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Cenozoic record of aeolian sediment accumulation and aridification from Lanzhou, China, driven by Tibetan Plateau uplift and global climate

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ABSTRACT

Previous work has shown that aeolian Red Clay first appears at around 8 Ma in the main Chinese Loess Plateau and at 25–22 Ma in the western Loess Plateau; however, records of aeolian deposition in the North Pacific suggest that aeolian accumulation occurred throughout the Cenozoic, and that changes in aeolian flux occurred in distinct stages. Tracing the Cenozoic aeolian history of the interior of the Asian continent may help us to understand the history of Asian aridification and its driving forces. In the Lanzhou area on the western margin of the Loess Plateau and the northeastern edge of the Tibetan Plateau, the Cenozoic stratigraphic sequence consists of fluvial–lacustrine sediments in the lower part, aeolian Red Clay with intercalated fluvial layers in the middle part, and predominantly aeolian loess in the upper part. We use high resolution paleomagnetic measurements of this sequence to construct a time scale, and measurements of sediment rock magnetic properties, grain-size, and color reflectance and sedimentary facies analysis to reconstruct the paleoenvironment. The results show that prior to 33 Ma the area was dominantly a fluvial–lacustrine environment, and that subsequently an aridification trend commenced, as indicated by the appearance of aeolian sediment. This change coincided with, and is thus explained as the environmental response to global cooling. A significant increase in aeolian sediments occurred at ~26 Ma, suggesting that a large scale arid environment had formed in the Asian interior since the late Oligocene. Stepwise increases of aeolian sediment, and decreases in sediments of hydraulic origin, occurred at ~22, ~14, ~8 and 2.6 Ma and represent important stages in the aridification process. This long-term trend was interrupted by intervals dominated by fluvial sedimentation at 23.6–22 Ma and 17.1–14.1 Ma and which were probably associated with warming of the global climate and the tectonic uplift of the northeastern Tibetan Plateau. Tectonic events occurring in Lanzhou at ~9–8 Ma and ~3.5 Ma indicate strong uplift of the northeastern Tibetan Plateau.

1. Introduction

The aridification of the Asian interior is one of the most significant global environmental changes during the Cenozoic era, and may be closely related to the uplift of the Tibetan Plateau (Kutzbach et al., 1989; Ruddiman and Kutzbach, 1989; Manabe and Broccoli, 1990; An et al., 2001; Miao et al., 2012; Li et al., 2014a), the ongoing global cooling (Liu and Ding, 1993; Guo et al., 1998; Dupont-Nivet et al., 2007; Jiang and Ding, 2008; Lu et al., 2010) and the retreat of the Tethys Sea (Ramstein et al., 1997; Zhang et al., 2007). The aeolian loess deposits of the Chinese Loess Plateau preserve a valuable record of this process of aridification (Liu, 1985; Rea et al., 1998; An et al., 2001; Guo et al., 2002; Sun et al., 2008). Research has shown that aeolian accumulation on the eastern and central Loess Plateau began approximately 7–8 Ma ago (Ding et al., 1998; Sun et al., 1998a,b; Qiang et al., 2001; Zhu et al., 2008; Fig. 1), possibly corresponding to the onset of a new phase of the aridification of the Asian interior. In the western Loess Plateau, the Red Clay sequences obtained from Xining, Qinan and Zhuanglang have basal ages of 14 Ma (Lu et al., 2004), 22 Ma (Guo et al., 2002) and 25 Ma (Qiang et al., 2011), respectively, suggesting that the dry environment of the Asian interior was formed not later than the late Oligocene (Guo et al., 2008; Qiang et al., 2011). However, the Cenozoic sedimentary record of the North Pacific (Rea et al., 1985) indicates that an aeolian component was present throughout the entire Cenozoic, and several stages of increased aeolian content are evident therein. Consequently, reconstructing the aeolian history of the entire Cenozoic in the Chinese Loess Plateau and its adjacent regions is an important scientific issue.

Located on the western margin of the Loess Plateau, Lanzhou is a key area connecting the Northwest China deserts and the main Loess Plateau (Fig. 1A). Previous work indicated that a ~320 m-thick loess–paleosol sequence had developed in this area in the last 1.4 Ma (Burbank and Li, 1985; Chen et al., 1989). The latest paleomagnetic and paleoenvironmental results show that a continuous aeolian Red Clay and fluvial–lacustrine sedimentary sequence with a thickness of ~360 m had developed in Lanzhou during the time interval of 8.3–

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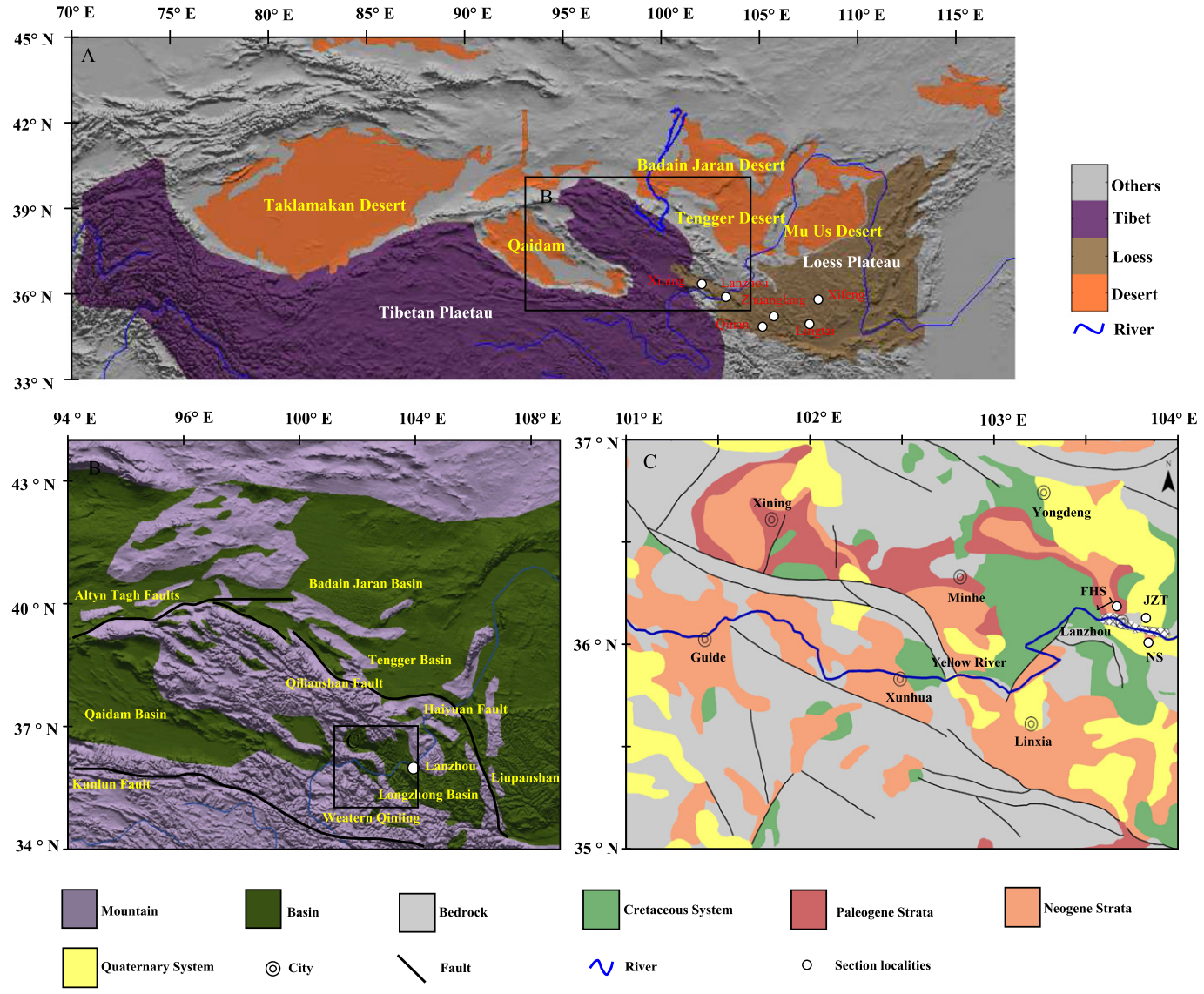

Fig. 1. (A) Aeolian sediment distribution in northern China (modified from Sun et al., 2011). (B) The structural setting and the Tertiary basin distribution of the northeastern Tibetan Plateau and its surroundings (modified from Sun et al., 2011). (C) Geological map of the Longzhong basin and the section locations. The studied sections include FHS—Fenghuangshan section, NS—Nanshan section and JZT—Jiuzhoutai section.

3.5 Ma, and that continuous aeolian accumulation began at 7.2 Ma (Sun et al., 2011). These findings are consistent with those of the main Loess Plateau, but the ages are much younger than those of other sites in the western Loess Plateau (Guo et al., 2002; Qiang et al., 2011). Early magnetostratigraphic studies of the Tertiary strata in Lanzhou were carried out (Flynn et al., 1999; Qiu et al., 2001; Yue et al., 2001) mainly to date the fossil mammal assemblages contained therein. However, the aeolian history and the nature of the sedimentary environments in this region prior to the late Miocene are poorly understood due to the lack of high-resolution chronological data and to limitations of the methods used for identifying aeolian components within the Tertiary strata. Thus reevaluating the aeolian history in the Lanzhou area may help us to understand the distribution pattern of aeolian sedimentation from west to east across the Loess Plateau and thus the process of aridification of the Asian interior.

From a tectonic standpoint, Lanzhou is situated at the northeastern edge of the Tibetan Plateau. The thick Cenozoic sedimentary sequence provides critical evidence for the tectonic history of the northeastern part of the Tibetan Plateau. A great deal of research has addressed various aspects of this topic (Fig. 1B) (Lu et al., 2004; Dai et al., 2006; Sun et al., 2005; Zheng et al., 2006; Lu and Xiong, 2009; Xiao et al., 2012; Li et al., 2014a,b). However, the various publications disagree about the tectonic history of this area, possibly due to differences both in the reliability of the dating methods and in the methods used for paleoenvironmental reconstruction. In the present study, a combination of magnetostratigraphy and measurements of various environmental proxies was applied to a sedimentary sequence from the Lanzhou Tertiary basin in order to provide new evidence for constraining the timing of aeolian accumulation in the western Loess Plateau, and thereby to improve our understanding of the evolution of the process of aridification of the Asian interior and the uplift history of the northeastern Tibetan Plateau during the Cenozoic.

2. Stratigraphy and methods

2.1. Strata and sampling

The Longzhong basin is one of Tertiary sedimentary basins surrounding the northeastern margin of the Tibetan Plateau. It is divided into the Lanzhou sub-basin in the middle, the Longxi–Jingning sub-