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Late Quaternary water depth changes in Hala Lake, northeastern Tibetan Plateau, derived from ostracod assemblages and sediment properties in multiple sediment records

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ABSTRACT

Late Pleistocene and Holocene climate dynamics along the marginal belt of the East Asian Summer Monsoon in China and their responses to hydrological cycles in lake basins of the Tibetan Plateau are still a matter of scientific discussion. Hala Lake, a closed 65 m deep lake basin in the western Qilian Mountains, Qinghai Province, is considered a monitor of climate-driven hydrological and environmental changes during the past 24 kyr BP. The distribution patterns of ostracod assemblages, stable isotopes, sediment–geochemical properties in four sediment records from different water depths and their combination with the unique limnological setting enabled us to reconstruct four major phases of centennial-scale water depth fluctuations from the global Last Glacial Maximum (ca 24 kyr BP) to the Present.

Our results show that Hala Lake experienced a very shallow and small water body during the LGM and Lateglacial under cold and dry climate conditions. Rapid increase of water depth and contemporaneous lake expansion started at around 14 kyr BP (Phase I), most likely as a result of glacier melt due to the onset of climate warming. The lake reached >45 m water depth at around 13.5 kyr BP. Reduced water depth during the Younger Dryas spell (ca 12 kyr BP) may be attributed to a short-term return to cooler and drier conditions. During the early Holocene (Phase II), water depth increased further toward lake highstands close to its present level, with a highest lake level of up to 9 m above the present lakestand at 8.0–7.8 kyr BP. Besides continued glacier melt supply, we assume that summer monsoon effective moisture contributed to the overall water budget, but remained relatively unstable, favoring water depth fluctuations. A pronounced lower water depth falls into the period between 9.2 and 8.1 kyr BP, perhaps the result of weak monsoon influence or its complete absence, although the warming trend continued toward its optimum at ca 8–7 kyr BP. A distinct mass flow, most likely triggered by an earthquake, occurred during a lake lowstand either at ca 7.0 kyr BP or at around 8.1 kyr BP.

The mid-Holocene (Phase III) was characterized by fluctuating water depths between 7.8 and 4.5 kyr BP. Conflicting trends of stable isotope data limit the validity of water depth estimations, but may show higher lake levels between 5.5 and 4.5 kyr BP, coincident with dated lake sediments in a cliff position at the northern lake shore. This positive water balance can most likely be attributed to increased westerly-derived moisture supply during autumn and late winter, although summer monsoon influence could also be of significance. Coincident with the 4.2 ka event, the lake experienced shallow water at around 4.1 kyr BP, perhaps as a result of continued cooling and drier climate conditions, supporting the arguments of a general cooling trend throughout the Holocene.

The Late Holocene (Phase IV) is characterized by extremely unstable hydrological conditions with rapid fluctuations in water depth, more frequently controlled by westerly-driven effective moisture supply. Since the lake lowstand at about 1.4–1.2 kyr BP, the lake has developed toward its present level.

Our research underlines the necessity for comparing multiple proxy records from different lake sites to better evaluate centennial-scale climate-driven variations throughout the late Pleistocene and Holocene periods.

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All presented data suggest the variable influence of summer monsoon effective moisture on the hydrological budget of the lake. Water depth variations did not follow the long-term pattern of the Asian monsoon system due to a potential modulation by westerly-derived moisture impact.

1. Introduction

Lake records from the Tibetan Plateau and adjacent regions are of considerable importance in deciphering paleoclimatic and environmental changes throughout the Late Quaternary. Detailed studies of the last decades reveal the exceptional influence of the Tibetan Plateau on the climate system, since its uplift seems to have enforced the northern hemispheric atmospheric circulation pattern, notably the onset of the Asian monsoon systems (Sun and Wang, 2005). Previous research indicates a close relationship between monsoon strength and orbitally controlled global insolation patterns (Dykoski et al., 2005; Wanner et al., 2008). The recorded strong variability of monsoonal moisture transport (e.g., Wang et al., 2010), perhaps the limited influence of the Himalayas (Boos and Kuang, 2010) and its spatial distribution pattern in China, however, remains a matter of debate, as the discussion about synchronous versus asynchronous monsoon climate and its spatial distribution over China (An et al., 2000; He et al., 2004; Herzschuh, 2006; Wünnemann et al., 2007; Chen et al., 2008; Zhang and Mischke, 2009; Wang et al., 2010) is far beyond a reasonable solution.

Based on recently published papers it seems obvious that the Late Pleistocene and Holocene climate history of the Tibetan Plateau is even more complex and spatially diverse than previously expected (Thompson et al., 2006; Lu et al., 2010, 2011). Notably, the discussion regarding the impact of the westerly air masses over the northern/northwestern part of China has intensified since Chen et al. (2008) postulated its out-of-phase relationship with the East Asian summer monsoon impact. Although external forcing of climate may have played a major role in moisture transport over the plateau, locally derived internal processes of latent heat transport (e.g., Herzschuh, 2006; Sato, 2009; Lin et al., 2012), potential water vapor recycling processes and topographic and geologic setting seem to be further important factors that influence moisture availability on a local to regional scale. Intra-mountain lake basins such as the closed Hala Lake in the Qilian Mountains of Qinghai Province, China, are considered to be excellent archives that monitor environmental and climate changes through time, as they react very sensitively to pulses that affect the sedimentary and hydrologic budget of the basin. Especially lakes, being the end member of interlinked sedimentary processes on a catchment scale, provide important signals for high-resolution reconstruction of present and past sediment fluxes, hydrological and ecological variations, as long as the lakes persist and the stored sediments are not subjected to erosion. Hence, they can be used to infer climate variations through time.

Published records from lakes on the Tibetan Plateau and adjacent areas refer to sediment and geochemical proxies, including stable isotope data from bulk sediments (e.g., Gasse et al., 1991; Shen et al., 2005; Morrill et al., 2006; Wu et al., 2006, 2007; Liu et al., 2007, 2009; Zhang and Mischke, 2009; Mügler et al., 2010; Zhao et al., 2010; Opitz et al., 2012) and mineral composition (Liu et al., 2008a; Wünnemann et al., 2010), pollen records (e.g., Campo and Gasse, 1993; Herzschuh et al., 2006, 2010; Zhao et al., 2009, 2011; Kramer et al., 2010), biomarkers (e.g., Günther et al., 2011; Aichner et al., 2012) and other fossil remains such as ostracods (Mische et al., 2005, 2010; Frenzel et al., 2010; Zhu et al., 2010). Most of these, however, are combined records, used to infer changes in lake level, salinity, ecological status and vegetation cover within a certain system as a response to changes in effective moisture availability, and thus, climate.

Most proxy records from Tibetan lakes and adjacent areas are attributed to climate-driven lake level changes, although most of them are not really able to quantitatively define water depth and lake levels throughout time. Many sediment properties and pollen data are indeed useful for estimating changes in the contribution of effective moisture and discharge to a certain lake system, but they nonetheless only provide relative changes in water budgets. Morphological indicators, such as paleoshorelines or lakeshore-terraces are commonly applied to estimate a certain lake level at a certain time, based on their dated sequences, for example, at Lagkor Tso (Lee et al., 2009), Donggi Cona (Dietze et al., 2010, 2012), Qinghai Lake (Liu et al., 2007) and Tangra Yumco (Long et al., 2012). Huth et al. (2012) also used paleoshorelines to develop a paleohydrologic model of Baqan Tso in south-western Tibet that potentially shows millennial-scale oscillations in water balance which accord to Chinese cave records and the broad insolation trend.

All this data can explain a certain lake stand at a dated time, while potential water volume and hydrological balances can be modeled for longer time scales, if a series of shorelines exist (Krause et al., 2010; Huth et al., 2012). However, continuous records of lake level changes are still lacking.

Research on ostracods (bi-valved micro crustaceans) in lake basins has been applied to paleoclimate and paleoenvironment studies in order to infer certain limnological conditions (e.g., Delorme, 1969; Carbonel, 1988; Meisch, 2000) at a given time and to reconstruct changes in the hydrological balance. Both are commonly linked with climate and local environmental variations (e.g., Mischke et al., 2007, 2010a,b; Frenzel et al., 2010; Wrozyna et al., 2010; Zhu et al., 2010; Liu et al., 2011). Beside studies on species assemblages in modern settings and their spatial distribution patterns on the Tibetan Plateau (Mischke et al., 2007, 2010a; Zhang et al., 2013), transfer functions were used on the base of individual site studies, supported by so-called “calibration training sets” to infer salinity preferences (based on electrical conductivity of the host waters) of various ostracod species in high-elevated regions of China (Mischke et al., 2010a), and to estimate hydrological balances, especially water depth of past periods throughout the Late Pleistocene and Holocene (Frenzel et al., 2010; Mischke et al., 2010b; Wrozyna et al., 2010; Zhu et al., 2010).

Stable isotope records from ostracod shells (preferably on a single species) were also applied to support changes and salinity of lake water, for example in Bosten Lake, Xinjiang (Mischke and Wünnemann, 2006), to infer general precipitation–evaporation ratios and residence time of lake water in various lakes (e.g., Lister et al., 1991; Liu et al., 2007; Mischke et al., 2008), and to estimate water resources (Liu et al., 2007; Zhang and Mischke, 2009). Commonly, these results referred to a single sediment core, which was achieved from lake centers and/or the deepest part of a lake. According to several studies it is obvious that differences in sediment composition, geochemical properties, fossil remains and limnological setting occur at different lake sites and water depth (e.g., Dearing, 1997; Last, 2002; Mischke et al., 2010a; Wünnemann et al., 2012), leading to incomplete interpretations of climate-