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Holocene cold events on the Tibetan Plateau

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ABSTRACT

A lake sediment core from the eastern Tibetan Plateau was investigated by multi-proxy geochemical, sedimentological and magnetic analyses and its age determined using ^{14}C AMS dating in an approach to use short-lived climate periods for a spatial assessment of the Holocene climate history on the Tibetan Plateau. Six cold events were identified from the Lake Ximencuo record which occurred between 10.3–10.0, 7.9–7.4, 5.9–5.5, 4.2–2.8, 1.7–1.3 and 0.6–0.1 cal ka BP. A comparison with previously published Holocene records from lake and peat sections, ice cores and glacial remains of the Tibetan Plateau revealed that the cold event starting around 4.2 cal ka BP had the most significant and widespread impact on almost all of the examined sites. This cold event lasted about a millennium in the western and central part of the Tibetan Plateau and possibly several hundred years longer at some sites in its eastern realm. The cold event inferred between 7.9 and 7.4 cal ka BP from Lake Ximencuo was recorded at a number of sites on the eastern Tibetan Plateau too and probably corresponds to a cold event identified around 8.2 cal ka BP at the sites on the western and central Tibetan Plateau. The coincidence with the 8.2 ka event of the North Atlantic region implies that the latter exerted a significant environmental impact on the Tibetan Plateau too. The cold spell between 10.3 and 10.0 cal ka BP was recorded at some marginal sites of the Tibetan Plateau but had apparently a less significant environmental impact. The more irregular pattern of cold events between about 7 cal ka BP and the onset of the cold event after 4.2 cal ka BP might be related to the catchment-specific response of the lake sediment and peat accumulation to the termination of the Holocene 'climatic optimum' on the Tibetan Plateau. The final two cold events between 1.7 and 1.3 cal ka BP and in the last several hundred years representing the Little Ice Age are more widely seen on the Tibetan Plateau although they did not reach the significance of the cold event at 4.2 cal ka BP. However, the three cold periods since 4.2 cal ka BP are apparently coeval with the decline and establishment of Chinese Dynasties implying a remarkable impact on the social systems in eastern China. The consistent inference of cold events around 8.2 cal ka BP or a few hundred years later and starting at 4.2 cal ka BP is evidence for a temporary trans-regional climatic response on the Tibetan Plateau in the Holocene regardless of the catchment-specific response of complex natural systems.

1. Introduction

In spite of its low population density, the Tibetan Plateau is a key site in climate and palaeoclimate research due to two different reasons: (1) the large alpine plateau region acts as a heating plate in summer and controls the air circulation over the vast region of monsoonal Asia, and (2) many large rivers originate on the Tibetan Plateau and in its adjacent mountain regions which support rapidly growing societies with about 3 billion people or almost half of the world's population. Possible environmental consequences of recent global climatic change, especially with respect to water availability in the lower reaches of the Tibetan Plateau, are uncertain. Reconstructions of the Holocene environmental response to climatic change may help to assess the amplitude and rapidity of environmental fluctuations and may provide analogues for future scenarios. However, the Holocene climatic and environmental history on the Tibetan Plateau is far from being well understood.

Early studies by Gasse et al. (1991), Kashiwaya et al. (1991), Lister et al. (1991), and Van Campo and Gasse (1993) led to the assumption that the Holocene 'climate optimum' on the Tibetan Plateau occurred during the early to mid Holocene as a result of the early Holocene insolation maximum in low latitudes of the northern hemisphere and an associated increase in monsoon strength (Berger and Loutre, 1991). In contrast, recently published results indicate a complex regional pattern of Holocene climate change and resulting environmental response on the Tibetan Plateau and adjacent regions (An et al., 2000; Herzschuh, 2006; Mischke et al., 2008). This complex pattern may result from the non-uniform behavior of the main circulation systems over the Tibetan Plateau which act as potential sources of precipitation: (1) the East Asian monsoon delivering

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moisture mainly from the South China Sea, (2) the South Asian (= Indian) monsoon bringing moisture from the Indian Ocean, and (3) cyclones triggered by the westerly jet stream which deliver moisture from the Atlantic Ocean or Mediterranean Sea and continental water sources further east.

Complexity arises also from the fragile balance between precipitation, evaporation and temperature in the semihumid and semiarid to arid regions of the Tibetan Plateau. The early Holocene insolation maximum may have led to a temperature, precipitation and related effective moisture increase at one site whereas the insolation-driven temperature and evaporation increase may have caused a decrease in effective moisture at another site (Yu and Kelts, 2002; Herzschuh, 2006). In addition, a strengthened summer monsoon with an increase in average cloudiness in summer potentially resulted in wetter and relatively cooler conditions in places, differing from the assumption that warmest and wettest conditions prevailed at the same time. The environmental response to climate change is further complicated through catchment-specific differences in water storage as snow, ice and frozen ground at high altitudes and spatially different thresholds to initiate significant meltwater runoff. As a result, it remains very difficult to identify a spatial pattern of environmental response to the Holocene climate history on the Tibetan Plateau.

In contrast to the focus on the timing of the Holocene 'climatic optimum' on the Tibetan Plateau and the following period of climate deterioration, the use of an event-stratigraphic approach in inter-site and inter-regional correlation possibly allows a better identification of specific regions with a common response to Holocene climate change. Inferred climatic events do not necessarily represent chronostratigraphic units, because of the time-transgressive nature of climate change. However, similar patterns of climatic events could be used to identify spatially specific mechanisms of climate-driven environmental response.

Well dated high-resolution records are a prerequisite to identify and use short-lived climate periods for the regional assessment of spatial patterns of the Holocene environmental history on the Tibetan Plateau. We significantly improved the chronological control for the Holocene part of a previously published late glacial and Holocene lake sediment record from the eastern Tibetan Plateau and performed additional geochemical analyses to tackle this problem (Zhang and Mischke, 2009). The short-term climatic events inferred from our Holocene Lake Ximencuo record are discussed and compared with records from the Tibetan Plateau and adjacent regions.

2. Study area

The large landmass of the Tibetan Plateau causes the landward migration of moist air from the south and east in the summer whilst the Mongolian–Siberian high triggers the penetration of cold and dry air towards the south during winter. As a result, the southern and eastern margins of the Tibetan Plateau receive much more moisture from the East Asian and South Asian monsoons during summer in comparison to the central, western and northern parts. Here, the westerly jet may provide small amounts of precipitation in addition to the northernmost advances of monsoon precipitation. Lake Ximencuo is located on the eastern Tibetan Plateau, which is under the influence of the East Asian and South Asian monsoon systems (Fig. 1).

Lake Ximencuo (33.38°N, 101.10°E, 4030 m above sea level [asl]) fills a glacially eroded U-shaped valley on the northern slope of the Nianbaoyeze Shan (Shan = mountains). The basin was occupied by the Nianbaoyeze glacier during the global last glacial maximum for the last time and filled by a lake since at least 19 cal ka BP (Owen et al., 2003; Zhang and Mischke, 2009). Granite is exposed upstream of the lake and lateral and terminal moraines form the slopes adjacent to the lake (Lehmkuhl and Liu, 1994). Mean annual precipitation at the station Darlag (Guymai, 3980 m asl) 140 km northwest of the lake is 550 mm, mean January, mean July and mean annual temperatures are −11.4 °C, 9.8 °C and 0.0 °C (WorldClimate). The lake is ice-covered for four to five months. The vegetation in the vicinity of the lake is characterized by alpine *Kobresia*-dominated meadows with dwarf shrubs and high alpine cushion and rosette plants (Schlütz, 1999; Schlütz and Lehmkuhl, 2009). Human impact on the lake results mainly from grazing of yaks and sheep in its catchment. Zhang and Mischke (2009), Lehmkuhl and Liu (1994), Lehmkuhl (1995, 1998) and Schlütz and Lehmkuhl (2009) provide additional information about Lake Ximencuo and the eastern Tibetan Plateau.

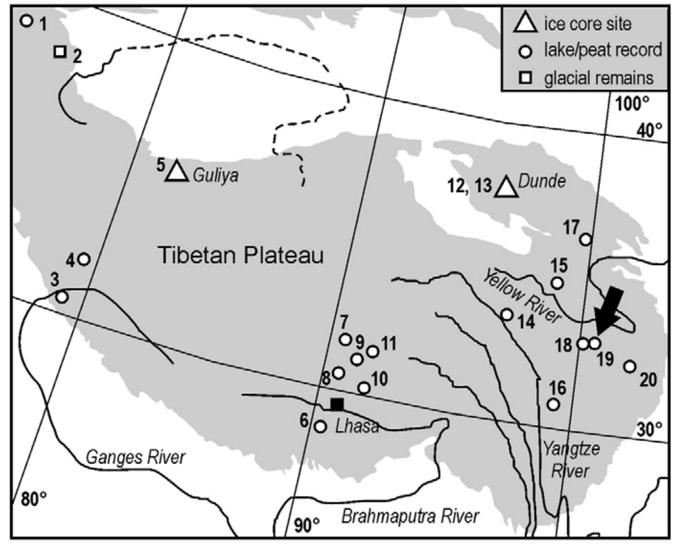

Fig. 1. The Tibetan Plateau, and position of Lake Ximencuo (arrow) and sites of Holocene climate records mentioned in the text. The grey-shaded area is higher than 3000 m asl. 1 Lake Karakul, Tajikistan (Mischke et al., 2010a); 2 glacier record of Muztag Ata and Kongur Shan (Seong et al., 2009); 3 Garhwal Himalayan peat, India (Phadtare, 2000); 4 Bangong and Sumxi Co (Gasse et al., 1996); 5 Guliya ice core (Thompson et al., 1997); 6 Chen Co (Zhu et al., 2009a); 7 Zigetang Lake (Herzschuh et al., 2006); 8 Nam Co (Zhu et al., 2009b); 9 Cuoe Lake (Wu et al., 2006); 10 central Tibetan peats (Wang and Fan, 1987); 11 Ahung Co (Morrill et al., 2006); 12 Dunde ice core pollen (Liu et al., 1998); 13 Dunde ice core $\delta^{18}O$ (Yao and Thompson, 1992); 14 Lake Koucha (Mischke et al., 2008); 15 Lake Kuhai (Mischke et al., 2010b); 16 Naleng Co (Kramer et al., 2010); 17 Lake Qinghai (Shen et al., 2005); 18 Nianbaoyeze Shan peats (Schlütz and Lehmkuhl, 2009); 19 Lake Ximencuo (this study); 20 Hongyuan peat (Yu et al., 2006).

3. Materials and methods

A lake sediment core of 12.81 m length was recovered from 56.2 m water depth in February 2004 with a UWITEC piston corer. The core segments were transported to Lanzhou in liners, visually described and cut into 1-cm slices.

Bulk samples were used for radiocarbon dating due to the lack of any macroscopic plant remains. The alkali soluble and insoluble fractions were dated separately because large age differences between both fractions were obtained during previous studies of comparable lake sediments from the Tibetan Plateau (Kramer et al., 2009; Mischke et al., 2010b; Zhang and Mischke, 2009). The radiocarbon age of the alkali soluble fractions for three samples from <3.0 m core depth was not determined since significant differences were not recognized for four samples from this core segment in a previous study (Zhang and Mischke, 2009). The radiocarbon age of 869 ^{14}C years BP for the core-top sample was regarded as 'lake reservoir effect' and subtracted prior to calibration of ^{14}C years to calendar years using CALIB and weighted averaging of ages at 2σ precision (Reimer et al., 2004, online version 5.1beta; Table 1). Linear interpolation was used to determine the age of each sampled horizon.

For the analysis of the stable carbon isotopes of the bulk organic matter, sub-samples were dried at 50 °C in an oven overnight and