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Quaternary paleoenvironmental evolution of the Tengger Desert and its implications for the provenance of the loess of the Chinese Loess Plateau

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ABSTRACT

The dust sources of the loess deposits of the Chinese Loess Plateau (CLP) are suggested to be the Gobi-deserts in north China and the Tibetan Plateau in southwest China. The Tengger Desert (TD), a major desert situated to the northeast of the Tibetan Plateau and to the northwest of the CLP, on the western margin of the present-day Asian Summer Monsoon domain, is an ideal area for assessing which of these potential dust source areas may be dominant. A 104-m-long drill core (BJ14) was obtained from the northwestern TD. The magnetostratigraphy, constrained by electron spin resonance dating in the upper part of the core, includes the Brunhes, Matuyama and beginning of the Gauss polarity chrons, with their boundaries at the depths of 44.57 m and 94.31 m, respectively. Sedimentary facies analysis based on lithological, grain-size, magnetic susceptibility and micropaleontological evidences indicates that the core is primarily composed of lacustrine deposits. Combined with the results of previous studies in the eastern TD and the adjacent regions, the sedimentary sequence of core BJ14 indicates that lakes occupied the northern and eastern TD during most of the early Pleistocene and that the onset of a desert environment occurred at ~0.9 Ma. Our results suggest that the TD may have contributed only a limited amount of dust to the CLP during the early Pleistocene.

1. Introduction

Knowledge of the provenance of the loess deposits of the Chinese Loess Plateau (CLP) is crucial for understanding the wind circulation patterns in East Asia (Liu and Ding, 1998), the aridification of the Asian interior (Guo et al., 2002), and the uplift history of the Tibetan Plateau (Fig. 1a) (Li, 1991). However, the provenance of the CLP is still debated. Based on the results of various tracing methods, the Gobi-deserts in north China and south Mongolia (e.g., Lu et al., 1976; Liu, 1965; Sun et al., 2008b), the piedmont of the Tibetan Plateau (Honda et al., 2004; Sun and Zhu, 2010) and fluvial deposits from the middle reaches of the Yellow River (Stevens et al., 2013; Che and Li, 2013; Nie et al., 2015; Bird et al., 2015; Licht et al., 2016; Zheng, 2016), have all been suggested as potential source areas. In early research, variations in grain-size distributions, the shape of quartz grains, and clay mineral assemblages, were used to conclude that the Gobi-deserts and the Quaternary glaciers in northwestern China were the provenance areas of the loess of the CLP (Lu et al., 1976; Liu, 1965). This conclusion was later supported by climate simulations and observations of modern dust (Zhang et al., 2003; Zhang, 2007; Shi and Liu, 2011; Amit et al., 2014). Similarly, by using electron spin resonance (ESR) signal intensity, crystallinity and the $\delta^{18}O$ values of fine-grained quartz, the Taklimakan Desert, Mongolian Gobi, and Chinese inland deserts were further suggested to be the major source areas of loess in the CLP (Sun et al., 2008b; Yan et al., 2014). Some studies have proposed that some components of the loess of the CLP were recycled from older glacial loess (Licht et al., 2016) or Miocene-Pleistocene age fluvial, marginal lacustrine and lacustrine sedimentary rocks in the Qaidam Basin (Pullen

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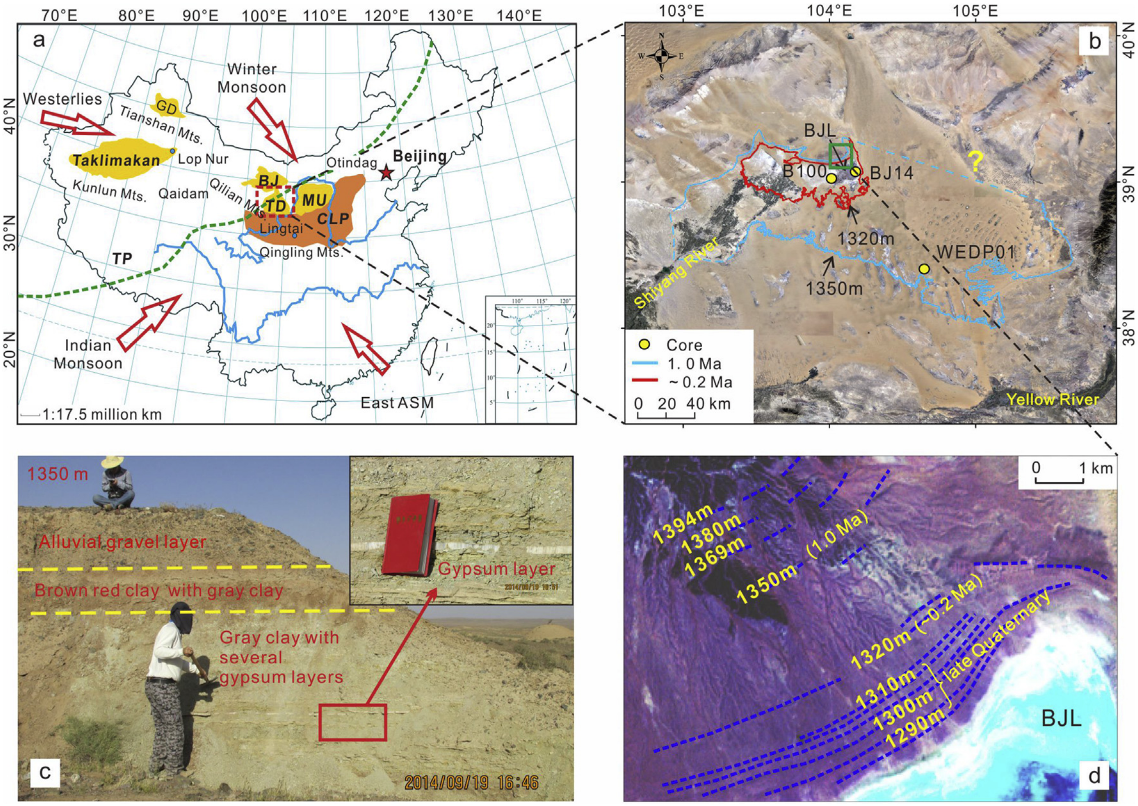

Fig. 1. (a) Geographic location of the study region in China and trajectories of the major atmospheric circulation systems. TD—Tengger Desert; BJ—Badain Jaran Desert; MU—Mu Us Desert; TP—Tibetan Plateau; CLP—Chinese Loess Plateau; GD—Gurbantunggut Desert; ASM—Asian Summer Monsoon; BJL—Baijian Lake. (b) Geographical setting of the study area (after Google Earth), location of cores, and the inferred lake area at 1.0 Ma and at ~0.2 Ma; contours are based on a digital elevation model (DEM) data from the USGS (http://glovis.usgs.gov/), and the locations of cores WEDP01 and B100 are referenced from Li et al. (2014b) and Pachur et al. (1995), respectively. (c) Shoreline features at ~1350 m a.s.l. on the northwestern margin of the Baijian Lake. (d) Shorelines distributed on the northwestern margin of the Baijian Lake (Xie and Wang, 2006; Liu, 2015) and their ages (after Pachur et al., 1995; Zhang et al., 2004; Long et al., 2012; Liu, 2015).

et al., 2011). The provenance areas of loess were also thought to be the Gobi in southern Mongolia and the deserts in north China, while deserts in three inland basins, Qaidam, Tarim and Junggar, were not considered important (Sun, 2002; 2004; 2005). In addition, it was proposed that since 2.6 Ma the role of these Gobi areas and deserts was solely as storage reservoirs of dust derived mainly from high mountain areas dominated by felsic rocks, as indicated by trace element compositions and variations in Pb isotopes (Sun and Zhu, 2010). Basing on U-Pb dating of detrital zircons, most recent studies have proposed that the loess originated from the Yinchuan–Hetao alluvial platform, southern Tengger and the Mu Us deserts, to which large quantities of sediment were transported from the northeastern Tibetan Plateau by the Yellow River (Stevens et al., 2013; Che and Li, 2013; Nie et al., 2015; Bird et al., 2015; Licht et al., 2016; Zhang et al., 2016).

It is important to note that although these previous studies of the provenance of the CLP dust were based mainly on geochemical tracing, which has the advantage of indicating the original provenance rather than the indirect source/temporary reservoirs, less attention has been paid to the paleoenvironmental status of the potential source regions where direct evidence of their role as a source may be preserved. For example, the Qaidam Basin was proposed as one of the dust source areas of the CLP by comparison of detrital zircon U-Pb age patterns (e.g., Pullen et al., 2011; Licht et al., 2016); however, this idea conflicts with the evidence of major differences in the dolomite characteristics of the loess of the CLP and the sediments of the Qaidam Basin (Li et al., 2007).

The Tengger Desert (TD) is one of the largest deserts located close to (~100 km) and upwind of the CLP and has long been regarded as one of the potential major source regions of the CLP (e.g., Sun et al., 2008b; Yan et al., 2014; Zhang et al., 2016). In addition, the lithology and grain-size analysis of core WEDP01, drilled in the southeastern part of the TD, indicates that the initial desert environment was initiated at ~0.9 Ma and expanded since 0.68 Ma (Li et al., 2014b), which is much younger than the age of the loess of the CLP, 2.6 Ma (e.g., Sun et al., 2006; Ding et al., 2002). Therefore, to evaluate the contribution of dust from proximal deserts to the CLP, the paleoenvironment of the Tengger, the closest major desert to the CLP, needs to be comprehensively reconstructed from direct evidence. Here, we present the results of paleomagnetic dating, ESR dating, and a paleoenvironmental reconstruction, of drill core BJ14 from the northwestern TD. Combined with geomorphic evidence and the results of previous research (Li et al., 2014b), we attempt to reconstruct the paleoenvironment of the Tengger area and to address its potential role as a source area of the dust deposited in the CLP.

2. Geographical setting and sampling

2.1. Geographical setting

The TD, one of the major proximal deserts upwind to the CLP, is in a wind eroded depression (Wang and Dou, 1998) to the northeastern Tibetan Plateau and on the western margin of the modern Asian Summer Monsoon domain in north China (Fig. 1a). The desert is bounded by the Yabrai Mountains to the west, the Qilian