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Climate variability on the south-eastern Tibetan Plateau since the Lateglacial based on a multiproxy approach from Lake Naleng – comparing pollen and non-pollen signals

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A B S T R A C T

A multi-proxy Lateglacial environmental record is described from Lake Naleng (31.10°N; 99.75°E, 4200 m above sea level), situated on south-eastern Tibetan Plateau to gain deeper insights into the hydrological and palaeoclimate development since 17.7 cal ka BP. Palynological reconstructions of variations in mean annual precipitation (MAP) and temperature (MAT), sedimentological data and sediment chemistry including weathering indicators provide a multi-faceted picture of local and regional environmental changes since the Lateglacial. Principal component analyses of all parameters provide information on interrelationships between each parameters, which help to evaluate their traceability to temperature and precipitation and to estimate their usability as proxy indicators for local and or regional variations.

During the Lateglacial from 17.7 to 14.0 cal ka BP Lake Naleng experienced cold and dry climate conditions with low biological productivity and supply of unaltered fine-grained material due to the high supply of glacier milk. During the second half of the Lateglacial, climate conditions changed abruptly: increases in MAT (from −4 to −2.2 °C) and MAP (from 500 mm to 820 mm) between 14.0 and 13.0 cal ka BP indicate a climate amelioration. This time interval can be correlated to the Bølling/Allerød (B/A) warming period in the North Atlantic region and is followed by the Younger Dryas cold reversal indicated by abrupt decreases of MAT (from −2.2 to −5 °C) and MAP (from 820 to 650 mm). The onset of the Holocene at about 11.5 cal ka BP is indicated by rises in reconstructed MAT (from −5 to about −0.3 °C) and MAP (from 600 mm to 950 mm), which led to an increased supply of weathered material and higher biological productivity. Between 5.0 and 3.0 cal ka BP, MAT increases to about 0.2 °C and MAP rises to maximum values of about 1000 mm, followed by slightly decreasing MAT and MAP between 3.0 and 0 cal ka BP.

The biogeochemical parameters (total organic carbon (TOC), C/N, $\delta^{13}C_{org}$) and weathering indicators (e.g. the chemical index of alteration (CIA) and Sr/Ba) are directly (erosion of soils) or indirectly (changing provenance) related to moisture availability on the south-eastern TP and shows matching regional climate oscillations since the Lateglacial. In comparison to other Lateglacial records from the TP, MAP reconstructions from Lake Naleng indicate wetter climate conditions in the south-eastern part of the TP and dryer conditions farther away from moisture sources.

1. Introduction

The Tibetan Plateau (TP) is the largest elevated landmass on Earth and triggers the onset of the monsoon circulation by increasing the insolation-driven thermal contrast between land and ocean (Prell and Kutzbach, 1992). Furthermore, the TP is very important for the water supply of billions of people, because it is

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the source area of the largest rivers in central Asia (Huang et al., 2011). Understanding regional natural landscape variability on the TP and adjacent areas will therefore provide insights into low-latitude climatic systems, and will enable better predictions of future climate change.

Because of its climatic impact on the atmospheric circulation system, the TP is a key region for palaeoclimate research. Most published palaeoclimate studies on the TP focus on the Holocene, and records including the Lateglacial are still rare (Herzschuh, 2006; Zhang and Mischke, 2009). A temporally and spatially extended data set of climate records from the Tibetan Plateau is useful for a regional assessment of the Lateglacial and Holocene climate and for a discussion of spatial heterogeneities of climate change on the TP (Shen et al., 2005; Mischke and Zhang, 2010). In this context, lake archives from the TP provide valuable information about environmental and climate change since the Lateglacial. However, different and interacting processes affect lake systems on the TP: hydrological and tectonic changes in the catchment, the existence of glaciers, or variations in precipitation, temperature and evaporation. Commonly used palaeolimnological proxies differ in the degree to which they are known to trace specific climatic parameters. For instance, individual proxies from the same site may suggest inconsistent climate reconstructions as they can reflect either local within-lake variations, regional variations or both (Wischnewski et al., 2011; Wang et al., 2014). Thus, validation procedures are needed to establish a reliable relationship between a climatic variable and a proxy indicator (IPCC, 2007).

Our objectives in this study were threefold. First, this study from Lake Naleng on the south-eastern TP presents quantitative palynological reconstructions for mean annual precipitation and temperature since 17.7 cal ka BP in comparison to other quantitative records from the eastern TP in order to determine the strength of, and the forcing mechanisms behind, climate oscillations in the Lateglacial and Holocene. Second, we present weathering indicator records (CIA, Sr/Ba, Y/Al, Al/Rb) to estimate the degree of weathering since the early Lateglacial. Third, we compared the palynological reconstructions with all newly available sedimentological and biogeochemical proxies (grain size, total organic carbon (TOC), C/N, $\delta^{13}C_{org}$) from Lake Naleng by principal component analyses to evaluate their traceability of temperature and precipitation and to estimate their usability as proxy indicators for local or regional environmental and climate variations.

2. Regional setting

Lake Naleng (also referred as Lalong Cuo; 31.10°N, 99.75°E; Fig. 1) is situated in a glacial tongue basin, 4200 m above sea level (asl) on the south-eastern TP in the Shaluli Shan mountain range in the Sichuan Province of the People's Republic of China. The open freshwater lake (specific conductivity of 0.045 mS/cm) has a surface area of 1.7 km^2, a catchment area of 470 km^2 and a maximum water depth of 36.7 m (Kramer et al., 2010a,b,c). The lake has a Secchi depth of 2.9 m (determined 19.09.2003), a pH of 8.1 and a dissolved oxygen content of 6.9 mg/L, and is classified as mesotrophic water body (Kramer et al., 2010b). Today, the main inflow to Lake Naleng occurs through a major river channel on the northern side of the lake. Furthermore, several small streams from the surrounding mountains reach the lake. They originate from an elevation of approximately 4900 m asl (Kramer et al., 2010b). The outlet at the southern edge drains towards the Xinlong Plateau. Lake Naleng is currently not affected by glaciers but erratic boulders within the catchment area and marginal moraines near the lake-shore indicate its origin as glacially-formed basin (Graf et al., 2008). The Shaluli Shan mountain area includes both high-relief mountains and relatively low-relief upland landscapes. The regional bedrock geology is mainly composed of Triassic flysch sequences of the Songpan-Garze terrane and Triassic volcanic and sedimentary rocks, intruded by Jurassic plutons (Ouimet et al., 2010). However, the catchment area of the lake is composed of Miocene granite and granodiorite (Reid et al., 2005; Graf et al., 2008; Strasky et al., 2009). The main geomorphological units in this area are the Haizishan Plateau and the Xinlong Plateau (Fu et al., 2013a,b).

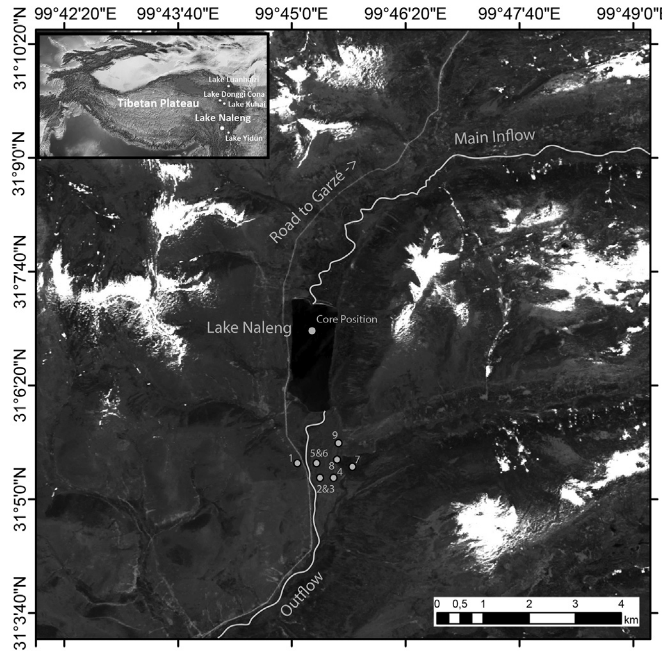

Fig. 1. Satellite image of Lake Naleng (31.10°N, 99.75°E) located on the south-eastern Tibetan Plateau about 4200 m asl (Landsat 8 scene from May 2013, Band 8 panchromatic, source: http://earthexplorer.usgs.gov/). Numbers one to nine indicate sampling points for ^{10}Be surface exposure dating from erratic boulders from inner, middle, lateral, and outer end moraines. The calculated erosion corrected ages for the separate sampling points are: 1. 21.6 ± 1.0 ka BP; 2. 21.2 ± 1.0 ka BP; 3. 20.7 ± 0.9 ka BP; 4. 20.1 ± 1.0 ka BP; 5. 17.6 ± 0.7 ka BP; 6. 18.9 ± 0.8 ka BP; 7. 19.5 ± 1.0 ka BP; 8. 17.5 ± 0.7 ka BP; 9. 22.0 ± 0.9 ka BP (Strasky et al., 2009).

The study area is mainly influenced by the Indian summer monsoon, which transports warm and humid air masses from the Gulf of Bengal to the TP (Domrös and Peng, 1988). During winter, dry and cold air masses prevail in the investigation area, driven by the anticyclone over Mongolia. Mean January temperature is −3.9 °C and mean July temperature is 14.3 °C. Most (90%) of the annual rainfall (560 mm) occurs during the summer monsoon season between May and October (measured at meteorological station Garzê, located about 80 km north-east of Lake Naleng, 31.62°N, 100.00°E, at 3522 m asl).

Lake Naleng is located at the upper tree-line and the vegetation between 3200 and 4400 m asl consists of conifer forests with *Abies squamata* and *Picea likiangensis*, and alpine meadows. The vegetation above the subalpine ecotone is mainly dominated by *Kobresia* species and *Polygonum sphaerostachyum* (Kramer et al., 2010b,c). Detailed information on the vegetation composition in the study area is given by Kramer et al. (2010a,b,c). The catchment area of the lake is used for grazing by yaks and sheep during summer.

3. Materials and methods

3.1. Sediment core and dating

A 1781 cm long sediment core was recovered from the centre of Lake Naleng (Fig. 1) during a field campaign in February 2004 from 32 m water depth using an Uwitec (Niederreiter 60) piston corer