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Oxygen isotope composition of diatoms as Late Holocene climate proxy at Two-Yurts Lake, Central Kamchatka, Russia

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Especially in combination with other proxies, the oxygen isotope composition of diatom silica ($\delta^{18}O_{diatom}$) from lake sediments is useful for interpreting past climate conditions. This paper presents the first oxygen isotope data of fossil diatoms from Kamchatka, Russia, derived from sediment cores from Two-Yurts Lake (TYL). For reconstructing Late Holocene climate change, palaeolimnological investigations also included diatom, pollen and chironomid analysis.

The most recent diatom sample ($\delta^{18}O_{diatom} = +23.3$‰) corresponds well with the present day isotopic composition of the TYL water (mean $\delta^{18}O = -14.8$‰) displaying a reasonable isotope fractionation in the system silica-water. Nonetheless, the TYL $\delta^{18}O_{diatom}$ record is mainly controlled by changes in the isotopic composition of the lake water. TYL is considered as a dynamic system triggered by differential environmental changes closely linked with lake-internal hydrological factors.

The diatom silica isotope record displays large variations in $\delta^{18}O_{diatom}$ from +27.3‰ to +23.3‰ from about ~4.5 kyr BP until today. A continuous depletion in $\delta^{18}O_{diatom}$ of 4.0‰ is observed in the past 4.5 kyr, which is in good accordance with other hemispheric environmental changes (i.e. a summer insolation-driven Mid- to Late Holocene cooling). The overall cooling trend is superimposed by regional hydrological and atmospheric–oceanic changes. These are related to the interplay between Siberian High and Aleutian Low as well as to the ice dynamics in the Sea of Okhotsk. Additionally, combined $\delta^{18}O_{diatom}$ and chironomid interpretations provide new information on changes related to meltwater input to lakes. Hence, this diatom isotope study provides further insight into hydrology and climate dynamics of this remote, rarely investigated area.

1. Introduction

Among terrestrial climate archives, lake sediments have great potential to provide high resolution and continuous information on environmental change (Leng and Barker, 2006). Multi-proxy studies of lake sediment cores contribute to the reconstruction of Late Quaternary climate from the terrestrial perspective allowing for correlation with continuous archives such as marine sediments (LR04 benthic stack: Lisiecki and Raymo, 2005) and ice cores of both hemispheres (i.e. NGRIP: Vinther et al., 2006; GISP2: Mayewski et al., 2004; EPICA Community, 2006). The use of oxygen isotopes in biogenic silica (diatoms) within aquatic sediments relates to milestone work by Labeyrie (1974) and Shemesh et al. (1992) and has become increasingly common since both, lacustrine and marine systems contain siliceous microfossils such as diatoms.

Diatoms are photosynthetic algae with cell walls composed of SiO_2 with a characteristic morphology and two intricately-patterned valves. Their ubiquitous growth in almost all aquatic environments make the analysis of fossil diatoms in lake sediments a particularly useful method for reconstructing spatial and temporal ecological, environmental and climate changes at the local to regional scale (Battarbee et al., 2005). However, it is difficult to estimate the exact palaeoenvironmental parameters from diatom species distribution.

The oxygen isotope composition of diatom frustules ($\delta^{18}O_{diatom}$) extracted from lacustrine sediments is used as a tool to assess changes in temperature, precipitation patterns, or evaporation in lacustrine ecosystems (Jones et al., 2004; Leng and Marshall, 2004; Leng and Barker, 2006). A substantial number of such records from different parts of the world underline the potential for reconstructing past climate changes from the oxygen isotope composition of biogenic silica ($\delta^{18}O_{Si}$).

However, a suitable lake for palaeoclimate reconstruction with oxygen isotopes in biogenic silica needs to be hydrologically known (Leng and Barker, 2006) including recent information on lake water temperature and isotope composition of the lake. Did the lake dry out or change its level during geological periods? What is the input signal to the lake and how did it change through time? What is the seasonality of precipitation to the lake? What is the hydrological balance (open/closed

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system, inflow/outflow, residence time)? How well is the lake mixed in terms of lake water temperature and chemical composition?

Within the scope of the Russian–German project KALMAR ("Kurile-Kamchatka and Aleutean Marginal Sea-Island Arc Systems: Geodynamic and Climate Interaction in Space and Time"), lake sediments and water samples were recovered from Two-Yurts Lake (TYL), Kamchatka to gain past environmental information. One main objective of the KALMAR project is to infer Late Quaternary climate change on Kamchatka on the basis of palaeolimnological records (Nazarova et al., 2013; Hoff et al., this issue).

We selected Two-Yurts Lake for our studies due to its setting, hydrological characteristics and readily available background information on important key parameters (i.e. sedimentology, age model). TYL sediments consist of diatom-rich oozes (interrupted by a few tephra layers) dominated by only a few diatom species (Hoff et al., this issue) yielding sufficiently high-purity diatom samples for oxygen isotope analyses. Additionally, diatom taxonomy and palynology (Hoff et al., this issue) as well as chironomids (Nazarova et al., 2013) were studied in parallel. Hence, the main aim of this study is to use diatom isotope signals of Two-Yurts Lake for Holocene palaeoenvironmental reconstruction, interpreted in comparison to local sedimentological, pollen and diatom assemblage data as well as to findings from TYL chironomid analyses as an independent temperature proxy. This regional environmental and climate information is then brought into the broader north hemispheric context to understand the linkage of Kamchatka to Holocene larger-scale climate patterns.

2. Regional setting

Two-Yurts Lake is situated at 56°49, 2′N; 160°06, 3′E in the Central Mountain Chain of Kamchatka at an elevation of 275 m a.s.l. (above sea level). The Central Kamchatka Mountain Chain is mostly built of Neogene to mid-Pleistocene volcanic rocks and extinct volcanoes (Solomina et al., 2007).

Two-Yurts Lake is oval-shaped and covers an area of 11.7 km^2 (Fig. 1). The mean water depth of this open through-flow lake system is about 25 m. TYL formed on a moraine of the Two-Yurts Lake Valley, located on the eastern slope of the Central Kamchatka Mountain Chain. There are three main inflows to TYL at the western part and one outflow at the eastern side. The basin of Two-Yurts Lake is embedded in a former glacial valley at the eastern slope of Kamchatka's central mountain arc, the Sredinnyi Ridge. Mountain peaks and ridges closest to the lake reach about 1.100 m a.s.l. The local vegetation is characterised by stone birch forest and subalpine shrubs with dwarf birch and shrub pine (Krestov et al., 2008).

In the generally maritime setting of Kamchatka, the study area represents Kamchatka's most continental climate with coastal influence either from the Pacific side, about 150 km to the southeast, or from the Okhotsk Sea, 180 km to the west. The meteorological station at Petropavlovsk-Kamchatsky situated about 440 km to the SW of TYL yields an annual precipitation of 1335 mm and a mean annual air temperature (MAAT) of +1.9 °C (Fig. 2). This station has been included in the Siberian Network of Isotopes in Precipitation (SNIP; Kurita et al., 2004) displaying mean annual oxygen and hydrogen isotope compositions of −13.3‰ and −100.7‰, respectively, with an overall low annual temperature and isotope variability typical of coastal stations (Fig. 2).

3. Material and methods

3.1. Field work and age model

In September 2007, six sediment cores were taken from TYL with a raft and a tripod-supported UWITEC-piston corer system. We refer to two overlapping sediment cores taken at site PG1857 (Fig. 1). Sediment core PG1857-2 includes the upper section downcore from the surface bottom sediment, which has been spliced at a 189–191 cm core depth to sediment core PG1857-5 at a 59–61 cm core depth to gather a 3.5 m long composite section. The TYL age model at site PG1857 relies upon nine radiocarbon dates carried out at Poznan Radiocarbon Laboratory, Poland and tephra layers related to a reference ash stratigraphy of Kamchatka (Dirksen et al., 2013). The radiocarbon dates of sediment core PG1857-2 range between 0.14 and 2.55 cal yr BP and those of

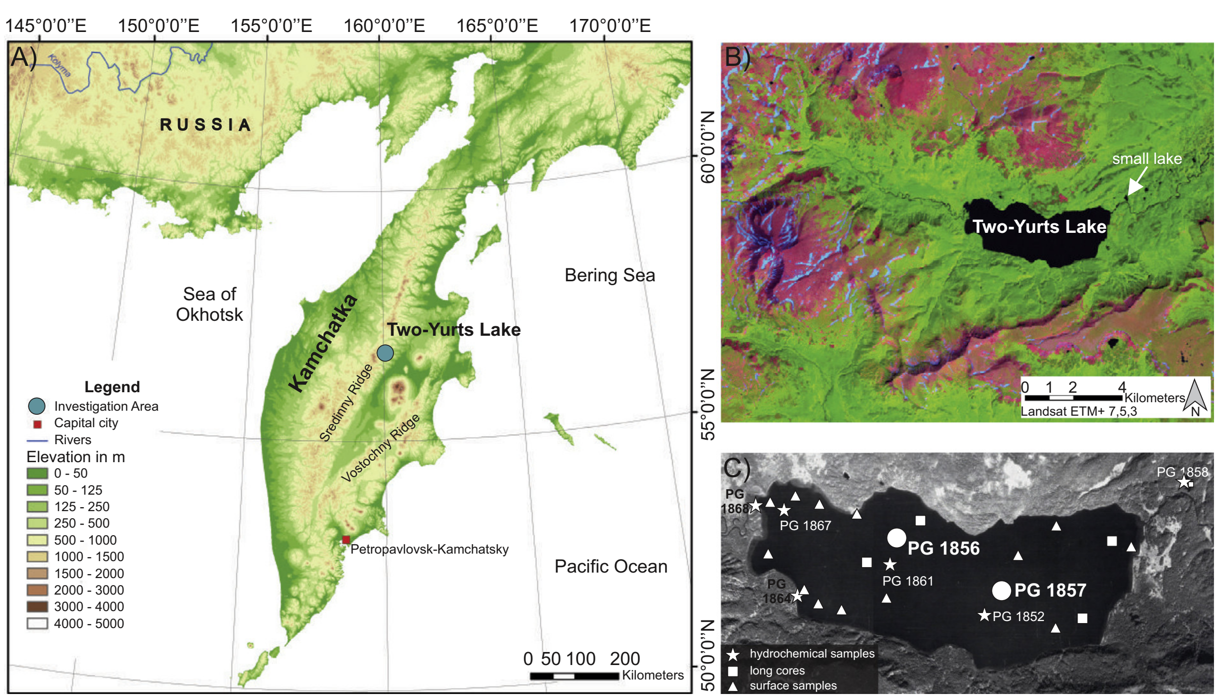

Fig. 1. Location of the study lakes in the Two-Yurts Lake area on the Kamchatka Peninsula, Russia with sampling positions for sediment cores (dots), surface samples (triangles) and hydrochemical samples (asterisks). Note: a small lake near TYL has been sampled for comparison.

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