Palaeogeography, Palaeoclimatology, Palaeoecology 294 (2010) 4–15

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Glaciers and meltwater flux to *Lake Baikal* during the Last Glacial Maximum

Eduard Y. Osipov *, Oleg M. Khlystov

Limnological Institute of SB RAS, 664033, Irkutsk, 3, Ulan-Batorskaya st., P.O. Box 278, Russia

A R T I C L E I N F O

Article history:
Received 26 May 2008
Received in revised form 12 January 2010
Accepted 22 January 2010
Available online 29 January 2010

Keywords:
Lake Baikal
LGM
Glaciers
ELAs
Climate change
Meltwaters
Lake level change
Paleohydrology

A B S T R A C T

Maximal 3D ice extent during MIS 2 around *Lake Baikal* has been reconstructed using glacial landforms in the field, aerial photos, satellite images, and GIS analysis. This regional glacial maximum is correlated (~18 kyr BP) with the global LGM based on available ^{14}C dates, cosmogenic ^{10}Be exposure ages, correlation of lakeshore moraines with two raised shorelines, and the IRD record in lake sediments. Total ice area was ~13,000 km^2 and ice volume ~2000 km^3 (~1800 km^3 in water equivalent). Ice distribution was controlled by topography and ice fields, with valley glaciers spreading to adjacent depressions. Locally, ice caps with outlet glaciers existed. Averaged regional ELA is estimated to be 1290 ± 240 m with the ELA depression at approximately 1340 m. More acceptable regional scenario of the LGM precipitation (reduction by 25–50%) implies that summer temperature decreased (by ~6–12 °C) along with an increased solid fraction in precipitation (up to 85%). There were primary climatic controls for glaciation. Meltwater supply, as a strong controller of LGM water budget (60% of total water input to the lake), is estimated to have been from 6.4 to 9.0 km^3 yr^{-1} (7–9 times less than present-day river input). Preliminary balance estimation shows that during full glacial stage *Lake Baikal* was overflowing, with the *Angara River* output as [4–9] km^3 yr^{-1} and with lake level close to that today. Lake level drop down to the depth of ~40 m is recorded by geological and geophysical evidence, perhaps explaining the abrupt increase in effective evaporation in the lake watershed at the start of MIS 2 (~24–18 ky BP).

1. Introduction

Lake Baikal (eastern Siberia) has experienced repeated glacial and interglacial periods during the Quaternary, as recorded by onshore (last review in Mats et al., 2001) and offshore (Grachev et al., 1997; Kuzmin et al., 2001 and others) records. On the one hand, followers of the "restricted glaciation" hypothesis assumed existence of only small mountain glaciers (Ivanovsky, 1982). On the other hand, there were interpretations of "ice sheet" types of Pleistocene glaciation (Grosswald and Kuhle, 1994). A possible explanation for these two hypotheses is the lack of quantitative ice reconstructions based on both onshore and offshore data.

Recent long-term multidisciplinary paleoclimate studies of sediment cores have revealed similarities (with some deviations) between Baikal and global marine and ice records (Kuzmin et al., 2001). Qualitative climatic changes have been obtained from lithologic, biologic, and geochemical proxies (Grachev et al., 1997, 1998; Goldberg et al., 2000) generally related to glacier activity in the lake watershed. However, glaciers themselves remained a mystery as a rule. Recently, we have reconstructed numeric parameters of glaciers and Equilibrium Line Altitude (ELA, altitude of a boundary on a glacier between the ablation area and accumulation area) in the northwestern part of Barguzinsky Ridge during the Last Glacial Maximum (LGM), correlated to marine isotope stage (MIS) 2 (Osipov et al., 2003; Osipov, 2004; Osipov and Savoskul, 2006). The preliminary results have allowed us to assume that mountain glaciers were able to affect hydrologic and geologic changes in the lake watershed in a similar way to that of the ocean and Quaternary continental ice sheets.

Actually, glaciers are temporary reservoirs of vast volumes of water, both liquid and frozen, that would otherwise flow to the ocean (Eyles, 2006). Numerous erosional and accumulative landforms and sediments of "glacial landscapes" in the Northern Hemisphere are related to Pleistocene meltwater activity. Melting ice is a significant process in the global water cycle and therefore controls global climate. During Quaternary glaciations, especially during deglaciation stages, meltwater impact on climate and hydrology was distinct. If *Lake Baikal* may be regarded as an analog of the ocean, more information about quantitative ice parameters are needed to determine the connection of glaciers with climatic, hydrologic, and sedimentologic changes. The purpose of this paper is to reconstruct quantitatively ice extent, regional snowlines, and climate changes in the *Lake Baikal* region as well as to estimate the contribution of glaciers to changes in lake hydrology (via meltwater input) during MIS 2, a key Pleistocene cold stage.

2. The study area

Lake Baikal (51.5–55.8° N, 103.7–109.9° E) is the deepest and largest freshwater lake by volume on Earth, located in southern East

* Corresponding author. Tel.: + 7 3952 42 53 12; fax: +7 3952 42 54 05.
E-mail address: eduard@lin.irk.ru (E.Y. Osipov).

0031-0182/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.palaeo.2010.01.031

Siberia (Fig. 1A–C) between humid forest and arid steppe zones. The area of the lake is 31,500 km^2, volume is 23,000 km^3, shoreline altitude is 456 m a.s.l., and maximal depth is 1637 m (Galaziy, 1993). The *Lake Baikal* rift consists of three separate basins joined by underwater topographic highs (Buguldeika Saddle and Academician Ridge) and surrounded by three high mountain ridges: Khamar-Daban (the highest peak is 2371 m), Baikalsky (2588 m), and Barguzinsky (2840 m), with the North Baikal Upland at 2578 m elevation. The total area of the *Lake Baikal* watershed is 557,000 km^2.

Averaged over the years of 1901–1955 (before the damming of the *Angara River*), the hydrologic budget of the lake is balanced from inputs via rivers (57.77 km^3), groundwater (3.12 km^3), and

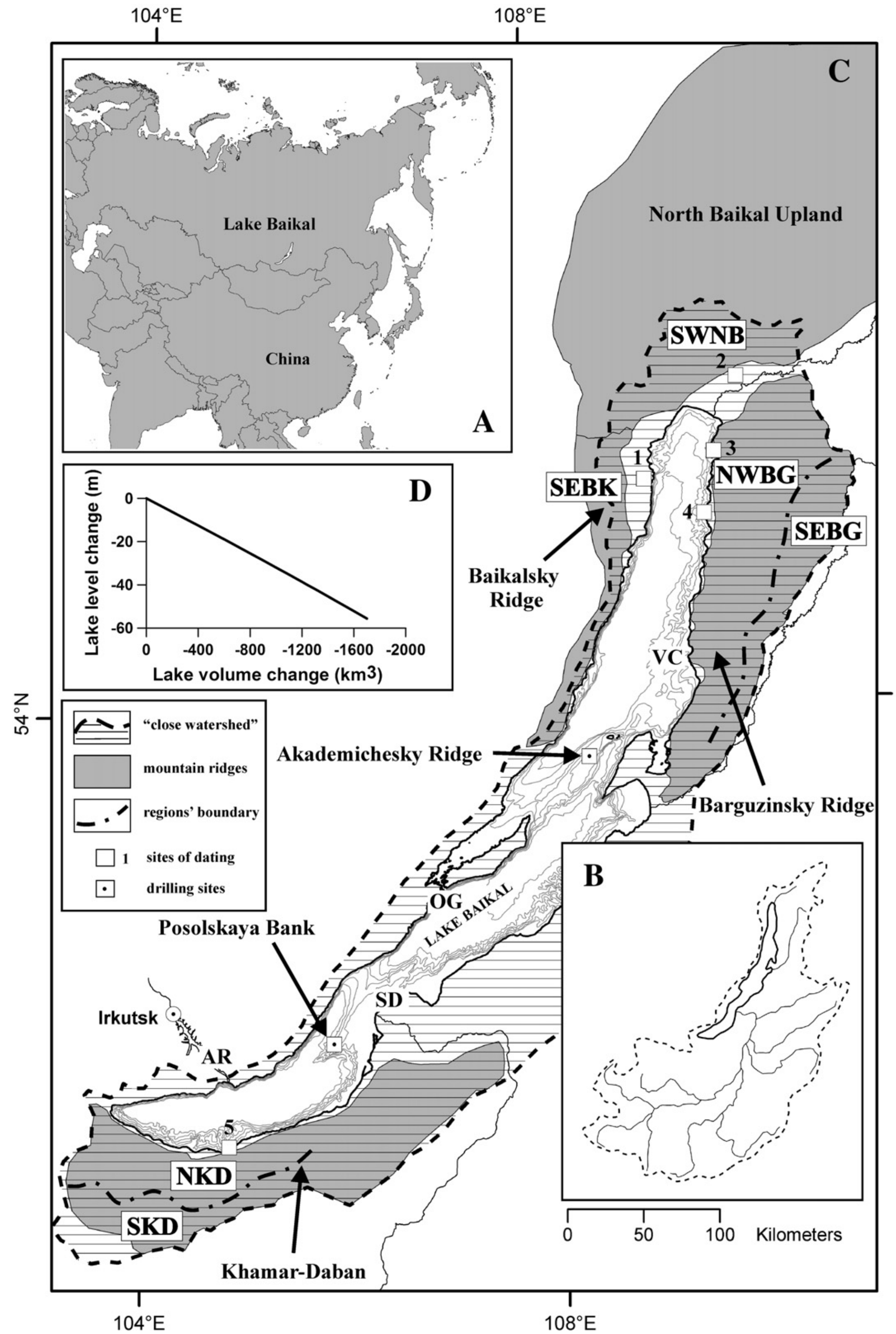

Fig. 1. The studied area. (A) Location of *Lake Baikal* in Asia. (B) Watershed of *Lake Baikal*, dashed line. (C) "Close watershed" of *Lake Baikal* (hatched contour with dashed outline). Gray-filled contours show mountain areas. Ridges used for ice reconstruction model are shown. Site locations: AR—*Angara River*, SD—Selenga Delta, OG—Olkhon's Gates, VC—Valukan Cape. (D) Relationship between lake volume and lake level changes derived from Digital Elevation Model (DEM) of *Lake Baikal*.