Quaternary International 384 (2015) 169–179

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Paleoenvironmental changes in northern Mongolia during the last deglaciation revealed by trace element records in ostracods from Lake Hovsgol

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A R T I C L E I N F O

Article history:
Available online 5 June 2015

Keywords:
Ostracod
Trace element
Lake Hovsgol
Last deglaciation
Paleoenvironment

A B S T R A C T

Ostracods possess bivalve carapaces composed of low-Mg calcite, which can be preserved in a variety of sedimentary environments. They are a useful paleoenvironmental indicator, in particular for non-marine environments. Although previous studies of Lake Baikal and Lake Hovsgol have provided some evidence of large-scale paleoenvironmental changes in central Asia during the late Pleistocene, trace element records in ostracods from these two lakes, which may reveal the detailed limnological processes, have not yet been reported. In this study, we analyzed stable isotopes and trace elements in ostracods in three gravity core sediments recovered from Lake Hovsgol, northern Mongolia, to reconstruct the long-term limnological histories of the lake. Radiocarbon dating results indicated that ostracod-bearing core sediments were deposited from ~14.5 to 21.5 ka, which corresponds to the early stage of the last deglaciation, including the Last Glacial Maximum (LGM). The Mg/Ca and Sr/Ca ratios from two species of ostracods, *C. lacustris* and *L. inopinata*, ranged from 4 to 25 and 3–5 mmol/mol, respectively, with distinct and consistent decreasing trends. The changes in the Mg/Ca and Sr/Ca ratios indicate that the salinity of the lake water decreased substantially at the initial transition from the last glacial to the current interglacial period, which was mainly due to the ice melting and introducing fresh water into the lake. Changes in the Fe/Ca and U/Ca ratios were interpreted as water circulation changes in the bottom of the lake. After the LGM, the Fe/Ca and U/Ca ratios gradually increased, indicating that inflowing cold water induced stronger water circulation and subsequently a higher dissolved oxygen content in the bottom water of the lake. The Mn/Ca ratio had the opposite trend to the U/Ca and Fe/Ca ratios, which suggests that it was affected by the weathering intensity in the area around Lake Hovsgol. The stable isotopic results for *C. lacustris* support our paleoenvironmental interpretations in the region on the basis of trace elements. As a result, ostracod geochemical records from Lake Hovsgol, northern Mongolia, provide new insights into paleoenvironmental changes in central Asia during the onset of the last deglaciation.

1. Introduction

Lake sediment is a useful material for paleoenvironmental and paleoclimatic studies because it is widely distributed in all continents, and contains a variety of proxies such as pollen, diatoms, ostracods, and clastic and carbonate materials (Williams et al., 1996; Bradley, 1998). Valuable paleoenvironmental data have been obtained from lake sediments in various parts of the world, including the East African Rift Valley region, Lake Baikal, Lake Titicaca, Lake Malawi, Great Salt Lake, and Great Bear Lake during the last few decades (e.g., Watanabe et al., 2004). The Baikal Drilling International Project (BDP) is regarded as the most successful study of lake sediments. The BDP team provided much information about global and regional climatic changes (Williams et al., 2001). Because Lake Hovsgol in northern Mongolia is part of the Baikal Rift System (Goulden et al., 2006), a paleoenvironmental study of the lake has the potential to provide useful information regarding long-term environmental changes in the middle of the largest continent.

Ostracods are micro-sized crustaceans that secrete a bivalve carapace composed of low-Mg calcite. The carapaces can be readily fossilized and are well-preserved in lake sediments. Ostracods live

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http://dx.doi.org/10.1016/j.quaint.2015.04.041
1040-6182/

in most aquatic habitats, including springs, ponds, lakes, streams, rivers, estuaries, and oceans (Schwalb, 2003). They are often used as a paleoclimatic proxy to acquire geochemical data from lake sediments, in which carbonate material is often rare. In non-marine environments, they play an important role as a paleoenvironmental indicator, enabling an understanding of past changes in water physicochemical conditions. Ostracods secrete their own shell from host water by maintaining a balance between their chemical composition and the surrounding water chemistry (Homes and Chivas, 2002). Thus, trace element and stable isotope data from ostracod shells provide valuable information regarding the temperature, salinity, and solute composition (ionic and isotopic composition) of the host water in the past. Furthermore, geochemical data from ostracods can be used to interpret the paleoclimatic changes in their habitats in terms of the effective precipitation, air temperature, lake water level (or depth), atmospheric circulation, and carbon cycle of a lake catchment (Homes and Chivas, 2002). Previous studies have used isotopic and trace element data from ostracods to interpret past changes in the physicochemical properties of water in the lakes and oceans in which they originated (Holmes et al., 1995; Wansard et al., 1998; Grafenstein et al., 1999; Cronin et al., 2000; Keatings et al., 2002; Schwalb, 2003; Decrouy et al., 2011a, b; Decrouy et al., 2012; Li et al., 2012; Schwalb et al., 2013). Chivas et al. (1985, 1986a, b) demonstrated the relationship between water physicochemical conditions and the trace element content of ostracods. They concluded that the Mg/Ca and Sr/Ca ratios of ostracod shells are good indicators of changes in water temperature and salinity. Rickette et al. (2001) studied the U/Ca ratio of ostracods to reconstruct the circulation pattern of deep water in the lake and concluded that high U/Ca values revealed the oxic environment caused by the stronger circulation and production of deep water in the lake.

Previous paleoenvironmental studies of Lake Hovsgol have been conducted to determine the sedimentation rate, clay mineral composition, and microfossil distribution (e.g., diatoms). Previous studies of Lake Hovsgol have also reported stable isotope data from ostracod shells (Prokopenko and Bonvento, 2009; Watanabe et al., 2012). However, paleoenvironmental interpretations using trace element data from ostracods in the sediment of Lake Hovsgol, which may reveal the detailed limnological processes, have not been conducted. The main objective of this study was to determine trace element records in ostracod shells from Lake Hovsgol, and to interpret them to reconstruct more details of the limnological processes in the late Quaternary. To achieve this, the Kangwon National University Research group recovered 14 gravity cores from the bottom of Lake Hovsgol in 2004, and subsequently performed both elemental and stable isotopic analyses.

2. Geological setting and climate

Lake Hovsgol in northern Mongolia lies at the southwestern part of the Baikal Rift System, and is estimated to have formed 2.5 to 4 Mya (Goulden et al., 2006, Fig. 1). The northernmost part of Lake Hovsgol is located about 200 km southwest of Lake Baikal. The altitude of the lake is 1645 m above sea level (a.s.l.), which is 1190 m higher than that of Lake Baikal (455 m a.s.l.) (Goulden et al., 2006). Lake Hovsgol is the second largest and deepest lake (136 km long, 20–40 km wide, and maximum depth of 262.4 m) in eastern Eurasia, after Lake Baikal (Goulden et al., 2006). The water of Lake Hovsgol is currently running into the southernmost bay of Lake Baikal via the Egiin Gol River, which is one of the tributaries of the Selenga River. The Lake Hovsgol region has a harsh continental climate characterized by very cold and dry winters and mild and windy summers (Namkhaijantsan, 2006). Most of the annual rainfall (300–600 mm per year; about 93% of the total) is concentrated in the summer and is directly related to the East Asian summer monsoon during July to August (Namkhaijantsan, 2006). The lake water is provided by river and groundwater inflow, and direct rainfall to the surface of the lake. From 1963 to 1967, the lake water was obtained almost equally from three sources (river: 36%, groundwater: 32%, rainfall: 32%) (Kumagai et al., 2006). From 1998 to 2002, the contribution of groundwater to the recharge of the lake water clearly increased, reaching 42%. This suggests that groundwater has become the dominant source of water due to the rapid increase in soil temperature and the subsequent melting of glaciers and/or permafrost in upstream highland areas (Kumagai et al., 2006). The loss of lake water is mainly due to evaporation (70–80%), with the outflowing discharge not being a major loss (20–30%) to the water body (Kumagai et al., 2006). The catchment is only 1.7-fold larger than the surface area of the lake. The changes in lake level strongly depend on precipitation and surface run-off from the surrounding region (Potemkina and Potemkin, 2002). This geological and environmental setting results in the lake level being very sensitive to climate change.

The south and southwestern regions of the lake's watershed consist mainly of Vendian-Early Cambrian shelf carbonates (limestone, dolomite) with phosphorite deposits, while most of the eastern side of the lake consists of olivine basalt from the late Miocene and Pliocene volcanism (Goulden et al., 2006). The northern and southeastern shores of the lake consist of Late Riphean ophiolites, Vendian–Early Paleozoic volcanogen-turbidite deposits, and Paleozoic granitoids. The lithology of the northeastern shore consists of Early Precambrian and Late Riphean-Early Paleozoic zonal metamorphic groups, with intrusions of various aged Paleozoic granitoids (Goulden et al., 2006).

The current average salinity of the lake water is 180–200 mg/l, and the water is almost saturated with $CaCO_3$. Most detrital particles originate from the northwestern source areas of the lake.

The species diversity of ostracods in Lake Hovsgol is relatively low, with 12–13 ostracod taxa present in the lake at the present time (Mazepova, 2006). Four species of ostracod, *Candona lepnevae*, *Cytherissa lacustris*, *Limnocythere inopinata*, and *Leucocythere* sp., were identified as being previously established in the lake from core sediments (Kim and Cheong, 2007). The occurrence of *Candona lepnevae* is relatively rare, with many breaks in its records of abundance. *C. lacustris* is the most abundant of the four species, accounting for 60% of all records of the four species in the sediments. *L. inopinata* is correlatively common, with a relative occurrence that displays trends opposite to those of *C. lacustris*. These two dominant species, *C. lacustris* and *L. inopinata*, were reported to be benthic ostracods (Loffler, 1975; Delorme, 1978; Griffiths, 1995; Geier et al., 1998; Mazepova, 2006; Poberezhnaya et al., 2006). *Leucocythere* sp. is observed discontinuously in very limited numbers as a minor species relative to the other three ostracods.

3. Materials and methods

3.1. Core sediments and age determinations

In 2004, 14 gravity core samples were collected from the bottom sediments of Lake Hovsgol by the Kangwon National University team, Korea, and were subsequently stored at 2–3 °C. The three gravity cores analyzed in this study (HS5, HS6, and HS7) were split into two and described in terms of their lithologic features; i.e., grain size, texture, water content, and fossil distribution (e.g., ostracods) (Kim and Cheong, 2007). HS7 was obtained from the deepest central part of the lake, while HS5 and HS6 were obtained from two southern locations that were shallower (Fig. 1). Accelerator mass spectrometry (AMS) ^{14}C age dating was conducted at the