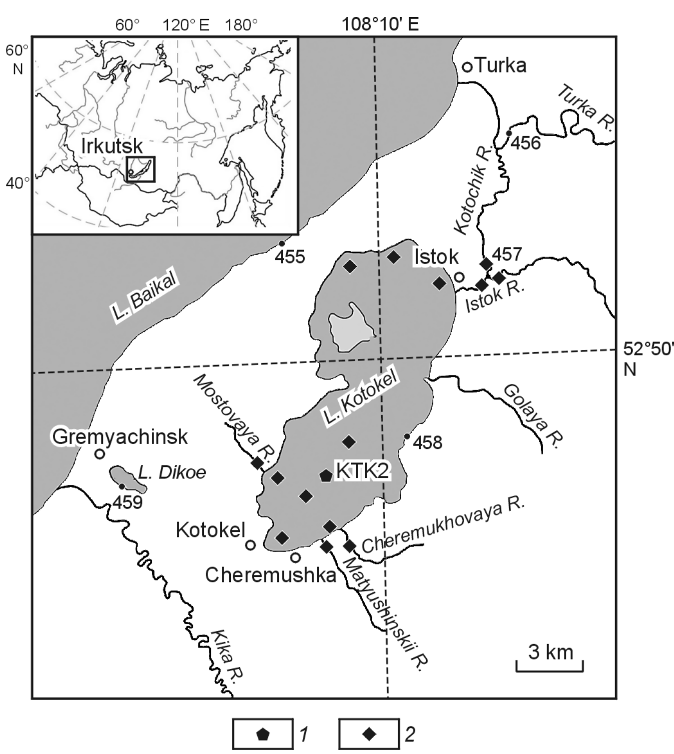

Fig. 1. Map of Lake Kotokel location. *1*, the KTK2 core; *2*, water sampling sites.

the ecological interpretation of palynological and diatom records (Bezrukova et al., 2008, 2010, 2011; Müller et al., 2014; Shichi et al., 2009; Tarasov et al., 2009).

Study area

Kotokel (52°50′ N, 108°10′ E, 458 m asl) is a relatively small (about 67 km^2) freshwater lake, as shallow as ~4 m on average (Zhang et al., 2013), with a catchment limited to 183 km^2 (Kuzmich, 1988) and a short water renewal period of ~7 yr (Shichi et al., 2009). It extends along the Buryatian shore of Lake Baikal, between the Turka and Kika Rivers (Fig. 1). Lake Kotokel is bordered by a 500–729 m high ridge, which separates it from Lake Baikal. A swampy area adjoins in the south, and the Ulan-Burgassy Range (up to 2033 m asl) is located in the east. It receives waters from several streams and creeks and discharges through the Istok River. Note that the latter can change its flow direction when the level of the Kotochik River rises considerably (Kostrova et al., 2012; Kuzmich, 1988). The shallow water of the lake warms up rapidly during warm seasons and lacks temperature stratification (Sheveleva and Krivenkova, 2010). The lake is covered with up to 70 cm thick ice from latest October to earliest May and is open from May to October, with a mean water temperature of ~18 °C (Kuzmich, 1988). Lake state generally reflects the continental climate of the area, with a cold winter and a moderately warm summer. The mean air temperatures are about –20 °C in January and +16 °C in July, while the mean annual precipitation does not exceed 400 mm (Galazii, 1993). Lake Kotokel lies at the crossways of two global air circulation systems: the Asian anticyclone and the North Atlantic transport. The western air transport predominant almost all year round fades in July and August, while the N–S transport and the polar cyclones become more active. Cyclones coming from the southeast bring warm and humid air, which causes heavy rainfalls. In autumn and winter, the area falls in the zone of high air pressure with its center over East Siberia and Mongolia, precipitation is low, and the weather is sunny and cold (Latysheva et al., 2009).

Materials and methods

Diatom frustules were extracted from a 1253 cm long core (KTK2) of bottom sediments sampled in the southern part of the lake at 52°47′ N; 108°07′ E (Fig. 1), under 3.5 m of water, in August 2005 (Bezrukova et al., 2010). Radiocarbon dates and the respective age model, as well as lithological, spore-pollen, and diatom results were presented in details by Bezrukova et al. (2010). Accordingly, all samples from the 1153–1182, 1113–1093, 1045–895 and 820–720 cm core intervals with extremely low diatom abundances (Fig. 2), which were deposited 42.3–40.3, 37.5–36.1, 32.8–24.7, and 22.0–17.0 kyr ago, respectively, were excluded from our current study. Diatoms were extracted from sediments at every 5 cm and cleaned by means of stepwise techniques developed