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Holocene temperature fluctuations in the northern Tibetan Plateau

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ABSTRACT

Arid Central Asia (ACA) lies on a major climatic boundary between the mid-latitude westerlies and the northwestern limit of the Asian summer monsoon, yet only a few high-quality reconstructions exist for its climate history. Here we calibrate a new organic geochemical proxy for lake temperature, and present a 45-yr-resolution temperature record from Hurleg Lake at the eastern margin of the ACA in the northern Tibetan Plateau. Combination with other proxy data from the same samples reveals a distinct warm–dry climate association throughout the record, which contrasts with the warm–wet association found in the Asian monsoon region. This indicates that the climatic boundary between the westerly and the monsoon regimes has remained roughly in the same place throughout the Holocene, at least near our study site. Six millennial-scale cold events are found within the past 9000 yr, which approximately coincide with previously documented events of northern high-latitude cooling and tropical drought. This suggests a connection between the North Atlantic and tropical monsoon climate systems, via the westerly circulation. Finally, we also observe an increase in regional climate variability after the mid-Holocene, which we relate to changes in vegetation (forest) cover in the monsoon region through a land-surface albedo feedback.

Introduction

Climate in the Holocene, over the past 12,000 yr, has been characterized by gradual cooling in Northern Hemisphere high and mid-latitude areas and a drying trend in tropical/monsoon regions (Mayewski et al., 2004). This pattern is controlled by a gradual decrease in boreal insolation (Kutzbach and Street-Perrott, 1985; COHMAP Members, 1998). Superimposed on this long-term trend are several millennial-scale cooling events in high-latitude regions and/or drought or weak-monsoon events in tropical regions (O'Brien et al., 1995; deMenocal et al., 2000; Bond et al., 2001; Gupta et al., 2003; Mayewski et al., 2004; Wang et al., 2005). These millennial-scale events have been attributed to solar variability and/or internal ocean-atmosphere variations (Gupta et al., 2003; Mayewski et al., 2004; Wang et al., 2005).

Arid Central Asia (ACA) today falls under the influence of the mid-latitude westerlies. It marks the southern limit of a major source region of atmospheric dust, which affects the radiative forcing of climate on a global scale (e.g., Köhler et al., 2010; Roberts et al., 2011; Rohling et al., 2012). In a synthesis of eleven lake-sediment records with relatively reliable chronologies and robust proxies, Chen et al. (2008) showed that Holocene climate in ACA experienced a gradual increase in humidity that was anti-phased with changes in the Asian monsoon region. However, other records for the late Pleistocene and Holocene indicate more complex and sometimes even opposite moisture changes within the ACA at various time scales (Lehmkuhl and Haselein, 2000; Yang et al., 2004; Yang and Scuderi, 2010; Yang et al., 2011). In the early Holocene, for instance, studies show that the climate around the boundary between the ACA and monsoon regions could be either dry (Mason et al., 2009) or wet (Yang et al., 2010) at different sites. In addition to the long-term trend, many lakes in the region have revealed major hydrological variations at millennial time-scales (Rhodes et al., 1996; Mischke et al., 2005; Mischke and Wünnemann, 2006).

Because of a dearth of paleoclimate records that give both temperature and moisture information from the same sites and same samples, understanding the nature of Holocene climate variability in the ACA is limited. Here we apply the new method for temperature reconstruction based on biomarker alkenone distributions in lakes to a sediment core from Hurleg Lake in the Qaidam Basin, northern Tibetan Plateau, to reconstruct a new quantitative temperature record for the ACA. Alkenones are produced by a limited number of haptophyte algae in the oceans and some lakes, and the ratio of different C_{37}-alkenone

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compounds is very sensitive to temperature changes (Chu et al., 2005; Sun et al., 2007). A specific index, the alkenone unsaturation index or $U^{K'}_{37}$ (see below for details), is widely used for marine surface temperature reconstructions (e.g. Kim et al., 2004). However, recent culture experiments and studies of surface sediments from modern Chinese lakes have revealed that lakes also show a positive relationship between $U^{K'}_{37}$ values and surface water temperature, which in turn reflects air temperature (Chu et al., 2005; Sun et al., 2007; Chu et al., 2012). Here we present a statistical calibration with full propagation of uncertainties. We then develop a high-resolution (45 yr) quantitative temperature record for the last 9000 yr in Hurleg Lake (Fig. 1A). We combine this with information from other proxies (Zhao et al., 2010) to assess the long-term orbital-scale trends, and millennial-scale climate variability around the Hurleg Lake region, and to test whether or not the monsoon influence expanded into the Qaidam Basin during the early-middle Holocene monsoon maximum.

Study site

Hurleg Lake and modern climate setting

The fresh-water lake, Hurleg Lake (37°17′N, 96°54′E; 2817 m above sea level [asl]) is located in the Qaidam Basin on the northern Tibetan Plateau (Fig. 1). The high surrounding mountains (~4000 m asl) are

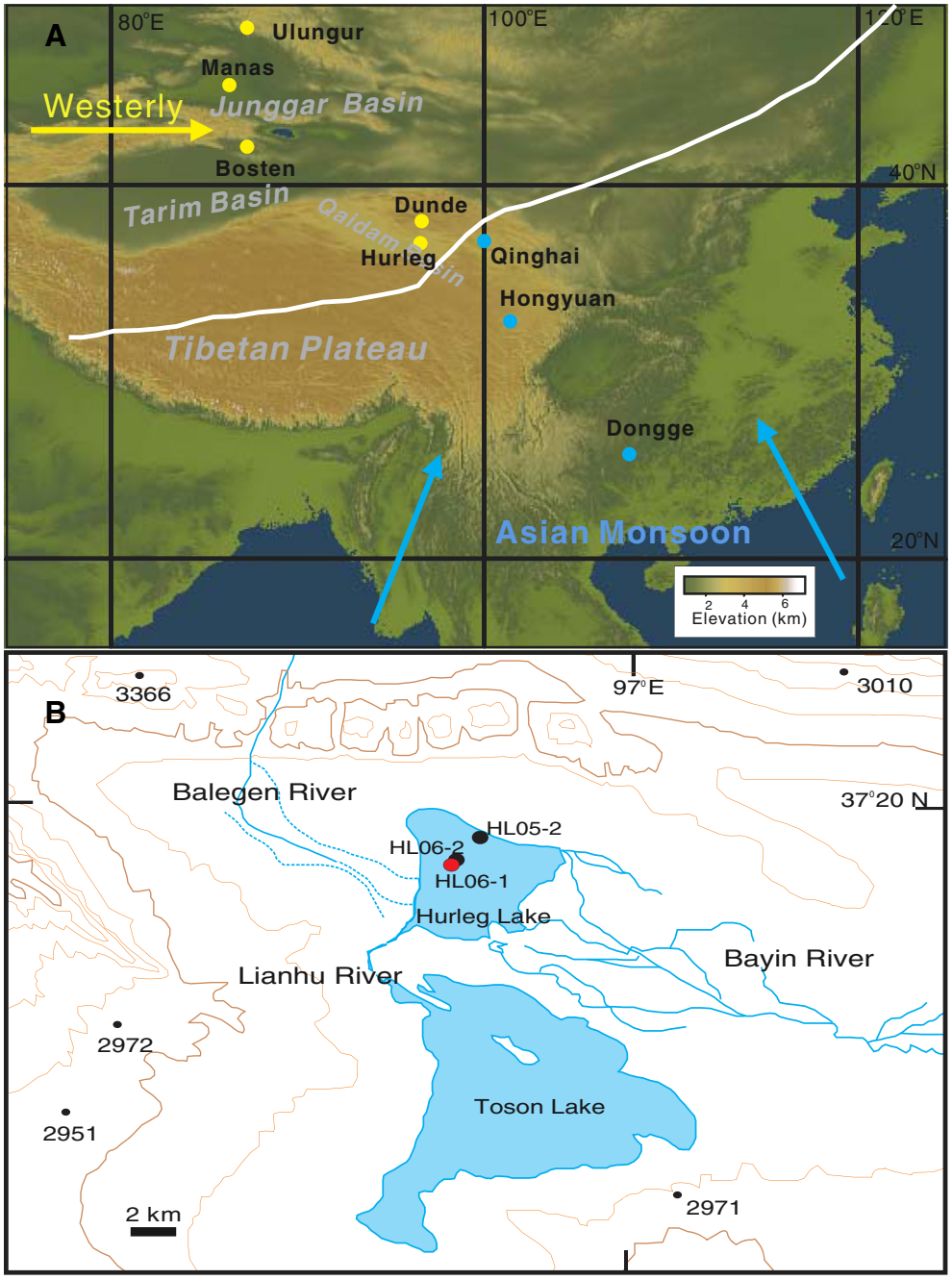

Figure 1. Location map. A. Hurleg Lake (yellow dot) is located in the northern Tibetan Plateau. Other sites mentioned include Lake Qinghai, Hongyuan Peat Bog, and Dongge Cave (blue dots) in the Asian monsoon region and Dunde Ice Cap, Bosten Lake, Manas Lake, Ulungur Lake (yellow dots) in westerly-dominated ACA. The bold white line approximately separates monsoon regions (blue) and ACA (yellow; after Chen et al., 2008). B. Topographic and hydrologic setting of Hurleg Lake. Red dot donates the coring location for core HL06-1, and black dots indicate two other cores from the same lake (after Zhao et al., 2010).