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Variations in the provenance of the late Neogene Red Clay deposits in northern China

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ABSTRACT

The voluminous loess-Red Clay deposits in northern China forming part of the Chinese Loess Plateau (CLP) are valuable terrestrial archives of climatic evolution for the late Cenozoic Era. Fundamental in reconstructing the late Miocene and Pliocene wind patterns and aridification history is a detailed knowledge of the provenance of these deposits. This paper provides end member modelling of bulk grain-size distributions and U–Pb dating of detrital zircons for three distant Red Clay sequences in the northeastern (Baode), southern (Lantian) and western (Dongwan) CLP. Data show that these different sections each display a distinctive compositional structure indicating variable depositional processes, but they also share two significant zircon age populations of 200–300 Ma and 400–500 Ma. While the Permian–Triassic (200–300 Ma) group accounts for a larger proportion of zircons' ages in the northeastern (NE) CLP, the Ordovician–Silurian (400–500 Ma) component is dominant in the southern and western CLP. It is suggested that the Red Clay in the southern and western CLP was mainly derived from the Northern Tibetan Plateau (NTP) and the Taklimakan desert by low-level westerly winds. Samples of the NE CLP show an increased signature of sediments transported by near-surface northwesterly winds from the broad area of the Central Asian Orogen Belt (CAOB). This spatial transport and deposition pattern is supported by the results from the backtrace trajectory modelling of the dominant dust transport pathways in the CLP. It is noted that the Red Clay sample of around 3.6 Ma obtained from the NE CLP shows increased detrital contributions from its west, possibly indicating an intensified westerly wind strength and/or aridity of the NTP and Taklimakan desert due to the uplift of the Tibetan Plateau and Tianshan Mountains in the Pliocene. The onset of enhanced drainage of the Yellow River caused by the increased denudation of the NETP since 3.6 Ma could also have contributed to this.

1. Introduction

The late Neogene wind-blown sediments in the Chinese Loess Plateau (CLP) comprise two widespread units: the Miocene–Pliocene Red Clay deposits and the Quaternary loess-paleosol sequences. These terrestrial deposits preserve valuable information for the understanding of paleoclimatic change such as the central Asian aridification and Asian monsoon patterns during the late Cenozoic Era (An et al., 2001). The origin of the Red Clay deposits has been extensively investigated since the turn of the century and a wind-blown origin has been widely accepted (An et al., 2001; Ding et al., 1998; Guo et al., 2002; Lu et al., 2001; Sun et al., 1998). Although generally characterised by distinct reddish fine-grained deposits with cyclic carbonate nodule-rich horizons, the sediment texture, structures and colours, degree of pedogenic alteration, and carbonate characteristics vary among different sites (Flynn et al., 2011; Kaakinen et al., 2013). A fluvial imprint in the lower part of some Red Clay successions and occasional laminated beds indicate that not all of these sections exclusively reflect an eolian deposition (Guo et al., 2001; Zhang et al., 2013).

The deserts and arid lands to the north and west of the CLP have long been regarded as the dust source areas of the plateau (Fig. 1) (Liu, 1985; Sun, 2002; Wu et al., 2011a). However, de-

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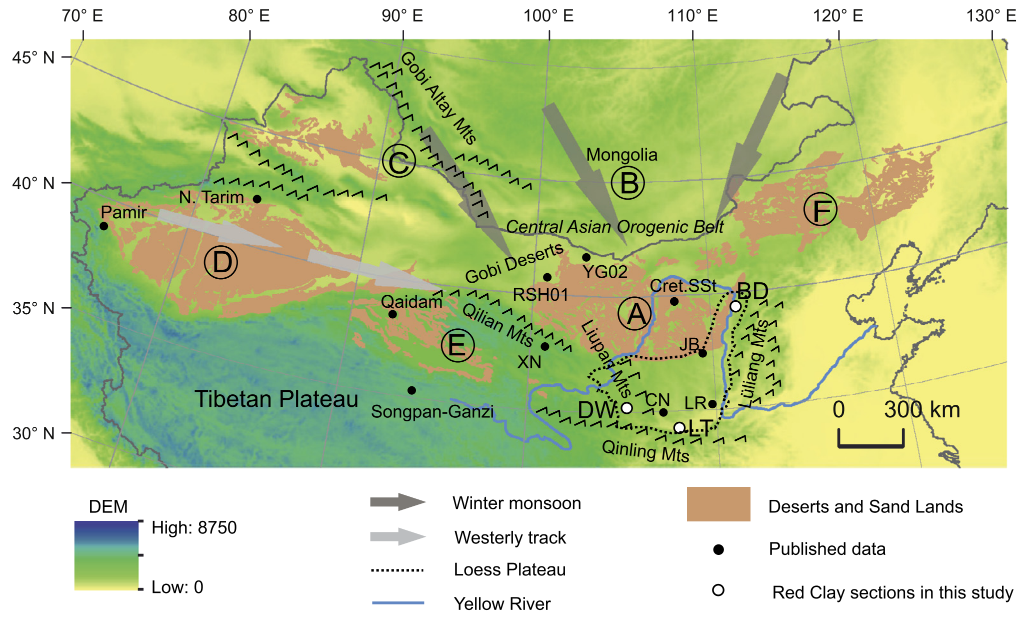

Fig. 1. Digital elevation model (DEM) map of northern China. A–F represent the potential source areas for the Chinese Loess Plateau (CLP): A – deserts located north and northwest to the CLP; B – southern Mongolia Gobi desert; C – Jungger Basin (Gurbantunggut desert); D – Tarim Basin (Taklimakan desert); E – Northern Tibetan Plateau (NTP), including Qaidam Basin and Qilian Mountains; F – sandy lands in the northeastern part of the CLP. A, B, C and F are within the widespread Central Asian Orogen Belt (CAOB) in northern China on the pathway of winter monsoon winds to the CLP. D and E represent the sources in western China. The white dots mark the examined Red Clay sections within this study (BD, Baode and Jingle Fm; DW, Dongwan; LT, Lantian). The black dots indicate the locations of published zircon samples: Red Clay, CN – Chaona (Nie et al., 2014); Loess, JB – Jingbian (Bird et al., 2015), XN – Xining (Che and Li, 2013); potential source areas: YG02 (GAMs – Gobi Altay Mts source) and RSH01 (mixed source of NTP and GAMs with NTP dominating) (Che and Li, 2013), N. Tarim – northern Tarim basin samples (Li and Peng, 2010), Pamir (Bershaw et al., 2012), Qaidam and Songpan-Ganzi complex samples (Pullen et al., 2011), Cret.SSt – Cretaceous Sandstone samples (Bird et al., 2015; Stevens et al., 2013), LR – Luo River (Diwu et al., 2012).

bate still exists over whether the eolian Red Clay was derived from the same source region; and whether it has been transported by westerly and/or by winter monsoon winds (Ding et al., 1998, 2001; Gong et al., 2015; Guo et al., 2004; Miao et al., 2004; Sun et al., 2008; Vandenberghe et al., 2004), just as it is disputed for the Quaternary loess (Chen et al., 2007; Chen and Li, 2013; Pullen et al., 2011; Sun, 2002). For example, Sun (2002) suggested that the deserts in northern China and the Gobi in southern Mongolia serve as a major dust source for the loess on the CLP whereas Chen and Li (2013) indicated that from 7 Ma to 1.2 Ma, the eolian sediments on the CLP had been constantly supplied by the arid lands between the Qilian mountains and the Gobi Altay Mountains (GAMs).

In recent years, the use of detrital zircon U–Pb geochronology has shed new light on the provenance of Quaternary loess and constrained its source areas to the Northern Tibetan Plateau (NTP), GAMs and proximal deserts (Bird et al., 2015; Che and Li, 2013; Pullen et al., 2011; Stevens et al., 2010, 2013; Xiao et al., 2012; Xie et al., 2012). Using zircon U–Pb ages, Bird et al. (2015) revealed marked spatial variability and multiple sources for the Quaternary loess: while the majority of the CLP loess originates from the northeastern Tibetan Plateau (NETP) and Yellow River (YR), the northeastern (NE) CLP receives a greater input from the northern deserts and North China Craton. Nie et al. (2015) addressed this question even further by using the extensive provenance dataset of both modern and paleo-river sediments. The findings enabled them to propose that since 3.6 Ma, substantial amounts of sediment eroded from the NETP were first carried by YR's upper reaches to the Yinchuan-Hetao Graben and from there transported by the winter monsoon winds to the Mu Us desert and eventually to the CLP. Little effort has hitherto been made to apply the single grain method to characterise the late Neogene Red Clay strata. Zircon U–Pb dating techniques have been hampered by the small number and size of suitable grains in these fine-grained sediments. A recent study by Nie et al. (2014) provided the first zircon U–Pb provenance data of the Chaona Red Clay sequence in the central CLP. Their results revealed that the late Miocene Red Clay (8–5.5 Ma) is likely sourced both from the Qaidam basin and transported by the fluvial system from the adjacent Liupan Mountains. In contrast, the early-mid Pliocene Red Clay (5.5–4 Ma) received material mainly from the Taklimakan desert, whereas the late Pliocene Red Clay (∼3 Ma) had multiple origins but was dominantly sourced from the NTP.

To provide a better insight in the spatial variation of the Red Clay provenance, we selected three well known Red Clay sequences distributed across the CLP (Fig. 1), namely: Baode in the northeast (Kaakinen et al., 2013; Kurtén, 1952; Zdansky, 1923; Zhu et al., 2008), Lantian in the south (Kaakinen and Lunkka, 2003; Liu et al., 1960; Zhang et al., 1978) and Dongwan in the west (Hao and Guo, 2004; Li et al., 2014; Liu et al., 2011). We employed an end member modelling approach to the grain-size distribution datasets to characterise sediment subpopulations and their relative contributions within the three sections (cf. Prins et al., 2007) to better understand the transport and (post-) depositional processes that affect the various components. Subsequently, we applied zircon U–Pb age dating and backtrace air trajectory modelling to further explore the potential sediment sources of Red Clay as well as the prevailing wind patterns over the CLP in the late Miocene and Pliocene.

2. Material and methods

2.1. Red Clay sections

The Liupan Mountains divide the CLP into western and eastern parts (Fig. 1). Most of the Red Clay sequences on the eastern part are younger than 11 Ma (Xu et al., 2009), while those on the western part have a basal age of 22–25 Ma (Guo et al., 2002; Qiang et al., 2011). These eolian deposits on the western CLP bear a close resemblance to the Quaternary loess and paleosol units and therefore are also referred to as Miocene loess-paleosol deposits (Guo et al., 2002; Hao and Guo, 2004) to differentiate them from