



Magnetostratigraphic dating of the Shixia red sediments and implications for formation of Nihewan paleo-lake, North China

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ABSTRACT

The sedimentary sequence in Nihewan Basin, northern China, is rich in mammalian fossils and Paleolithic sites. Extensive magnetostratigraphic investigations have been carried out in the Nihewan sediments, but precise age control on the earliest Nihewan red sediments, which have a fluvio-lacustrine origin in the upper part and an eolian origin in the lower part, has remained unavailable. The formation process of Nihewan paleo-lake, therefore, remains unclear. Here we contribute to understanding the age of the early Nihewan reworked and eolian red clays by presenting detailed magnetostratigraphic and rock magnetic results from the Shixia section coupled with geochemical and petrographic analyses. Magnetostratigraphic correlation to the geomagnetic polarity timescale indicates that the Shixia sedimentary sequence recorded part of the Gilbert Chron with the onset of deposition of the Nihewan Formation occurring prior to the Gilbert-Gauss geomagnetic reversal at 3.6 Ma. With tectonic development of a graben basin, early red clay was deposited first in Nihewan Basin during the Early Pliocene before giving way to lacustrine environments in Nihewan paleo-lake. Geochemical and petrographic results indicate a wind-blown origin for the lower red clay deposits, which have been reworked and mixed with conglomerates produced by local tectonic activity to produce the basal Nihewan sediments. Later formation of carbonate nodules has given rise to the sediments that are now exposed in Nihewan Basin.

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1. Introduction

Nihewan Basin is famous for its numerous Paleolithic sites and mammalian faunas (Zhou et al., 1991; Wei, 1997; Xie, 2006; Xie et al., 2006; Zhu et al., 2003, 2004, 2007). This basin lies approximately 150 km west of Beijing, and is located in the transition zone

between the North China Plain and the Inner Mongolian Plateau (Fig. 1). It is a down-faulted basin filled with Pliocene to Holocene lacustrine, fluvial and wind-blown deposits (Wei, 1985; Zhou et al., 1991; Zhu et al., 2007; Deng et al., 2008). The fluvio-lacustrine sedimentary sequences have been named the Nihewan Beds (Barbour, 1924) or the Nihewan Formation (Yuan et al., 1996). During the past decades, detailed magnetostratigraphic dating has been conducted on the Nihewan Formation and associated Paleolithic sites and mammalian faunas (Zhu et al., 2001, 2003; 2004, 2007; Wang et al., 2004, 2005; 2008; Deng et al., 2006a, 2007; 2008; Li et al., 2008; Liu et al., 2010, 2012; 2016, 2017; Ao et al., 2013a; b; Yang et al., 2016; Chen and Tong, 2017). Many of the Paleolithic sites in this basin have been dated reliably by magnetic

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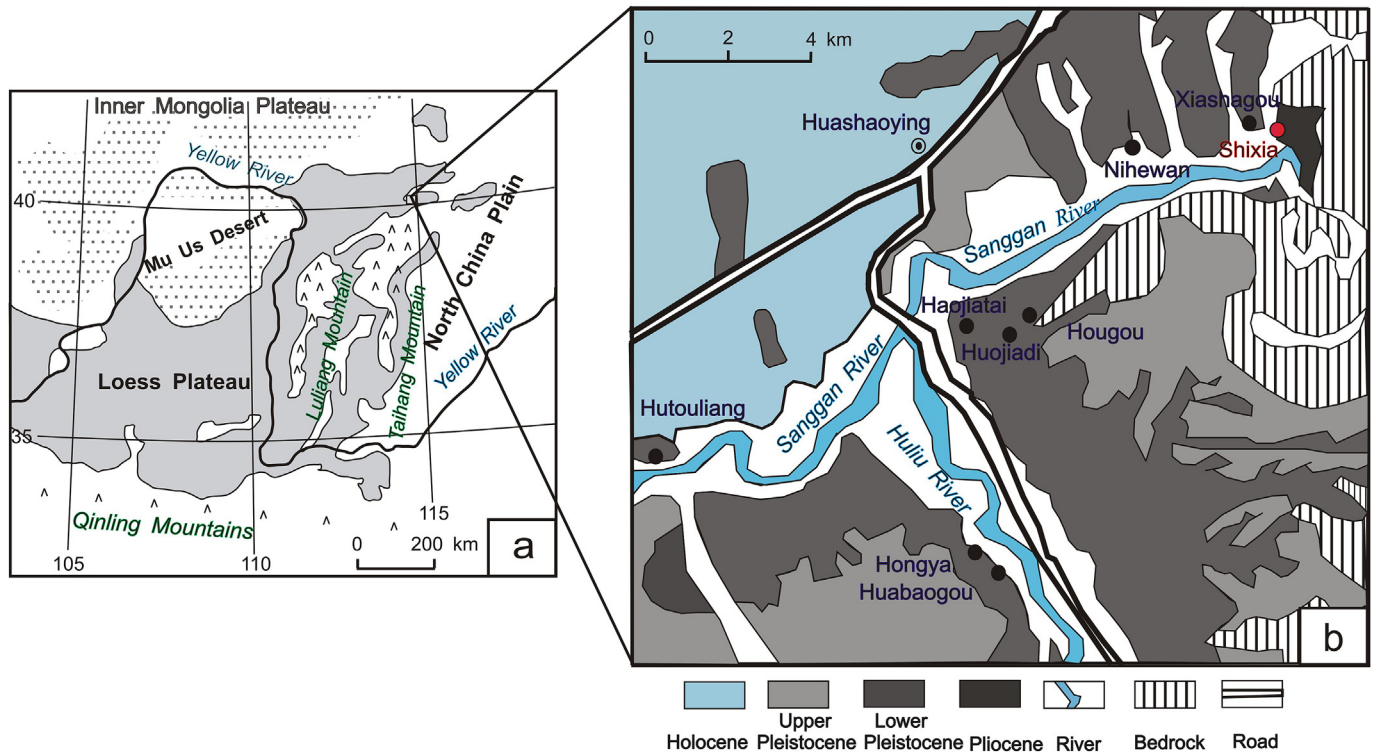


Fig. 1. Schematic map of (a) the Chinese Loess Plateau with the Yellow and Yangtze Rivers indicated, which are the major river systems in north and south China, respectively. (b) Nihewan Basin, with the location of the sections mentioned in the text, including the studied Shixia section (red circle) (modified from Guo et al., 2002; Min et al., 2015). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

polarity stratigraphy coupled with lithostratigraphy, biostratigraphy and rock magnetic stratigraphy. These sites include Xiaochangliang (Zhu et al., 2001), Majuangou and Banshan (Zhu et al., 2004), Donggutuo (Li and Wang, 1982; Wang et al., 2005), Maliang (Wang et al., 2005), Dachangliang (or Xiantai) (Deng et al., 2006a), Cenjiawan (Wang et al., 2006), Feiliang (Deng et al., 2007) and Huojiadi (Liu et al., 2010). The Nihewan Fauna (*sensu lato*) comprises a series of mammalian faunas from Nihewan Basin, such as the Donggutuo (Li and Wang, 1982; Wei, 1985, 1991; Wang et al., 2005), Maliang (Wei, 1991; Wang et al., 2005), Xiaochangliang (You et al., 1980; Tang et al., 1995; Zhu et al., 2001), Banshan (Wei, 1994; Zhu et al., 2004), Majuangou-I, Majuangou-II, Majuangou-III (Zhu et al., 2004), Hongya (Huang and Tang, 1974), Huabaogou-I (Wang, 1982), Huabaogou-II (Wang, 1982; Zhou et al., 1991), Yangshuizhan (Ao et al., 2013b; Liu et al., 2017), Shanshenmiaozui (Liu et al., 2016; Chen and Tong, 2017; Tong et al., 2017), Danangou (Li, 1984), Daodi-Dongyaozitou (Tang, 1980; Tang and Ji, 1983) and Xiashagou (Teilhard de Chardin and Piveteau, 1930; Liu et al., 2012, 2016) faunas, some of which have been well dated by comprehensive stratigraphic investigations.

Nihewan Basin has been called “the Chinese Olduvai Gorge” due to its abundant Paleolithic artifacts (Yuan et al., 2009). It is located at the northeastern end of the Fen-Wei graben. The sediments of Nihewan paleo-lake provide information about the environment and living conditions for early humans. The basin consists of reworked red clay at the Xiashagou, Hongya and Huabaogou sections (see locations in Fig. 1b), which contain the oldest sediments in the basin. The eolian red clay in Nihewan Basin looks like the similar red clay deposits on the Chinese Loess Plateau (Ding et al., 1998). The oldest Nihewan sediments at Xiashagou were deposited just prior to the Gauss-Matuyama geomagnetic reversal at 2.58 Ma, which corresponds to the Plio-Pleistocene boundary (Liu et al.,

2012, 2016). The age of termination of the Nihewan Formation is as a result of Nihewan paleo-lake drying. It is important to get the exactly age of initiation of the Nihewan paleolake and its environmental change and the precise location of the Pliocene-Pleistocene boundary. Here we contribute to understanding the age of the earliest Nihewan deposits by presenting a detailed magnetostratigraphic and rock magnetic investigation from the Shixia section, coupled with geochemical and petrographic analyses, in order to date the poorly understood formation of Nihewan paleo-lake.

2. Geological setting and sampling

The Shixia section ($40^{\circ}15'48.48''N$, $114^{\circ}43'29.34''E$) is located on the eastern margin of Nihewan Basin, about 1 km southeast of the well-known Xiashagou mammalian fossil sites (Fig. 1b). The underlying reworked red clay at the bottom of the Xiashagou section also occurs in the upper part of the studied Shixia section, which represents the base of the Nihewan Formation. Nihewan Basin is drained by the Sanggan River and a major tributary, Huli River, which flows out of this basin at Shixia. Here the red sediments have a thickness of 53.8 m, and are divided into two parts. The upper part consists of reworked fluvio-lacustrine red sandy silts intercalated with fine-grained sands and several conglomerate layers, which are the same as those deposited at the Huabaogou and Hongya sections. The lower part comprises red clay that is similar in appearance to those exposed on the Chinese Loess Plateau, and contains intercalated calcareous layers. The stratigraphic boundary between the two parts is located at 27.6 m in the Shixia section. Carbonate nodules have also formed in the lower sediments. The underlying eolian red clay was deposited in Nihewan Basin during the Early Pliocene, prior to initiation of Nihewan paleo-lake. The Pliocene red

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