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Reconstruction of Lake Balkhash levels and precipitation/evaporation changes during the last 2000 years from fossil diatom assemblages

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ABSTRACT

Environmental changes in arid central Asia are prominently manifest through changes in the water balance. Lake Balkhash, the largest lake in Kazakhstan, is a shallow lake situated in a closed basin. We obtained a 600-cm-long core from the western part of the lake in 2007 and carried out analyses of fossil diatoms and ostracods, geochemistry, and grain size of the sediments. The age control of the core is based on radiocarbon ages of fossil ostracods and, in the uppermost part, the AD 1963 ^{137}Cs activity peak and the first appearance of ^{137}Cs in AD 1952. We recognized two main diatom assemblages by detrended correspondence analysis, one characterized by the dominance of freshwater planktonic species, and the other dominated by brackish planktonic, brackish, and marine benthic, and freshwater benthic species. The first assemblage suggests higher lake levels, and the second suggests lower lake levels. The observed assemblage changes are consistent with lake-level observations recorded during the last 120 years. The diatom assemblage data from the core indicate that there were seven periods when the lake level was low during the last 2000 years; moreover, the pH of the lake changed together with the lake level. In addition, during periods when the lake level was low from AD 1260–2000, the abundance of fossil ostracods and the Ca and TOC contents were low in comparison with the periods before AD 1260. The causes of low water levels were essentially the same between Lake Balkhash and the Aral Sea during the studied period. One likely cause of the low water levels, especially those during the last 1200 years, is changes in solar activity. Furthermore, some environmental changes during the past 40 years can be explained by human activities.

1. Introduction

Environmental changes in arid areas such as variation in precipitation and evaporation are caused by changes in the water balance due to fluctuations in rainfall (e.g., Sakai et al., 2012), evapotranspiration (e.g., Sorrel et al., 2006), water infiltration, and snow and ice runoff and ice volume in mountainous areas (Thompson, 2000; Narama, 2002; Narama et al., 2010). Past environmental changes, including changes in the paleomonsoon, have had huge effects on human activities in the arid and semi-arid areas of Central to East Asia (e.g., Mayewski et al., 2004; Solomina and Alverson, 2004; Chen et al., 2008, 2010; Yang et al., 2009; Mischke and Zhang, 2010; Lei et al., 2014). In arid areas, the supply of freshwater is very important for not only humans but also the regional fauna and flora. In the Aral Sea, changes in the freshwater supply have been recorded by microfossil and chemical proxies in lake sediment core samples, and numerous studies have examined the relationships among lake-level changes, paleoenvironmental changes, and human activities (reviewed by Boomer et al., 2000, 2009).

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Recent studies have used data from sediment cores to reconstruct paleoenvironmental changes in Central Asia during the last 1600–2000 years associated with changes in the area of the Aral Sea (Boroffka et al., 2006; Sorrel et al., 2006, 2007a, 2007b; Austin et al., 2007; Huang et al., 2011). Mischke et al. (2010) used environmental proxies in sediment core samples from Lake Karakul, Tajikistan, to reconstruct air temperature changes during the late Holocene. Ricketts et al. (2001), and Ferronskii et al. (2003) investigated Holocene paleoenvironmental and lake-level changes recorded in the bottom sediment of Lake Issyk-kul, Kyrgyzstan. Thus, these studies reconstructed paleoclimates and paleoenvironmental changes in Central Asia on both long (millennial) and short (decadal to centennial) time scales. The details of the timing and the causes of paleoenvironmental changes in Central Asia are not yet well understood, however, and it is accordingly important to study environmental changes in arid Central Asia by examining changes in the water balance. Lake Balkhash, Kazakhstan, which is located at a similar latitude to the Aral Sea, is a huge terminal lake and an important site for studying water supply changes in arid Central Asia, as well as for estimating both paleo-environments and future simulations.

Diatoms are a useful proxy for water environments (e.g., Vos and de Wolf, 1993; Van Dam et al., 1994), and many studies have used diatoms to reconstruct paleoenvironmental changes in lakes (e.g., Stoermer and Smol, 1999). For example, Naya et al. (2007) used diatoms to examine not only natural environmental changes but also anthropogenic influences in Lake Kitaura, Japan, over the past 500 years. Austin et al. (2007) reconstructed paleoconductivity and lake-level changes at high resolution in the Aral Sea during the last 1600 years. Additionally, Hayashi (2011) investigated the environments in paleo-Kathmandu Lake in Nepal during the middle Brunhes Chron and reported that benthic diatoms increased when the lake level declined. In this study, we investigated paleoenvironmental changes in Lake Balkhash by using changes in the diatom assemblage as a proxy for lake-level changes.

2. Lake Balkhash

Lake Balkhash is a huge shallow terminal lake in Kazakhstan, Central Asia (Fig. 1). Lake Balkhash has a catchment of 501,000 km^2, a surface are of 15,730 km^2, and a volume of 87.7 km^3 (Kawabata et al., 1997). The Ili, Karatal, Aksu, and Lepsy rivers flow into, and terminate in, Lake Balkhash, which has no outlet (Abrosov, 1973; Sevastyanov et al., 1991). Among these rivers, the Ili River has the largest discharge (Sevastyanov et al., 1991; Kawabata et al., 1997; Shimizu et al., 2012), and changes in the lake level are controlled mainly by the Ili River flow rate and the lake salinity and EC (1.92–4.97 mS/cm) increase eastward (Kawabata et al., 1997). The climate in Lake Balkhash area is continental, with low annual precipitation (200 mm) and severe daily and annual temperature variations (Kawabata et al., 1997).

During the last 30 years, the water level of Lake Balkhash has risen, and lacustrine landforms such as gravel or sand bars showing the erosional trend. In addition, submergence in a tip of delta and linear sand dune that formed when the lake level was lower than at present has been recognized near the modern lakeshore (Endo et al., 2012) has occurred.

The bottom sediment of Lake Balkhash consists of clay and contains abundant microfossils (Sevastyanov et al., 1991). Although Kawabata et al. (1997) investigated phytoplankton assemblages and water quality in Lake Balkhash, only a few studies have analyzed the lake sediments. Lake Balkhash is expected to contain an undisturbed succession of lake sediments deposited during a period of stable sedimentation, so paleoenvironmental changes are

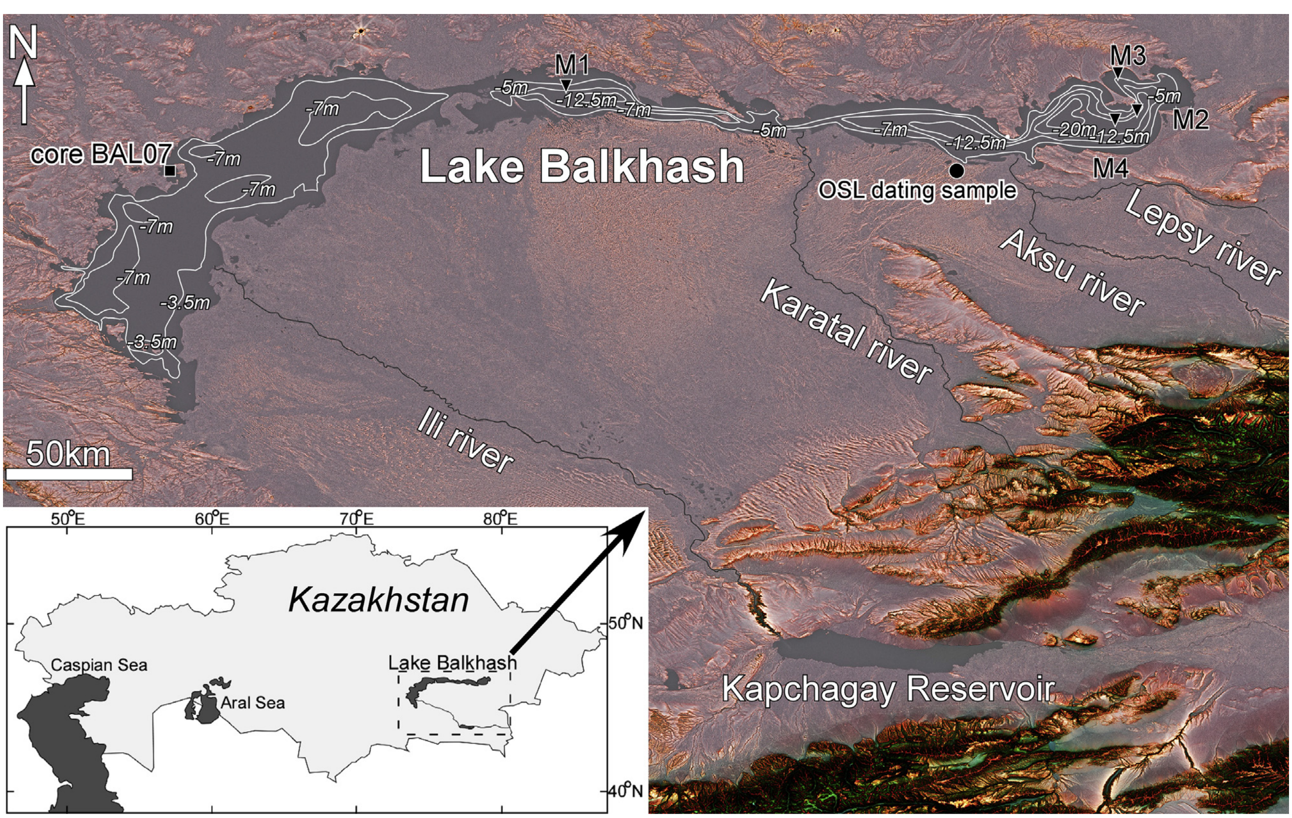

Fig. 1. Location of Lake Balkhash in Kazakhstan (inset), and a map showing Lake Balkhash bathymetry, the core site, and surface sediment sampling sites.

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