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High-resolution geochemical record for the last 1100 yr from Lake Toson, northeastern Tibetan Plateau, and its climatic implications

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ABSTRACT

Knowledge of the origin of past climatic variations on annual to decadal timescales is important for assessing the likelihood of the occurrence of similar variations in the future. Here we present a high-resolution (82-μm) element record, obtained using Synchrotron Radiation X-ray Fluorescence, from the sediments of Toson Lake in the northeastern Tibetan Plateau. The record, which spans the last ~1100 yr, exhibits variability on an annual to decadal scale. The results of principal component analysis of the element dataset indicates that the first three principal components reflect variations in detrital inputs (via runoff and possibly eolian activity), drought conditions and temperature variations, respectively. Spectral analysis of samples scores on these components reveals strong El Niño-Southern Oscillation (ENSO)-like variability at periods of 3–8 years which indicates that the regional climatic variability was effected by ENSO events over the last ~1100 yr. On the centennial time scale, the element data and TOC record suggest a warm and dry climate during the Medieval Warm Period (MWP) and a cold and wet Little Ice Age (LIA). The early 20th century was a warm interval, and drier than the LIA but wetter than the MWP.

1. Introduction

The Tibetan Plateau (TP), because of its elevation, size, geographical location and sensible heat flux, plays a key role in modulating regional atmospheric circulation patterns and climatic variability, on a regional as well as on a global scale (Liu et al., 2009; Grieβinger et al., 2011). Therefore, paleoclimatic reconstructions from the TP region are essential for improving our understanding of how complex forcing mechanisms can affect the regional climate (Liu et al., 2006). The climate of the TP during the last few millennia was characterized by significant variability, including the Medieval Warm Period (MWP) and the Little Ice Age (LIA), and knowledge of such intervals is important for evaluating the global warming trend of the past century (Xu, 2001; Holmes et al., 2009; Pu et al., 2013). During the late Holocene, the climate of the region is generally believed to have been characterized by warm-wet or cold-dry combinations, controlled by the Asian Summer Monsoon (An, 2000). However, in the Westerly-dominated regions of Asia, wet LIA conditions and dry MWP conditions have been identified (Qiang et al., 2005; Chen et al., 2010; Liu et al., 2011). Moreover, on short time scales, the relationship between air temperature and precipitation variations may be ambiguous (Pu et al., 2013). For example, Qiang et al. (2005) established the sequence of climatic changes at Lake Sugan, which consisted of warm-dry, cold-dry, and cold-wet combinations during the past two millennia. Toson Lake is in the transitional zone of the two regions and its climatic record is potentially important because of its marginal position in relation to the Asian Summer Monsoon. In addition, many studies suggest possible solar, ENSO and Pacific Decadal Oscillation (PDO) forcing of moisture oscillations in the TP during the last millennium (Zhao

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et al., 2009; Chu et al., 2011; Gou et al., 2014). Temperature variability over the TP is also affected by solar insolation, ENSO, North Atlantic Oscillation (NAO), Atlantic Multidecadal Oscillation (AMO), volcanism and greenhouse gas variations (Pu et al., 2013; Wang et al., 2014). However, the physical mechanisms responsible for these modes of variation are still not well understood, especially for the Asian continent, and further research needs to be undertaken (Fang et al., 2010).

Although previous investigations of paleoclimatic changes in the TP have been conducted, little is known about monsoon climate variability on annual to seasonal time scales (Chu et al., 2011), which impinges directly on people's lives (Yan et al., 2014). For example, ENSO, a coupled atmospheric–oceanic phenomenon, is the most significant factor causing global hydroclimatic variability (Allan, 2003; Fagel et al., 2008). It has been responsible for decreased rainfall and drought conditions in many regions of China, heavily impacting the livestock industry, water supplies and the overall economy. Therefore, it is crucial to understand the processes and mechanisms of high-frequency paleoclimatic variations in order to assess the probability of their occurrence in the future (Chu et al., 2013). However, one factor making it difficult to combine and compare paleoclimatic records with modern instrumental data is the limitations imposed on high-resolution paleoclimatic reconstruction imposed by traditional methods of geochemical analysis (Liu et al., 2014b). High-resolution proxy climate records from the TP are mainly derived from tree rings (Grieβinger et al., 2011; Shi et al., 2011; An et al., 2012; Xu et al., 2012; Sano et al., 2013; Liu et al., 2014a; Yang et al., 2014), ice cores (Thompson et al., 1989, 1997, 2000; Yao et al., 1997, 2002, 2006; Wang et al., 2003), and lacustrine sedimentary records (Zhou et al., 2007; Mischke et al., 2010; Chu et al., 2011; Wang et al., 2012). These archives provide various proxy records with an inherent annual-resolution chronology enabling high-resolution paleoclimatic reconstruction. However, few techniques can be used to obtain high-resolution data at annual to seasonal time scales. Recently, non-destructive analyses such as the micro X-ray Fluorescence (μ-XRF) core scanner (Rothwell et al., 2006; Das et al., 2008; Francus et al., 2009; Chawchai et al., 2015; Kelloway et al., 2015) and Synchrotron Radiation X-ray Fluorescence (SRXRF) have been developed. SRXRF is an effective method for analyzing element variations and the results can be correlated to climatic parameters such as seasonal or annual temperature and humidity (Kalugin et al., 2007, 2013; Chu et al., 2013; Ling et al., 2014; Xie et al., 2015; Sun et al., 2016).

In this study we present a high-resolution element dataset spanning the last ~1100 yr from the varved sediments of Lake Toson. The variations of K, Ca, Ti, Mn, Fe, Cu, Zn, Br, Rb, and Sr exhibit distinct inter-annual features, and we compare the results with multiple records derived from various proxies in order to characterize and interpret regional climatic variations over the last millennium.

2. Geological setting

Qaidam Basin, located in the northeastern TP, has an area of about 12×10^4 km^2 and an average altitude of about 2800 m. It is surrounded by the Kunlun Mountains to the south, the Altun Mountains to the west and the Qilian Mountains to the north and east (Zhao et al., 2007). The surrounding mountains rise to an elevation of >5000 m above sea 1evel and the region has an extremely arid desert climate. Lake Toson (37°04′–37°13′N, 96°50′–97°03′E, altitude 2808 m, surface area of 165.9 km^2) is located on the northeastern edge of Qaidam Basin (Fig. 1a). Toson is a typical magnesium sulfate subtype lake with a salinity of 38.7 g/L. Western Hurleg Lake flows out through a small stream to feed Toson Lake, and snow melt water from the mountains to the north also enters the lake (Fig. 1b and c). The maximum water depth is 25.7 m and the lake shore is surrounded by pluvial and alluvial sand-gravel beds, saline-alkali soil and aeolian sand dunes.

Lake Toson is located on the margin of the region influenced by the East Asian summer monsoon (EAM) (Chen et al., 2008; Zhang et al., 2011), which results in a complex local climate system compared to other parts of the TP. Meteorological data from 1956 to 2004 from Delingha station indicate a mean annual temperature of ~4 °C, a mean annual precipitation of ~160 mm, falling mainly during summer, and a mean annual potential evaporation of ~2000 mm (Zhao et al., 2010). The lake is ice-covered from the end of November until early April.

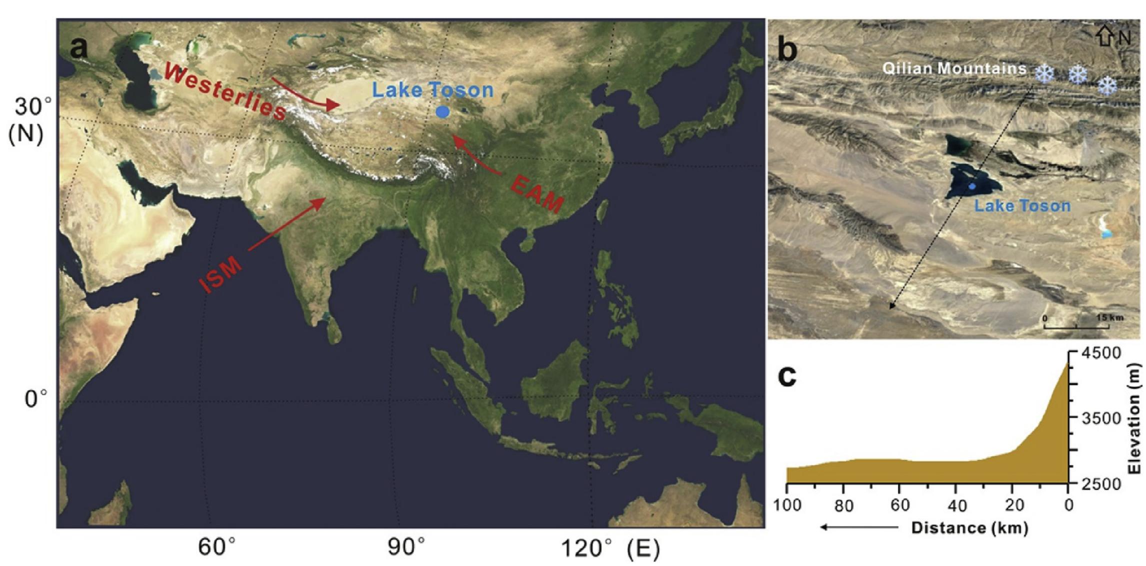

Fig. 1. (a) Location of Lake Toson within Asia; red arrows indicate the dominant directions of the East Asian monsoon (EAM), Indian Summer Monsoon (ISM) and the Westerlies. (b) Satellite photo of Toson Lake; the blue circle indicates the coring site, and the black line indicates the elevation profile shown in (c), from northeast to southwest. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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