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Miocene vegetation and climatic changes reconstructed from a sporopollen record of the Tianshui Basin, NE Tibetan Plateau

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ABSTRACT

The Miocene vegetation and climate history of western China remains unclear. However, widely-distributed Miocene sediments of the Tianshui Basin in the NE Tibetan Plateau provide a great potential for deciphering the Miocene vegetation and climate history of this region. This paper presents first sporopollen record from these sediments, covering the period from 17.1 to 6.1 Ma. Sporopollen data reveal that temperate, warm-temperate broad-leaved forest of *Quercus*, *Ulmus* and *Betula* dominated the Tianshui region between 17.1 and 14.7 Ma, which was replaced by forest or forest-steppe of *Ulmus*, *Artemisia* and *Betula* between 14.7 and 11.7 Ma. After a return to a broad-leaved forest of *Betula* and *Quercus* during 11.7–8.5 Ma, the forest decreased rapidly and was replaced mostly by steppe vegetation (mainly composed of *Artemisia*, Chenopodiaceae and Poaceae) after 8.5 Ma. We interpret the observed vegetation changes as a result of global climate change, which is characterized by global cooling, development of Arctic ice-sheets and permanent El Niño state after the Middle Miocene Climatic Optimum. The rapid development of steppe at about 8.5 Ma suggested a permanent drying of the Asian interior at this time, coinciding with the onset of the well-known *Hipparion* red clay deposition in North China.

1. Introduction

The Miocene was a very important period of climatic transition in the Earth's Cenozoic climate evolution, in which the Earth's climate underwent a great change from unipolar glaciation to climatic conditions related to bipolar glaciation (Shackleton and Kennett, 1975; Miller et al., 1987; Zachos et al., 2001). The warmest interval (17–15 Ma) of the Neogene, known as the Middle Miocene Climatic Optimum (MMCO) (Flower and Kennett, 1994), produced one of the most striking climatic events during this stepwise cooling process. This Climatic Optimum was ended by a rapid, global cooling event (Mi3/4), which researchers have suggested relates to the significant growth of the East Antarctic Ice-Sheet (EAIS) (Flower and Kennett, 1994; Miller et al., 1996; Zachos et al., 2001). Middle and high latitude temperatures dropped sharply with the expansion of the EAIS, but low latitude temperatures remained stable (and even rose slightly in some areas), thus resulting in an increase of the meridional surface temperature gradient, extending the width of the climatic zones; together, these led to middle latitude aridification, e.g., in Australia, America and East Africa (Savin et al., 1975; Flower and Kennett, 1994). However, the timing of the aridification in interior Asia, the largest mid-latitudes arid zone in the Northern Hemisphere, remains a controversial issue. The complexity of possible causes and the different proxies used by authors for reconstructing the history of this arid zone may be responsible for the different viewpoints. Numerical climate models show that the uplift of the Tibetan Plateau and retreat of the Paratethys Sea might play important roles in the initiation and development of the arid zone in Asia's interior (Ramsein et al., 1997; An et al., 2001). Recent research demonstrates that global cooling during this period (especially the creation and development of the Arctic ice-sheet) provides a major contribution to the formation of this arid zone (Guo et al., 2004; Lu et al., 2010). Furthermore, the establishment of the modern Asian monsoon made this issue more complex (Sun and Wang, 2005; Liu et al., 2009). At present, two main ideas about the timing of aridification in the Asia's interior exist. One view holds that aridification began in the Late Miocene (7–8 Ma), as indicated by plant and mammal fossils (Ma et al., 1998; 2005; Wang et al., 1999; Liu et al., 2009, 2011). The other view suggests that aridification began much earlier, in the Early Miocene (22 Ma), as recorded by eolian deposition in the Tianshui Basin, NE Tibetan Plateau (Guo et al., 2002). Evidence for the latter view is mainly based on field

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observation, mineral assemblage, grain size and morphology and susceptibility which is similar to that of Quaternary loess. Recently, based on extensive sedimentological study through the whole Tianshui Basin, Alonso-Zarza et al. (2009) proposed the Tianshui Basin was filled with mudflat/distal fan and shallow lake deposits (including the reported oldest aeolian deposition section QA-1, Fig. 1c) during the Miocene, implying the timing of the Asian interior aridification may not have been as far back as 22 Ma. However, their conclusions on this issue have been obtained from inorganic evidence in this region. Information from paleovegetation buried in the strata of basins surrounding the Tibetan Plateau provides more direct evidence for the aridification of the Asian interior. Thus, we chose to carry out our palynological analysis in the area of the Tianshui Basin, NE Tibetan Plateau (Fig. 1).

This paper reports our results in reconstructing the paleoclimate and vegetation during the Middle–Late Miocene in the Tianshui Basin and provides palynological evidence for the aridification of the Asian interior. We also discuss the relationship between climate changes in the Tianshui Basin and global climate changes during the Miocene.

2. Geological and geographical settings

The Tianshui Basin lies at the northeast margin of the Tibetan Plateau (Fig. 1a), limited on the north by the Haiyuan fault (a large scale, left-lateral, strike-slip fault), to the east by Liupan Shan Mountain, and on the south by West Qinling Mountain (Fig. 1b). The basin sits at the junction of the monsoon region, the northwest arid area, and the Tibetan Plateau, just at the peak of 'monsoon triangle' (Li and Feng, 1988), a region very sensitive to climatic change. Moreover, the widely distributed, continuous mudflat/distal fan and shallow lake Neogene deposits in this basin provide an ideal setting for the study of the paleoclimate history of western China (Li et al., 2006; Alonso-Zarza et al., 2009).

At present, the East Asia monsoon influences the climate of the Tianshui area, providing a semi-humid, warm temperate, continental monsoon climate, characterized by relatively hot, humid summers and cold, dry winters. Based on Tianshui station meteorological data from 1971 to 2000, the mean temperature is 10.4 °C, with monthly mean annual temperature in July and January of 22.8 °C and −2 °C, respectively. Mean annual precipitation is 504 mm, with rainfall concentrated mainly in the summer and autumn, with a peak mean precipitation of 84.6 mm in July. Mean annual latent evaporation reaches to 1380 mm, almost three times as much as the mean annual precipitation.

The modern natural vegetation consists of warm-temperature forest-grasslands, dominated by the herbaceous species *Bothriochloa ischaemum*, *Artemisia giraldii*, and *Stipa bungeana*. Warm grasslands are distributed in valleys lower than about 1000 masl, and they consist mainly of *Arundinella hirta*, *Spodiopogon sibiricus*, and *Themeda triandran*. Shrubs such as *Zizyphus jujub*, *Sophora viciifolia*, and *Ostryopsis davidiana* lie on the hills, and trees (including *Quercus liaotungensis*, *Pinus tabulaeformis*, *P. armandi*, and *Platycladus orientalis*) grow in the mountains (Huang, 1997).

The selected Yanwan section (Lat. 34°58′ N, Long. 105°34′ E) lies about 14 km northwest of Qin'an county, Gansu province (Fig. 1c), and has an altitude of 1540 m at the top. In this section, the Neogene sequence, capped by about 60 m of Quaternary loess, consists of about 288 m of sediment overlying unconformably above the metamorphic rocks of the Sinian period. Based on lithologic properties and depositional characteristics, three lithostratigraphic units can be distinguished. From the bottom to the top of the Yanwan section, Unit I, about 132.3 m thick, consists mainly of yellow-brown calcareous mudstone or marl and reddish brown mudstone; Unit II, about 128.2 m thick, is characterized by yellow-brown calcareous mudstone or siltstone intercalated with light reddish brown

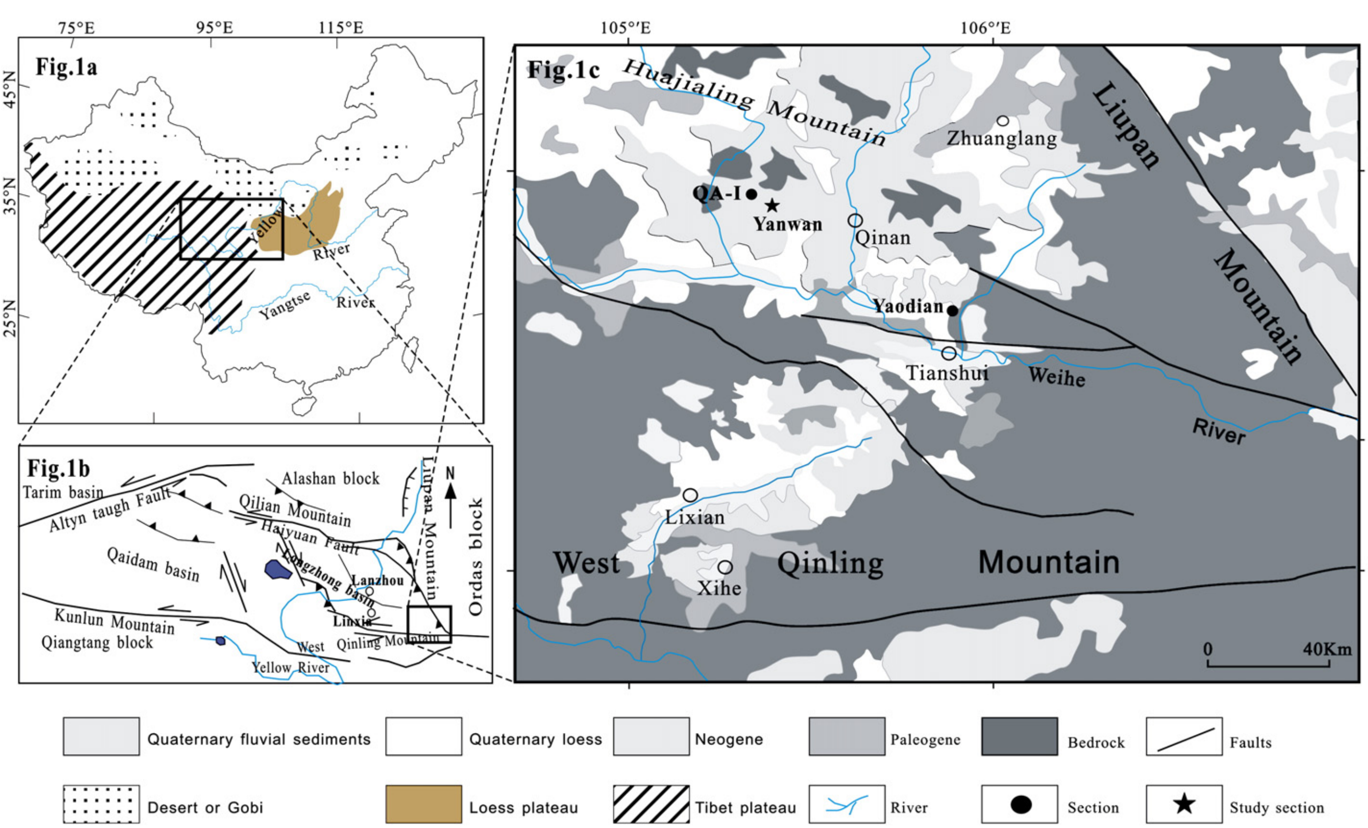

Fig. 1. Geological setting of study area, location map of Yanwan section and other locations mentioned in this text.