



Last glacial to post glacial climate changes in continental Asia inferred from multi-proxy records (geochemistry, clay mineralogy, and paleontology) from Lake Hovsgol, northwest Mongolia

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ABSTRACT

Multi-proxy records (geochemistry, clay mineralogy and paleontology) from three sediment cores from Lake Hovsgol, northwest Mongolia, provide paleoenvironmental changes in continental Asia from the last glacial to the present (during the last 29 cal ka BP). This paper presents the first continuous $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ dataset for ostracod shells (*Cytherissa lacustris*) from Lake Hovsgol sediments. A positive shift in ostracod $\delta^{13}\text{C}$ values (from +0.5‰ to +3.2‰) began at ca. 21 cal ka BP, and was associated with a decrease in $\delta^{13}\text{C}$ values of total organic carbon (from −24.7‰ to −27.3‰) and an increase in the mass accumulation rate of total organic carbon (MAR-TOC). These results suggest that increased lake productivity led to the ^{13}C -enrichment of dissolved inorganic carbon in Lake Hovsgol. In addition, decreases in clay content and the illite crystallinity index (full width at half maximum of the 10 Å peak) began at ca. 21 cal ka BP, indicating an increase in surface runoff and a change in sources of clastic materials in the watershed. The highest $\delta^{18}\text{O}_{\text{ostracod}}$ values (up to −4.8‰) at 16–15 cal ka BP indicate the increases in precipitation from the East Asian monsoon. The total pollen amount increased, and *Betula*, *Alnus*, and *Salix* were dominant (up to 53%, 30%, and 6%, respectively) after 16–15 cal ka BP. These findings indicate that broad-leaved trees expanded around Lake Hovsgol. In addition, fossil diatom valves appeared after 16–15 cal ka BP, suggesting climate amelioration, and increased input of soil-derived nutrients and dissolved silica. Between 10 and 5 cal ka BP (Holocene climate optimum), productivity was high in and around the lake (MAR-TOC, up to 47.3 mg/cm² kyr; MAR-diatoms, up to 14.4 × 10⁸ valves/cm² kyr; total pollen concentration, up to 9.0 × 10⁵ grains/cm³). Environmental changes during the last 29 kyr in and around Lake Hovsgol are clearly associated with fluctuations in summer insolation and East Asian monsoon intensity.

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1. Introduction

Lake Hovsgol, northwest Mongolia, is at an altitude of 1645 m above sea level (asl) within the Baikal rift zone (Kozhova et al., 1989; San'kov et al., 2003; Goulden et al., 2006) and has a surface area of 2760 km² and a maximum depth of 262 m (Fig. 1). Three main rivers flow into Lake Hovsgol, and the one outflowing river drains to Lake Baikal via the Selenga River (Fig. 1). The water level of Lake Hovsgol is very sensitive to moisture and precipitation changes in continental Asia

because of the lake's unique hydrologic and topographic features, namely a relatively small catchment area (5130 km²) is surrounded by high mountains with elevations of ~2800–3400 m asl (Krivonogov, 2006; Prokopenko et al., 2007; Prokopenko and Bonvento, 2009). Therefore, lake sediments preserve a significant and unique archive for paleo-environmental studies, particularly of moisture changes, in the continental Asia. In addition, the sediments provide a record of the biological changes that have occurred in response to climatic changes in continental Asia.

Paleoclimate studies using sediment samples from Lake Hovsgol have been carried out under the auspices of the Hovsgol Drilling Project (Prokopenko and Catto, 2005; Hovsgol Drilling Project Group, 2007; Hovsgol Drilling Project members, 2009; Kashiwaya et al., 2010). Environmental and biological changes during the late Quaternary

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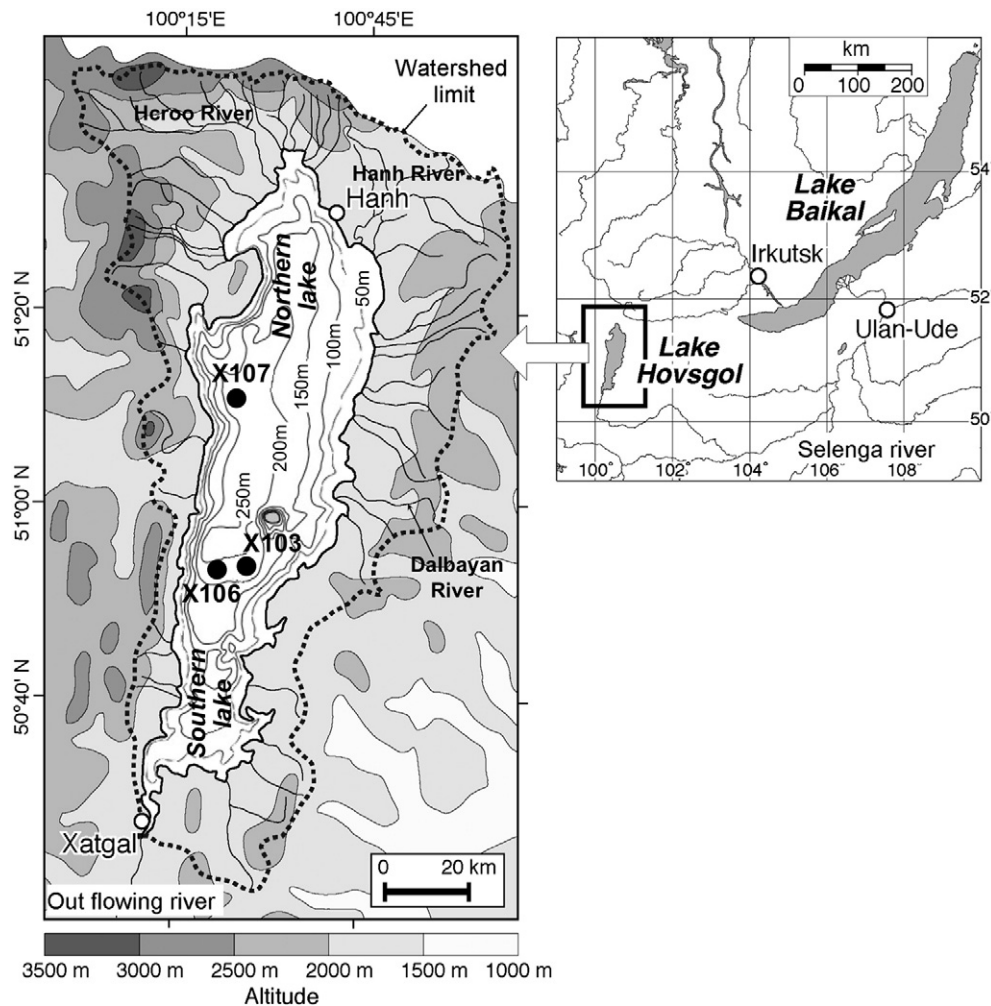


Fig. 1. Map showing the location of Lake Hovsgol in southwest Mongolia, and the coring sites (X103, X106 and X107).

have been determined by geological, geochemical and paleontological studies using sediment cores from Lake Hovsgol (Fedotov et al., 2004; Karabanov et al., 2004; Nara et al., 2005; Prokopenko et al., 2005, 2007; Watanabe et al., 2009a; Murakami et al., 2010). Nara et al. (2005) showed by organic geochemical studies (total organic carbon: TOC and total chlorophyll-*a*: total chl-*a* concentrations) of sediment cores from Lake Hovsgol that primary productivity gradually increased from ~21 to 13 cal ka BP (climate transition from the last glacial to Holocene). In addition, Prokopenko and Bonvento (2009), who studied stable oxygen isotope ratios of bulk carbonates ($\delta^{18}\text{O}_{\text{bulk}}$) and of ostracod shell carbonates ($\delta^{18}\text{O}_{\text{ostracod}}$) from Lake Hovsgol sediment cores, observed a positive $\delta^{18}\text{O}$ shift of about 1.5‰ during the climate transition from the last glacial to Holocene (beginning of the Bølling–Allerød period, 14.5 cal ka BP). Prokopenko and Bonvento (2009) concluded that the positive $\delta^{18}\text{O}$ shift has been caused by an increase in ^{18}O -enriched summer precipitation associated with the East Asian monsoon. However, their results were based on a rough chronology, and most of the data were from bulk carbonates in sediments. A continuous $\delta^{18}\text{O}$ dataset of ostracod shell carbonates from Lake Hovsgol sediments has not been reported prior to this study.

$\delta^{18}\text{O}$ values (IAEA, 2006; average data during 1960–2001) of modern precipitation in eastern Asia during summer (June–September) and winter (November–March) are shown in Fig. 2. In the Siberian region, the average $\delta^{18}\text{O}$ values of summer and winter precipitation are -10‰ and -25‰ , respectively (Fig. 2). Over middle latitudes of eastern Asia, the Siberian High affects atmospheric circulation and dominates the climate in winter: cold and dry air masses cover the area,

and the air temperature decreases to as low as -50 °C (Kozhova et al., 1989; Herzsuh, 2006). During winter, the cold air masses in the Siberian region supply ^{18}O -depleted precipitation. In contrast, the East Asian monsoon supplies ^{18}O -enriched precipitation during summer. The circulation of humid air masses during summer is strongly controlled by the East Asian monsoon and to a lesser extent by the prevailing westerly winds (Herzsuh, 2006).

The main objective of this study is to evaluate climatic and environmental changes, particularly moisture changes, in continental Asia from the last glacial to the present (from the late part of oxygen isotope stage (OIS) 3 to OIS 1; 29–0 cal ka BP). For this purpose, we constructed a new age model and analyzed clay content, clay mineral composition, fossil diatoms, pollen, and stable isotope ratios for the last 29 cal ka BP in three sediment cores (X103, X106 and X107) from Lake Hovsgol. Grain size and clay minerals in lake sediments have often been used to infer past weathering conditions in lake watersheds of the Siberian region (Horiuchi et al., 2000; Sakai et al., 2005; Fagel et al., 2007; Hovsgol Drilling Project Group, 2007). In this study, clay content (particles less than $2\text{ }\mu\text{m}$ diameter) and the full width at half maximum (FWHM) of the 10 Å illite peaks (after ethylene glycol solvation) were used as indicators of weathering intensity and of the sources of clastic materials in the Lake Hovsgol watershed. Biogenic silica content, diatom valve abundance, and fossil pollen composition in lake sediments reflect climatically induced changes in paleoproductivity and vegetation in the lake watershed (Prokopenko et al., 2007; Shichi et al., 2007, 2009).

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