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Vegetation and climate changes in the western Chinese Loess Plateau since the Last Glacial Maximum

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A B S T R A C T

Pollen analysis was conducted for loess deposits from three sites in the western Chinese Loess Plateau, i.e. the loess area west of the Liupan Mountains. Results show that during the Last Glacial Maximum (LGM), in-situ vegetation was dominated by *Artemisia* and some drought–tolerant species such as *Echinops*-type, Chenopodiaceae, *Nitraria*, and *Ephedra*, while coniferous forest (mainly *Picea*) flourished in nearby river valleys. During the Holocene Optimum, *Picea* almost disappeared, and *Echinops*-type, Chenopodiaceae, *Nitraria* and *Ephedra* decreased; vegetation was characterized by *Artemisia*, *Taraxacum*-type, Polygonaceae and Leguminosae, implying the climate was warmer and wetter than during the LGM. During the late Holocene, Chenopodiaceae, indicator of human–managed habitats, increased in the study area, indicating enhanced human activity.

The climate was warmer and more humid in the loess areas east of the Liupan Mountains than in the west during both the LGM and Holocene Optimum. Likewise, a significant difference in specific plant types was observed between the east and west since the LGM. During the LGM, *Pinus* and some broadleaf trees emerged, but no *Picea* forest grew, while in the west, vegetation was characterized by desert shrub and desert steppe in situ, and by dark coniferous forests (mainly *Picea*) in nearby river valleys. During the Holocene Optimum, treeline advanced upward as a result of increased temperature. *Picea* thus withdrew from the western loess areas. Therefore, temperature is the major factor controlling the growth of *Picea* in the Chinese Loess Plateau.

1. Introduction

Over the last 20,000 years, the Earth has experienced a cold extreme (the Last Glacial Maximum: LGM) and a warm period (the Holocene Optimum). Ecological responses to these climatic extremes are useful in facilitating our understanding for climate changes and mechanisms. The Chinese Loess Plateau, characterized by an arid and semi–arid climate, is sensitive to climate changes (Chen et al., 1997; Ding et al., 1999; An, 2000). Therefore, knowledge of natural vegetation during typical cold and warm periods in the Loess Plateau, can not only help us to understand past climate and environmental changes, but also to forecast future trends of climate change and to provide a good reference for ecological management (Jiang et al., 2013).

Vegetation on the Loess Plateau is a long–debated topic. Some researchers insisted that forests developed on the Loess Plateau based on the historical documents (Shi, 1991). However, according to studies of phytoliths (Lü et al., 1999), organic carbon isotope (Liu et al., 2005) and pollen (Ke et al., 1992; Liu et al., 1996; Sun et al., 1997, 1998; Li et al., 2003a; Jiang and Ding, 2005; Cheng and Jiang, 2011), the Loess Plateau was mainly dominated by steppe vegetation, and no dense forest was present. Recently, Jiang et al. (2013, 2014) carried on systemic vegetation studies along a north–south and an east–west transect and concluded that 1) in the Loess Plateau, most areas are covered by thick loess (>20 m) and dominated by steppe vegetation, because rainwater infiltrates quickly and moisture in the surface soil is insufficient to maintain forests; 2) trees can grow in areas of thin loess underlain by bedrocks (e.g. incipient floodplains, low river terraces and deep gullies), where the groundwater table is relatively high; 3) in rocky mountainous areas, bedrock itself can serve as a water–resistant layer which allows the surface soil to retain the rainwater, and forests thus can develop.

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To date, most pollen records on the Loess Plateau were derived from soil–loess sequences east of the Liupan Mountains. However, pollen records in loess area west of the Liupan Mountains were obtained from wetland–lacustrine–loess complex, which are all located in riparian zones of tributaries of the Yellow River (An et al., 2003; Feng et al., 2006; Sun et al., 2007; Tang and An, 2007; Wu et al., 2009). Pollen records from pure loess deposits are scarce. Therefore, two questions arise: (i) did steppe prevailed in the loess area west of the Liupan Mountains? and (ii) if so, were there any differences in specific plant types between the loess areas east and west of the Liupan Mountains?

In this study, we present pollen records from three loess sections in the western Loess Plateau (Fig. 1), with the objective of reconstructing vegetation and climate changes since the LGM and to compare spatial changes in specific plant types between the loess areas east and west of the Liupan Mountains.

2. Sites and stratigraphy

The study area is located in the western Loess Plateau, a loess area west of the Liupan Mountains (Fig. 1). It is characterized by arid and semi–arid climate, with precipitation mainly concentrated in summer. Typical modern vegetation is dry steppe and desert steppe (Editorial Committee of Vegetation Map of China, Chinese Academy of Sciences (2007)).

Three loess sections, located at Weiyuan, Huining, and Jingtai, were logged (Fig. 1). The Weiyuan section (35°08′N, 104°15′E, 2061 m a.s.l.) is situated on the terrace of the Weihe River. The Huining section (36°07′N, 104°52′E, 1911 m a.s.l.) is located on ‘Yuan’, a high table–land consisting of thick loess. The Jingtai section (37°06′N, 104°28′E, 1883 m a.s.l.), also on the ‘Yuan’, is located in the transitional zone between the Loess Plateau and the Tengger Desert. At present, the mean annual temperature and precipitation are 6.8 °C and 363 mm at Weiyuan, 8.3 °C and 332 mm at Huining, and 9.7 °C and 102 mm at Jingtai.

Fresh samples (~500 g each) were taken at 5–10 cm intervals. A total of 424 samples were collected. All sections consisted of soil unit S_0, loess unit L_{1-1} and the upper part of weakly developed soil L_{1-2}. Previous studies have shown that L_{1-2} was deposited in the late marine isotope state (MIS) 3 (~40–28 ka), L_{1-1} was deposited in the MIS 2 (~28–11 ka) which includes the LGM (~26.5–19 ka), and S_0 developed in the Holocene Optimum (~11–9–~3 ka) (Ding et al., 2002; Yang and Ding, 2004, 2014; Lu et al., 2007). For detailed stratigraphic information, please refer to Yang and Ding (2008, 2014).

3. Methods

Grain size was first measured for all samples using a SALD–3001 laser diffraction particle analyser. Ultrasonic pretreatment, with the addition of 20% $(NaPO_3)_6$ solution, was used to disperse the samples prior to particle size determination. The analytical procedures used were as detailed by Ding et al. (1999). Results showed that soil unit S_0 and the weakly developed soil L_{1-2} are consistently finer grained than loess unit L_{1-1} (Fig. 2). The correlation of the lithostratigraphy and grain size curves between sections indicates the continuity of the loess deposits.

A total of 68 samples were selected for pollen analysis (Fig. 2). Samples from the coarse–grained unit L_{1-1} represent deposition during a cold and dry glacial period, while those from the fine grained soil units (S_0 and L_{1-2}) represent deposition during relatively warm and humid interglacial intervals. Pollen grains were extracted using the heavy–liquid method (Li et al., 2006) and identified at ×400 magnification using a Nikon ECLIPSE 50i microscope. For each sample, ~150–300 pollen grains were counted (Figs. 3–5). Percentages of pollen, spores and algae were calculated relative to the sum of all land pollen counted. Pollen concentrations were calculated by adding *Lycopodium* spore tablets (Batch No. 483216) prior to chemical treatment (Berglund and Ralska-Jasiewiczowa, 1986). Pollen diagrams were drawn using the C2 program (Juggins, 2007; Wang et al., 2012).

4. Results

A total of 41 pollen types were identified in the three loess sections. The major pollen assemblages found in the loess and soil units in each loess section are detailed below.

4.1. Weiyuan section

L_{1-2}: Pollen concentration and types are low. Arboreal pollen (AP) (<5%) includes *Pinus*, *Betula* and Rhamnaceae (Fig. 3). Pollen of *Artemisia* (66%) and *Echinops*-type (21%) dominates the spectrum. Fern spores are low in abundance (~2%).

L_{1-1}: AP is as high as 18%, mainly derived from *Picea* (up to ~13%). Small amounts of *Pinus*, *Abies*, *Betula*, *Corylus*, *Carpinus*,

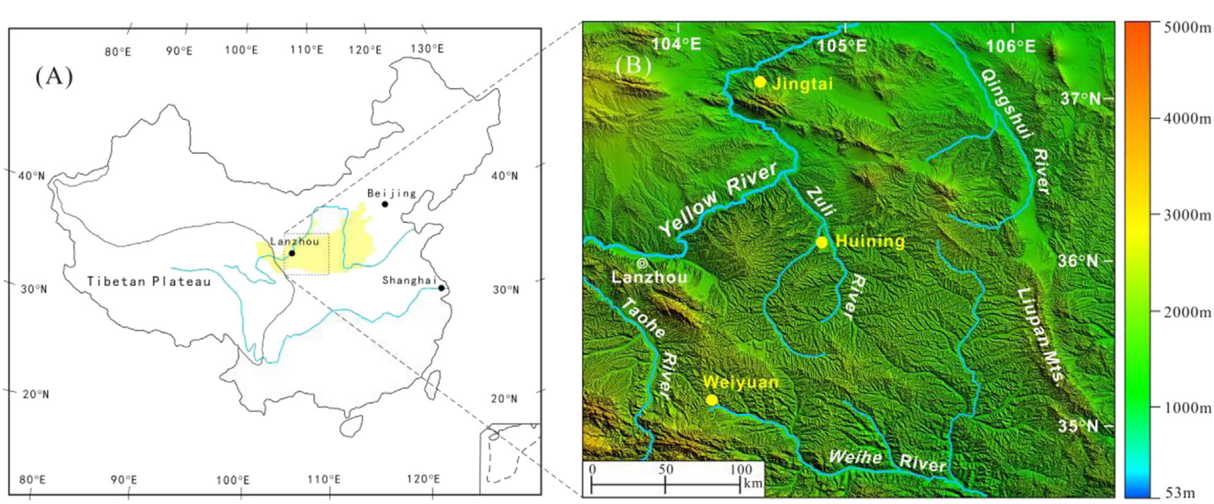

Fig. 1. Map showing location of the Loess Plateau (A) and the studied sites (circles) (B).

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