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Reconstructed late Quaternary hydrological changes from Lake Tso Moriri, NW Himalaya

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ABSTRACT

We present the results of our investigations on the radiocarbon dated core sediments from the Lake Tso Moriri, NW Himalaya aimed at reconstructing palaeohydrological changes in this climatically sensitive region. Based on the detailed geochemical, mineralogical and sedimentological analysis, we recognise several short-term fluctuations superimposed upon seven major palaeohydrological stages identified in this lake since ~26 cal ka. Stage I (>20.2 cal ka): shallow lake characterised by input of coarse-grained detrital sediments; Stage II (20.2–16.4 cal ka): lake deepening and intensification of this trend ca. 18 cal ka; Stage III (16.4–11.2 cal ka): rising lake levels with a short term wet phase (13.1–11.7 cal ka); Stage IV (11.2–8.5 cal ka): early Holocene hydrological maxima and highest lake levels inferred to have resulted from early Holocene Indian monsoon intensification, as records from central Asia indicate weaker westerlies during this interval; Stage V (8.5–5.5 cal ka): mid-Holocene climate deterioration; Stage VI (5.5–2.7 cal ka): progressive lowering of lake level; Stage VII (2.7–0 cal ka): onset of modern conditions. The reconstructed hydrological variability in Lake Tso Moriri is governed by temperature changes (meltwater inflow) and monsoon precipitation (increased runoff). A regional comparison shows considerable differences with other palaeorecords from peninsular India during late Holocene.

1. Introduction

The modern climate in the Asian region is influenced by the Asian monsoon in the east (East Asian monsoon) and south Asia (Indian summer monsoon), the midlatitude westerlies in central Asia, the orographic influence of the Tibetan Plateau, and the Siberian Anticyclone (Raymo and Ruddiman, 1992; Gong and Ho, 2002; Herzschuh, 2006; Anoop et al., 2013a). The relative influence of the moisture pathways (westerlies and the Asian monsoon) in these regions has shown considerable variations in intensity and spatial extent in the past (e.g., Herzschuh, 2006; Chen et al., 2008; Demske et al., 2009). The hydrological budget of the Himalayan lakes and rivers is controlled by both the snowmelt and monsoon rainfall contribution. Modern data (1998–2007) indicates that the western part of the Himalaya (Indus catchment) receives 50% of the discharge from monsoonal rainfall during summer and the remaining 50% from summer melting of snow precipitated during winter (Bookhagen and Burbank, 2010). However, the contribution of seasonal precipitation and snowmelt to the hydrological balance of lakes over longer time scales is not yet well documented. Additionally, prolonged droughts have been reported from central and NE India during the late Holocene (Prasad et al., 2014) though their impact, if any, in the NW Himalayan region is unknown. These lacunae need to be urgently addressed as a major percentage of the Asian population is directly or indirectly dependent on the freshwater supplied from the Himalayan region.

In this study, we investigate core sediments from Lake Tso Moriri, NW Himalaya, India (32°40′–33°02′N, 78°14′–78°25′E,

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>4500 m asl) as a palaeoenvironmental archive. Lakes in these high altitude regions respond to modest environmental changes (Herzschuh et al., 2009; Mischke and Zhang, 2010; Wünnemann et al., 2010), and are less influenced by the local human impact. Leipe et al. (2014a) have shown that higher *Artemisia* percentages in the pollen spectra and higher *Artemisia*/*Chenopodiaceae* (A/C) values in Lake Tso Moriri sediments are linked to increased moisture availability and have reconstructed a mean annual precipitation (MAP) curve for the Holocene. However, the relative-role of seasonality of precipitation or meltwater to the Lake Tso Moriri hydrology is as yet unknown. Our study is aimed at palaeohydrological reconstruction using geochemical, mineralogical, and sedimentological proxies from a composite core raised from the Lake Tso Moriri. We compare our reconstruction with other records in the monsoon and westerly domains for a better understanding of the moisture sources (Fig. 1a).

2. Study area

2.1. Regional climate

Lake Tso Moriri lies within the rain shadow region of the NW Himalaya with summer and winter temperature variations between 0° to +30 °C and −40° to −10 °C, respectively (Mishra and Humbert-Droz, 1998). Annual precipitation in the Tso Moriri region is ~250 mm (Leipe et al., 2014a). Modern climate data suggest that the Lake Tso Moriri is situated in a transitional zone affected by both the Indian summer monsoon and the mid-latitude westerlies (Bookhagen et al., 2005; Bookhagen and Burbank, 2010).

2.2. Geology

Lake Tso Moriri is situated in the Tso Moriri crystalline complex (Steck et al., 1998; de Sigoyer et al., 2004), which is bounded by a NW–SE trending belt (Zildat ophiolite mélange of Indus-Tsangpo suture zone) to the north (Berthelsen, 1953) and sedimentary rocks of the Tethyan Himalaya to the south (Singh et al., 2013). The northern boundary of the lake catchment is characterised by the Puga gneiss complex comprising of quartzo-feldspathic augen gneiss as well as boudins of eclogites and discontinuous layers of metasedimentary schists (Steck et al., 1998). The northeastern part of the lake is dominated by the Lamayuru Formation (Mesozoic age), consisting of interbedded marls, limestone, dolomites, shales and sandstone (Steck et al., 1998) (Fig. 1b). The lower Proterozoic to Cambrian sediments of the Haimanta group with dominant carbonate lithology are exposed in the southern boundary of the catchment. To the south of the Kurzok village, the Haimanta group has been intruded by the unfoliated, coarse-grained Rupshu granite (Fig. 1b) (Fuchs and Linner, 1996).

The geomorphology in the Tso Moriri catchment is dominated by glacial and fluvial landforms; most common Quaternary sediments are characterised by alluvial and moraine deposits (Hedrick et al., 2011). Cosmogenic ^{10}Be dating of moraine deposits suggested that the glacial advance in Kurzok valley (~3.6 ± 1.1 ka) is

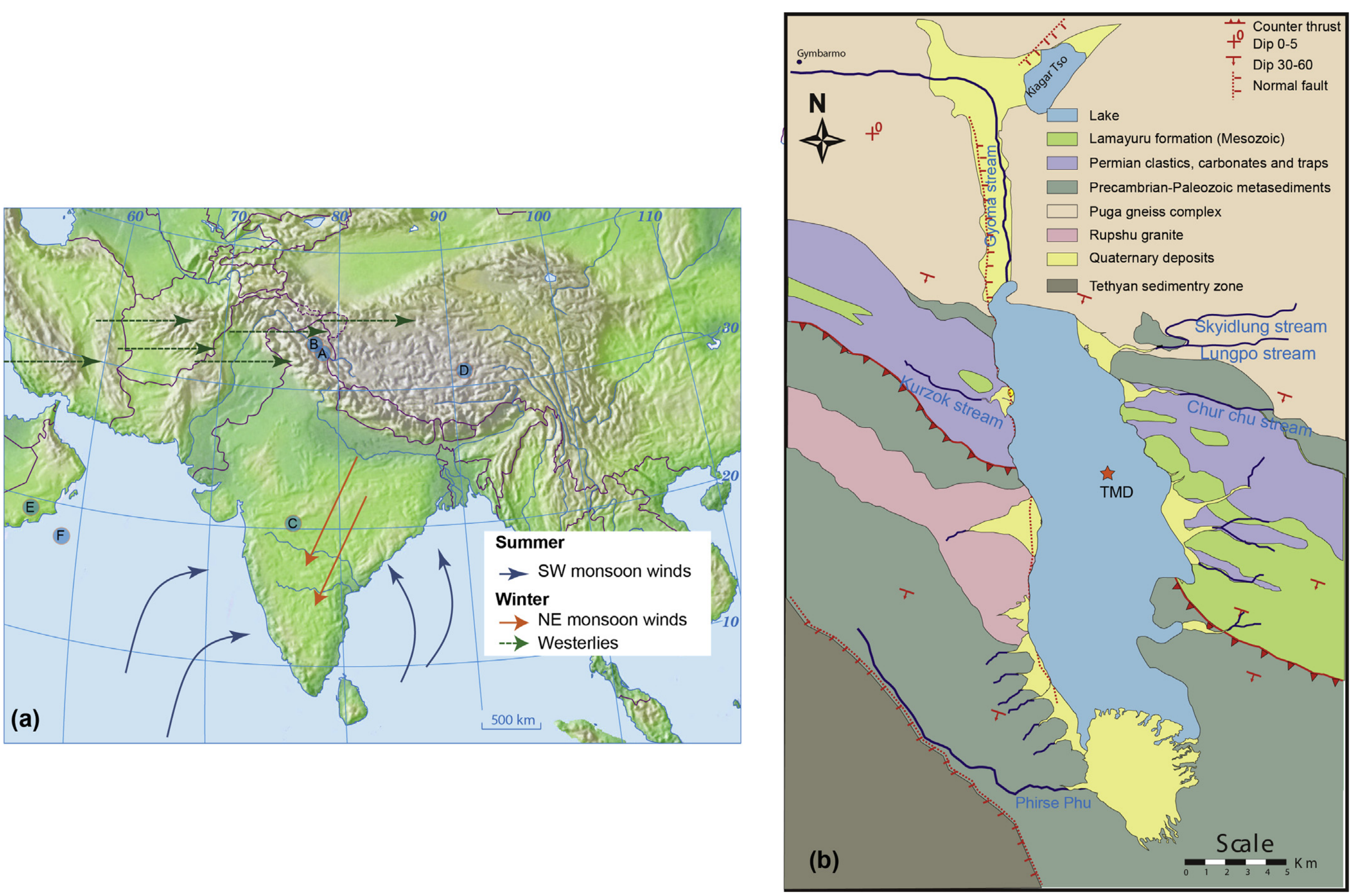

Fig. 1. Geographical setting of the Lake Tso Moriri. (a) Large scale morphological map with dominant seasonal hemispherical airflows (modified after Prasad and Enzel, 2006; Prasad et al., 2014) and different palaeoclimatic sites discussed in the text, (A) Tso Moriri (this study), (B) Tso Kar (Demske et al., 2009), (C) Lonar lake (Anoop et al., 2013b; Prasad et al., 2014), (D) Nam Co Lake (Doberschütz et al., 2014), (E) Qunf cave, Oman (Fleitmann et al., 2003), (F) Arabian sea (Gupta et al., 2003); (b) Geological map of Tso Moriri Lake catchment (modified after Fuchs and Linner, 1996; Steck et al., 1998; de Sigoyr et al., 2004). The star represents the location of the composite core (TMD).