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Lithologic and rock magnetic evidence for the Mid-Miocene Climatic Optimum recorded in the sedimentary archive of the Xining Basin, NE Tibetan Plateau

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ABSTRACT

Thick Cenozoic deposits in the Xining Basin provide great potential for understanding the tectonic and climatic evolution of the NE Tibetan Plateau. However, the Middle Miocene Climatic Optimum (MMCO) in this basin has not been reported up until now, due to the poor exposure of the uppermost strata covering this interval. In this study, a 194 m-deep core of flood–plain to channel–flood deposits was obtained from the Tashan flats above the Xiejia Section in the Xining Basin. Magnetostratigraphic dating of the core determines its age at ca. 18.5–13.5 Ma. Lithological and rock magnetic analyses demonstrate that the most prominent changes recorded in the present study occurred between ~17 and ~14 Ma. During this period, the sedimentary sequence mostly consists of gray-white or bluish-gray claystone and muddy siltstone, intercalated with some thin red claystone. The rock magnetic parameters show a large variability, with higher values in thin red claystone beds and lower values in gray-white or bluish-gray layers. These features demonstrate that, due to a warm and wet climate, extensive rivers had developed in the Mid-Miocene and that a reducing sedimentary environment prevailed. These "favorable" climatic conditions coincide with the MMCO as based on global deep-sea deposit records, indicating that this warm event exerted a major impact on regional climate change in the NE Tibetan Plateau during the Mid-Miocene.

1. Introduction

Marine oxygen isotope records (e.g., Miller et al., 1987; Zachos et al., 2001, 2008) demonstrate that the global climate underwent significant change during the Cenozoic era, changing from an ice-free, warm climate to a cold climate marked by the development of massive continental ice sheets. It has been suggested that the Earth's climate remained relatively stable until the Late Oligocene Warming (Zachos et al., 2001) and the Mid-Miocene Climatic Optimum (MMCO; 17–14 Ma; Flower and Kennett, 1994). After the MMCO, which was characterized by a mid-latitude warming of ca. 6 °C relative to the present, an abrupt cooling occurred at middle and high latitudes (Miller et al., 1987, 1991). According to Flower and Kennett (1994), the average global temperature following this cooling process (the Mid-Miocene Climatic Cooling; MMCC) dropped more than 5 °C as the East Antarctic ice sheet developed.

Until now, MMCO and MMCC conditions have mostly been reconstructed using oxygen isotope records from deep-sea sediments (e.g., Miller et al., 1987; Zachos et al., 2001, 2008). Although terrigenous sediments contain climatic information in addition to that stored in oceanic sediments, evidence of the MMCO from the terrestrial sedimentary archive remains relatively scarce because of the depositional hiatuses. In this context, the identification of continuous sedimentary sequences in terrestrial systems covering the Mid-Miocene can provide new insights into the evolution and driving mechanisms of the MMCO (Jiang and Ding, 2008; Sun and Zhang, 2008; Miao et al., 2011, 2012; Zhang et al., 2014).

Along the northeastern margins of the Tibetan Plateau (TP), the best exposed, most continuous and longest Cenozoic records are preserved in Qinghai Province, NW China, of which those from the Xining Basin are highly representative (Dai et al., 2006; Dupont-Nivet et al., 2007; Fang et al., 2007; Xiao et al., 2012). Previous studies indicate that the fluvial-lacustrine stratigraphy from the Xining Basin holds an Eocene to Mid-Miocene (52–17 Ma) sedimentary record of both TP uplift (Dupont-Nivet et al., 2008; Xiao et al., 2012) and global climate change (Dupont-Nivet et al., 2007; Xiao et al., 2010; Abels et al., 2011; Long et al., 2011; Hoorn et al., 2012; Bosboom et al., 2014; Licht et al., 2014). Recent lithofacies and geochemical studies from the Xiejia and the Shuiwan sections have further demonstrated that the rapid cooling events of the Oi-1 and Mi-1 glaciations and the Late Oligocene Warming were well-recorded in the sedimentary archive of the Xining Basin (Dupont-Nivet et al., 2007; Abels et al., 2011; Hoorn et al., 2012; Chi et al., 2013; Licht et al., 2014).

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However, MMCO investigations have not been conducted in the Xining Basin because the uppermost strata covering this interval are poorly exposed (Dai et al., 2006; Xiao et al., 2012). In the field, stratigraphic correlation indicates that an additional ~120 m of the Xianshuihe Formation, which is approximately horizontal, exists above the Xiejia Section. The age of this set of sediments is estimated at ~14–13 Ma by extrapolating up the additional ~120 m of the Xianshuihe Formation using the accumulation rate for the Xiejia Section (819 m, 52–17 Ma; Dai et al., 2006). This provides an excellent opportunity to reconstruct the tectonic and climatic evolution of the NE TP during the Mid-Miocene. We have recently obtained a 194 m core of the uppermost strata from the Tashan flats above the Xiejia Section. In this study, we present the magnetostratigraphic results we used to date the core and then employ lithological and rock magnetic records to reconstruct in detail the climate history of the Mid-Miocene in the NE TP.

2. Regional setting and stratigraphy

The Xining Basin is located on the northeastern edge of the TP at an elevation of between ~2000 and ~3000 m (Fig. 1a). The exposed Xining Basin is confined by the Dabanshan Mountains to the north, the Lajishan Mountains to the south, and the Riyueshan Mountains to the west, with the east open to the Lanzhou Basin (Fig. 1b). The present semi-arid climate controls the Basin's weather (Fig. 1a). Recent mean annual temperatures in the Basin range between 5–6 °C, with annual precipitation between 350 and 500 mm.

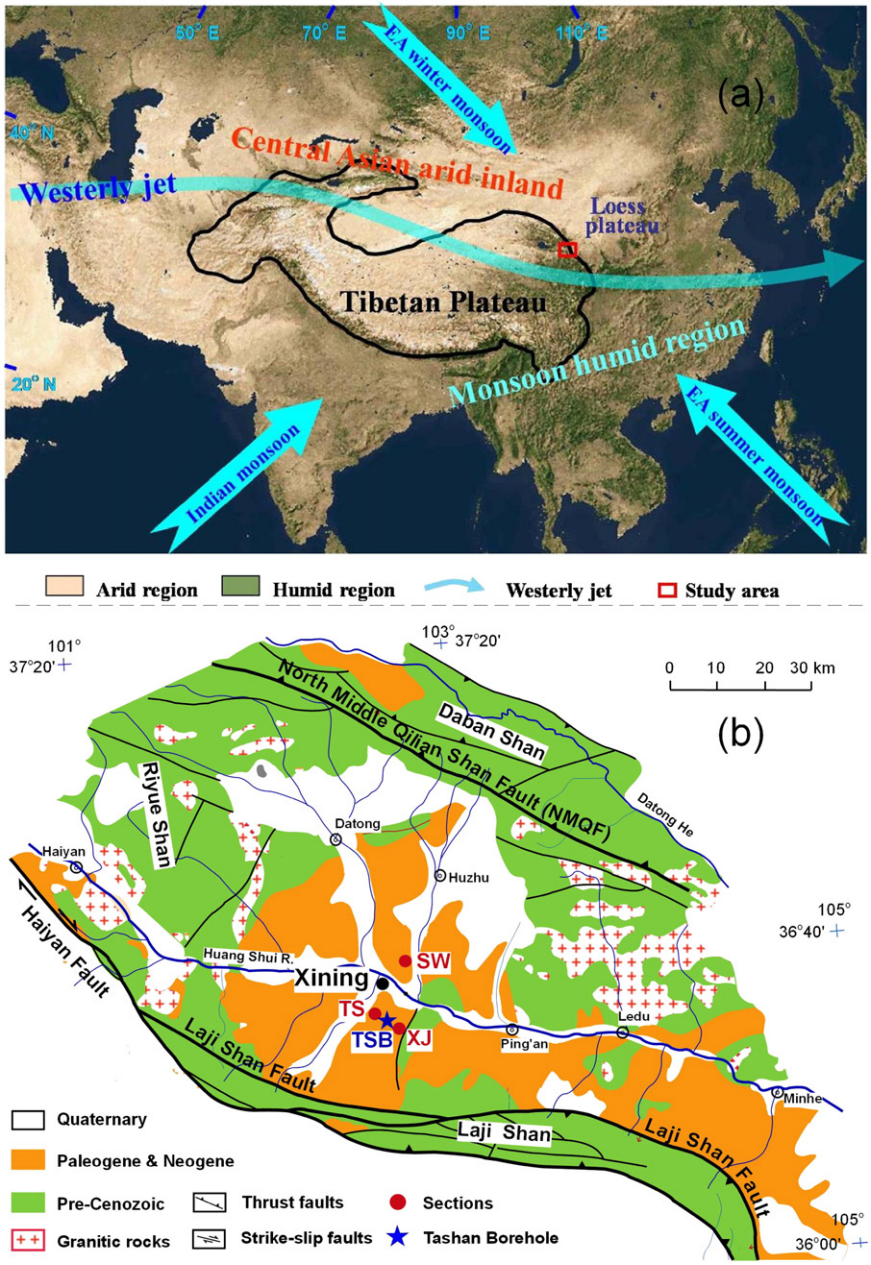

Fig. 1. (a) DEM and geographic map showing the location of the Xining Basin *vis-à-vis* the configuration of the arid Asian interior and the region affected by the East Asian Monsoon. (b) Geologic map of the Xining Basin (modified from Dai et al., 2006). Red circles indicate the locations of the Shuiwan Section (SW), the Xiejia Section (XJ) and the Tashan Section (TS). The blue star indicates the location of the Tashan Borehole (TSB). EA: East Asian.