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Last glacial pollen record from Lanzhou (Northwestern China) and possible forcing mechanisms for the MIS 3 climate change in Middle to East Asia

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ABSTRACT

The vegetation on the northeastern margin of the Tibetan Plateau is highly sensitive to climatic changes and thus represents a potentially interesting environmental archive. Pollen samples from the Fanjiaping Loess section in Lanzhou on the western Chinese Loess Plateau (CLP) were analyzed in conjunction with OSL dating. The results indicate that pollen zone B (60.6–46.0 ka, correlative to the early MIS 3) had the greatest abundances of Cupressaceae, *Tsuga*, Gramineae and Cyperaceae of the entire section, suggesting a warm phase during the last glacial period. These pollen taxa decreased significantly in abundance in the zones C (46.0–39.0 ka) and D (39.0–27.0 ka), reflecting a substantial climate cooling from the middle MIS 3 to MIS 2. These results correlate with climate records from the South China Sea, the CLP, Baikal Lake, North America, North Atlantic Ocean and other regions, and probably correspond with the decline of northern high-latitude insolation and the increase of global ice volume from 50 to 20 ka. In particular, arboreal pollen, fern spore and algae abundances declined sharply since ~40 ka, while shrub and herb pollen reached the highest abundances. Conifer pollen *Picea* and *Abies* abundance also rose markedly and increased up the section. This implies significant climate deterioration and likely corresponded with substantial growth of the polar ice sheets since ~40 ka. The decreasing temperature caused by an insolation decline during the last glacial period probably reinforced the cooling effect in a 'snow/ice/albedo' feedback, which would result in less climate sensitivity to radiative forcing. Meanwhile, vegetation decline in the Northern Hemisphere during the last glacial period and tundra development at high latitudes possibly caused additional cooling, enhancing the growth of polar ice sheets since 40 ka. The development of polar ice sheets increased the polar-to-equator temperature and pressure gradients, strengthening the westerlies and supplying plenty of moisture to Northwest China during 40–30 ka. Lake sediments developed widely on the Tibetan Plateau during 40–30 ka, probably related to an increase in the seasonality of middle-to-low latitude insolation which caused an enhancement of glacier melting on the Plateau.

1. Introduction

With more and more investigations conducted on climate and environment changes in Northwest China and on the Tibetan Plateau during the late Quaternary (e.g. Chen et al., 1990; Thompson et al., 1997; Wu et al., 2004; Yang et al., 2006a,b; Herzschuh, 2006; Colman et al., 2007), the possibility of a warm and humid climate in Central to East Asia during the late MIS 3 has been the focus of recent studies (e.g. Yang et al., 2003, 2010). High lake levels during this time period were first inferred from the analysis of lake sediments and landscape of the Qaidam Basin (Chen et al., 1990), the Tarim Basin (Yang et al., 2006b) and other neighboring lake basins (Herzschuh, 2006) along the northeastern margin of the Tibetan Plateau. An ice core record from the Guliya ice cap on the Tibetan Plateau provided evidence of regional warm climatic conditions during the late MIS 3 (Thompson et al., 1997). High content of arboreal pollen from Nam Co Lake also implied a warm and humid climate during 40–30 ka (Wu et al., 2004). Multiple studies of stratigraphic, geochemical, and fossil data suggest that fresh-mesohaline paleolakes started to develop around 42 ka ago in the Tengger Desert in Northwest China and the highest lake levels were reached between 35 and 22 ka under the influence of warm-humid climates (e.g. Pachur et al., 1995; Ma et al., 1998; Zhang et al., 2002). However, these patterns of climate change, as pointed out by Colman

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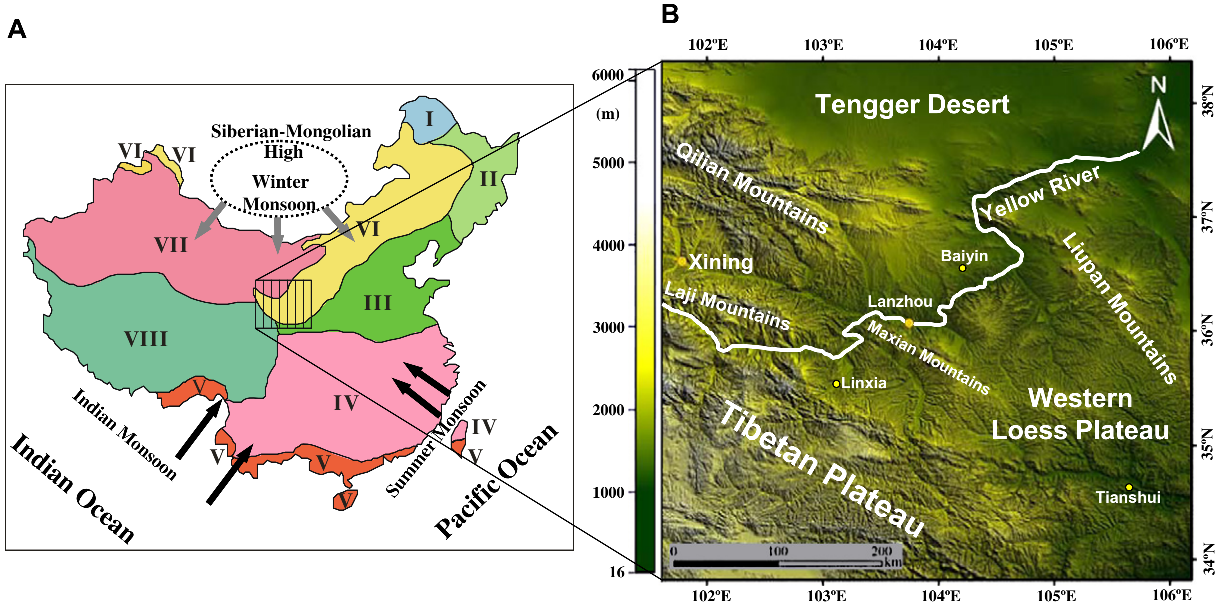

Fig. 1. Schematic map showing the location of the studied section, modern vegetation zones and the climatic system of China including the East Asian and Indian summer monsoons and the winter monsoon (A), and shaded relief of the landscape near Lanzhou (B). I. Cold-temperate conifer forest; II. Temperate mixed conifer-broadleaved forest; III. Warm-temperate broadleaved deciduous forest; IV. Subtropical evergreen broadleaved forest; V. Tropical rainforest and seasonal rainforest; VI. Steppe; VII. Desert; VIII. Tibet-Qinghai cold and highland vegetation, compiled from Zhang et al. (2007).

et al. (2007), contradict the last glacial stepwise increase of global ice volume and the gradual decrease of sea-surface temperatures (SSTs) toward the Last Glacial Maximum (LGM) as inferred from deep-sea benthic $\delta^{18}O$ records (e.g. Imbrie et al., 1984, 1993).

High paleolake levels on the Tibetan Plateau are also supported by the presence of various high-terraces, ranging from 10 to 280 m higher than present-day lake levels (Lehmkuhl and Haselein, 2000; Shi et al., 2002; Yang et al., 2004). For example, the highest terrace identified from the southern bank of the Qinghai Lake is ~120 m higher than the present lake level, and was believed to have formed at 38 ka (Chen et al., 1990; Yuan et al., 1990). Nevertheless, recent studies on the Qaidam Basin and the Qinghai Lake indicate that high lake levels occurred only during the early to middle (instead of the late) MIS 3 (e.g. Liu et al., 2010; Fan et al., 2010; Sun et al., 2010). Hence, the existence of a warm and humid climate in Central to East Asia during 40–30 ka is still a matter of debate.

The mechanism responsible for the supposed MIS 3 moist interval in Northwest China is also an unanswered question. One group of authors suggested that the strengthening of the Asian monsoon, driven by the precession cycle, brought more moisture to a larger area of China (e.g. Shi et al., 2001, 2002). Another group of authors argued against the monsoon hypothesis, suggesting that a moist climate during MIS 3 could be explained by the strengthened westerlies, which transported more moisture into Northwest China (e.g. Porter and An, 1995; Wunnemann and Hartmann, 2002; Yang et al., 2004, 2006b; Yang and Scuderi, 2010). The Tianshuihai and Balikun records could provide data to test this idea, because climate conditions in this region are dominantly controlled by the westerlies. However, carbonate $\delta^{18}O$ values in both regions progressively increased during MIS 3, implying an aridification trend into the LGM (Zhou and Zhu, 2001; Ma et al., 2004).

The dynamic relationship between Middle and East Asia paleoclimatic evolution with global climate change 40–30 ka remains uncertain. As a potentially sensitive region between Northwest China and the Tibetan Plateau, Lanzhou lies at the edge of the farthest inland reach of the East Asian summer monsoon. Thus, examining the monsoon record in Lanzhou is pivotal to understanding the evolution of East Asia palaeoclimate during the last glacial period. In this paper, we present a detailed pollen analysis of the Fanjiaping Loess section in Lanzhou in an effort to reconstruct the paleoclimate evolution of the western Chinese Loess Plateau (CLP). We compared our paleoclimate interpretations from the Lanzhou pollen sequence with a variety of different paleoclimate proxy records from China and around the world to gain insight about the mechanisms of MIS 3 climate change in Middle to East Asia.

2. Geographical and geological settings

Modern vegetation in China can be divided into eight zones, distributed in a fan shape around the northeastern margin of the Tibetan Plateau (Fig. 1). Such a distribution indicates that the vegetation covering the northeastern margin of the Tibetan Plateau is highly sensitive to climate change and thus provides the opportunity to study possible environmental changes. The study area also belongs to the Western Loess Plateau strongly influenced by the Asian monsoon circulation. For the Western Loess Plateau, mean annual precipitation (MAP) decreases from ~600 mm/yr in the southeast to <200 mm/yr in the northwest. The modern vegetation ranges from forest-grassland, to grassland to desert-grassland along the same gradient (Editorial Board of China's Physical Geography, 1985). The main herbs in the study area include *Aneurolepidium chinense*, *Stipa baicalensis*, *Filifolium sibiricum*, *Thymus mongolicum*, *Artemisia frigida*, *Lespedeza davurica*, *Leymus secalinus* and *Artemisia scoparia*, and are accompanied by shrubs such as *Prunus sibirica*, *Salix mongolicus*, *Ulmus pumila*, *Bothriochloa ischaemum*, *Themeda triandra* var. *japonica*, *Zizyphus sativa*, *Sophora viciifolia*, *Hippophae rhamnoides*, *Rosa hugonis*, *Prinsepia uniflora*, *Lycium chinense*, *Prinsepia uniflora* and *Buddleia alternifolia*. In addition, there are some patches of forest distributed on the surrounding mountains and along the edges of gullies of foothills or tablelands, mainly dominated by *Populus*, *Ulmus*, *Betula*, *Quercus*, *Picea* and *Pinus*.

The Western CLP is closer to eolian dust sources and has a 3–4 times higher dust deposition rate than the central CLP. Consequently, it has the world's thickest Loess deposit (318 m). Lanzhou, in the western CLP, is located on the northwest front of the summer monsoon, receives significantly less precipitation and has weaker