Global and Planetary Change 76 (2011) 106–116

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Magnetostratigraphy and palaeoenvironmental records for a Late Cenozoic sedimentary sequence from Lanzhou, Northeastern margin of the Tibetan Plateau

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ARTICLE INFO

Article history:
Received 8 July 2010
Accepted 15 December 2010
Available online 23 December 2010

Keywords:
paleomagnetism
aeolian sediments
Tibetan Plateau uplift

ABSTRACT

Geological studies indicate that several Tertiary fluvial–lacustrine basins existed in northwestern China. Progressive uplift of the Tibetan Plateau forced these Tertiary basins to dry, and eventually became accumulation areas for aeolian sediments. Continuous sedimentary sequences consisting of alluvial–fluvial sediments and aeolian Red Clay occurred in the Lanzhou area. We used palaeomagnetic and palaeoenvironmental techniques to investigate a late Tertiary section that has a Quaternary loess cover. Our results indicate that the area was a low altitude basin with a fluvial–lacustrine environment before ~7.2 Ma. Starting from ~7.2 Ma, the basin became a dry land and was exposed to aeolian accumulation. The presences of unconformities and sedimentary facies changes suggest that strong tectonic activity occurred during the interval of 3.5–1.8 Ma, which forced the Lanzhou Tertiary Basin to break up and became elevated to its present altitude. Gradual variations in sediment colour, grain-size and magnetic susceptibility imply that the Lanzhou area experienced progressive cooling and drying in the Late Cenozoic due to local tectonic uplift and global cooling.

1. Introduction

During the Cenozoic era, uplift of the Tibetan Plateau and the associated drying of the Asian continental interior have controlled the palaeoclimatic and palaeoenvironmental evolution of northwestern China. On Chinese Loess Plateau, Tibetan Plateau uplift has greatly affected aeolian accumulation and precipitation through its effects on aridity, atmospheric circulation and monsoon strength (Ye and Gao, 1979; Ruddiman and Kutzbach, 1989; Manabe and Broccoli, 1990; Harrison et al., 1992; Ramstein et al., 1997; Rea et al., 1998; An et al., 2001), which are recorded in the aeolian sequences of the Loess Plateau. Initiation of aeolian accumulation on the central Loess Plateau 7–8 Ma ago has been interpreted as the onset of aridity in the Asian interior (Ding et al., 1998; Sun et al., 1998a, 1998b; Qiang et al., 2001; Zhu et al., 2008). And aeolian accumulation might have initiated as early as 22 Ma in the western Loess Plateau (Guo et al., 2002). Located on the northwestern margin of the Loess Plateau, aeolian accumulation rates in the Lanzhou area are much higher than in eastern areas. Previous work indicated that 312 m of loess has accumulated in the last 1.4 Ma (Burbank and Li, 1985; Chen et al., 1989), which was deposited unconformably on Tertiary Red Clay strata. However, the aeolian history and sedimentary environments before 1.4 Ma are poorly understood due to a lack of reliable chronological and palaeoenvironmental results from the Tertiary strata. Tracing the aeolian history in the Lanzhou area may help us to understand the pattern of aeolian sedimentation from the east to the west of the Loess Plateau in the Late Cenozoic.

In the northern and northeastern areas of the Tibetan Plateau, uplift has directly controlled the drainage system and sedimentary basin distribution. Stratigraphic results demonstrate that sedimentary environments in northwestern China before the uplift were substantially different from those at present (Fig. 1). Tertiary fluvial–lascustrine sequences indicate that several large sedimentary basins existed in northwestern China, and the Lanzhou Tertiary Basin was one of them (Zhai and Cai, 1984) (Fig. 1B). Tibetan Plateau uplift forced these basins to break up and elevate to form the northeastern margin of the plateau. Reconstructing the history of these Tertiary basins may provide sedimentary evidence for uplift processes of the Tibetan Plateau.

In this research, palaeomagnetic and palaeoenvironmental techniques were applied to Late Tertiary strata below the Quaternary aeolian sequence at the Nanshan section (Fig. 1B) to develop a chronological frame work. Measurements of sediment grain-size, rock magnetism and colour reflectance of late Tertiary strata and Quaternary loess enabled development of detailed palaeomagnetic and palaeoenvironmental records of Late Cenozoic strata, which reveal the evolution of the area from fluvial and alluvial environments to dry land, and finally to an environment with aeolian sediment accumulation.

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0921-8181/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.gloplacha.2010.12.006

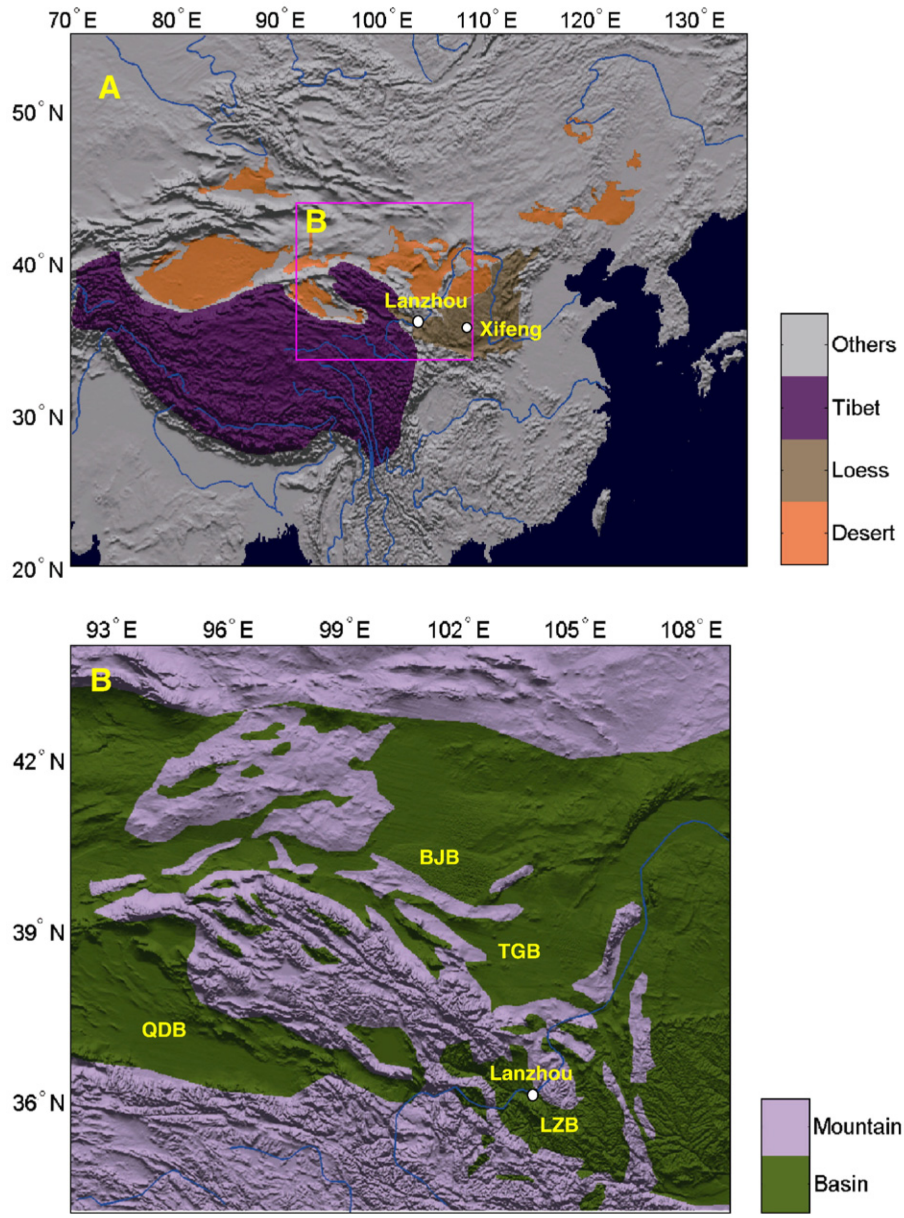

Fig. 1. Aeolian sediment distribution of China projected on a digital elevation model (A) and the Tertiary Basin distribution (B) modified from Zhai and Cai (1984). The main Tertiary basins include: LZB—Longzhong Basin, TGB—Tengger Basin, BJB—Badain Jaran Basin, QDB—Qaidam Basin.

2. Stratigraphy and methods

2.1. Strata and sampling

The Lanzhou Tertiary Basin belongs to part of the Longzhong Tertiary Basin system (Fig. 1B). Stratigraphic studies indicate that over 3000 m of sediment was deposited in the basin during the Tertiary, which has been divided to four formations based on sedimentary facies and fossils (Zhai and Cai, 1984) (Table 1). The oldest, Xiliugou formation, is a brick red massive sandstone with large-scale cross-bedding. The second oldest, Yehucheng formation, is mostly a reddish fluvial sandstone with clay and gravel layers. Abundant gypsum layers formed in the strata. The third, Xianshuihe formation, is a massive clay without obvious bedding that contains 7 gravel layers as markers within the strata. The uppermost, Linxia formation is composed of deep-red to red clay and sandstone, which was studied here.

At the Nanshan section, 2 km south of the Lanzhou railway station, the Linxia formation is exposed with a bedding attitude of declination 210° and inclination 18° (Fig. 2). It consists of four sedimentary sub-units: (1) a lower red sandstone with massive bedding (602–684 m), (2) a dark red mudstone that is interbedded with thin layers of sand (455–602 m), (3) a thick brownish yellow mudstone with thin greyish-white sand layers (322–450 m), and (4) a gravel layer named the Wuquan Gravel (312–322 m) (Young and Bien, 1936; Wu et al., 1988). The Linxia formation was overlain unconformably by an 8-m thick Yellow River terrace gravel that formed in the 1.8–1.4 Ma age interval (Li et al., 1996) and a 312-m thick Quaternary loess of which lowest age is palaeomagnetically dated at 1.4 Ma (Burbank and Li, 1985; Chen et al., 1989).

702 oriented sample blocks were collected from the 372-m thick late Tertiary strata of the Nanshan section at a ~0.5-m sample spacing, and 1180 powder samples were collected for measurements of colour reflectance, sediment grain-size and rock magnetism at a 0.3-m sample spacing from the same strata. 650 powder samples were collected from the 312-m Quaternary loess of the Jiuzhoutai section, 5 km northwest of the Nanshan section with a sample spacing of about 0.5-m for measurements of colour reflectance, sediment grain-size and rock magnetism.