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Long-term Pleistocene aridification and possible linkage to high-latitude forcing: New evidence from grain size and magnetic susceptibility proxies from loess-paleosol record in northeastern China

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ABSTRACT

Loess deposits are regarded as good indicators of the inception and development of arid and semi-arid climate in central Asia and northern China during the late Cenozoic. In northeastern China extensive loess deposits are found surrounding the Horqin and Otindag sand fields, and they have great potential for reconstructing the long-term aridification history of the region. However, these loess deposits are currently poorly understood. Here, we present a high-resolution magnetic susceptibility (MS) and grain-size record spanning the last 1.0 Ma from a 36.6-m-thick loess-paleosol sequence at Niuyangzigou site (NYZG) in NE China. The grain-size record reveals a long-term drying trend in NE China since ca. 1.0 Ma, punctuated by two significant abrupt drying events at ~0.65 Ma and ~0.3 Ma. These results demonstrate a process of stepwise intensification of drying in NE China over the past 1 Ma, and lend support to the hypothesis that global ice volume/temperature changes were the major driver of the long-term aridification of Asian dust source areas. However, unlike the widely studied loess deposits on the central Chinese Loess Plateau (CLP), the MS record in paleosol units S1, S2 and S4 from the NYZG site do not show evidence of enhanced monsoon precipitation resulting from decreased global ice volume and the prolonged episodes of interglaciation after the Mid-Pleistocene Transition evident in the ice volume record. We hypothesize that this may be due to differences in the climatic sensitivity of the MS of Chinese loess deposits on a regional scale, rather than to in regional differences in monsoon intensity.

1. Introduction

The extensive Gobi and sandy deserts in the continental Asian interior have long been considered as major candidates for the main provenance of eolian dust in northern China (e.g. Liu, 1985; Ding et al., 2005; Guo et al., 2002b; Nugteren and Vandenberghe, 2004; Zhang et al., 2016). The loess of the Chinese Loess Plateau (CLP) is the best-known example of this quasi-accumulating dust archive (Lu et al., 2004, 2006), preserving a record of the influence of both the arid and semiarid climates of the northwest as well as the humid summer monsoon climate in the southeast (Fig. 1a). A range of climate proxies, such as the grain size and accumulation rate of loess deposits on the CLP, have been interpreted as reflecting the progressive drying of the Asian interior during the late Cenozoic era (Lu and An, 1998; Lu et al., 2010; Ding et al., 2005).

In addition to the extensively studied deposits of the CLP, loess deposits in Northeastern (NE) China are also widely distributed, especially in eastern Inner Mongolia, downwind of the Horqin and Otindag sandy deserts (Fig. 2a). These semi-stabilized and stabilized sandy deserts mark the transition zone between loess and shifting sandy desert/Gobi, which is equivalent to the current northern margin of the East Asian Summer monsoon (EASM). This semi-arid zone is geographically close to the densely populated plains in eastern China, where desertification and dust storms have become a serious environmental problem affecting the human livelihood and health (Wang et al., 2008). Thus, research into the drying process and forcing mechanisms in this region are of relevance from both paleoclimatic and human welfare perspectives.

Provenance studies using both using Nd-Sr isotopic composition (Chen and Li, 2011; Zhao et al., 2014) and detrital zircon U-Pb age analyses (Xie et al., 2012) have demonstrated that the major source areas of the loess deposits in NE China are likely to be the upwind Horqin and Otindag sandy deserts. Therefore, the loess and adjacent sandy deserts

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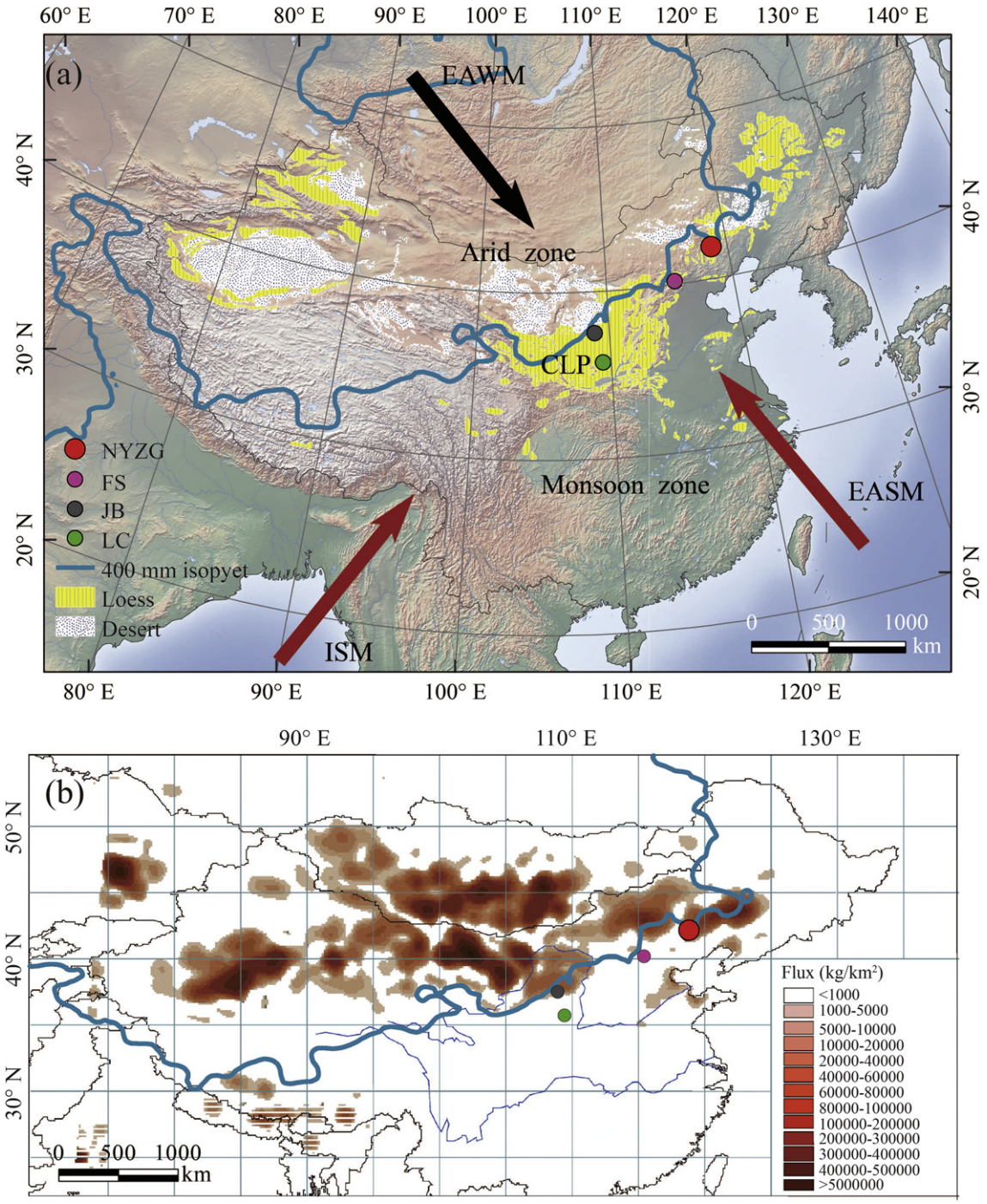

Fig. 1. (a) Distribution of deserts and loess in China and the locations of the Niuyangzigou (NYZG), Fanshan (FS), Jingbian (JB), Luochuan (LC) loess sections, shown on the shaded relief map. (b) Simulated springtime dust emissions flux between 1960 and 2002, indicating the primary Asian dust sources (revised from Zhang et al. (2003)). The bold blue line is the modern 400 mm annual average isohyet, representing the approximate boundary of the arid zone and East Asian monsoon zone. EASM: East Asian summer monsoon; EAWM: East Asian winter monsoon; ISM: Indian summer monsoon; CLP: Chinese Loess Plateau.

in NE China can be regarded as a coupled system, with dust source and sink formed under a semi-arid climate, which is quite distinct from the loess deposits of the CLP and their corresponding sources areas in northwestern and central China. Thus, the loess deposits in this area should have great potential for revealing the development and variability of aridity and dust emission in NE China.

There has been considerable research on the origin and aridity history of the sandy deserts in the northwest and central China (Guo et al., 2008; Lu and Guo, 2014). For example, the Taklimakan Desert was recently dated back to the Late Oligocene-early Miocene based on loess deposits preserved in the Cenozoic strata along the margin of the Tarim Basin (Zheng et al., 2015), although this result is still in debate (Sun et al., 2015). In addition, work on the Red Earth formation in the western CLP has revealed that desertification of the Asian interior was initiated at least by the late Oligocene (Guo et al., 2002b, 2008; Qiang et al., 2011); and work on the loess-paleosol sequence in the northern part of CLP has documented the stepwise expansion of the Mu Us Desert in the past 3.5 Ma (Ding et al., 2005). However, at the easternmost