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Reconstruction of the vegetation distribution of different topographic units of the Chinese Loess Plateau during the Holocene

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ABSTRACT

Soil erosion and related ecological restoration present a tremendous challenge to the socioeconomic development of the Chinese Loess Plateau (CLP). Although the Chinese government has addressed the problem of soil erosion via an afforestation programme, there have been several negative outcomes. One of the reasons for this is our incomplete understanding of the past natural vegetation distribution in the various topographic units of the CLP under different climate scenarios. Consequently, we used fossil pollen data from 41 sites from different topographic units, together with the biomization method, to reconstruct the Holocene vegetation distribution of the CLP. The results demonstrate significant differences in vegetation types between different topographic units: forest was distributed in mountainous areas, steppe was dominant in Yuan areas, and desert vegetation was distributed in the transition zone between loess and desert. The vegetation in the gully areas exhibited significant spatial differences during the mid-Holocene. In addition, the vegetation on the various topographic units was well-developed during the interval from 9 to 4 ka B.P., when regional moisture levels reached a maximum. This suggests that the East Asian Summer Monsoon was one of the main factors controlling the evolution of vegetation patterns during the Holocene. In addition, our results confirm that both topography and human activity were fundamental factors determining the vegetation distribution of the region. Against a background of ongoing global warming, we advocate a program of vegetation restoration including planting trees and shrubs in the mountainous areas, and promoting the growth of grasses in the Yuan areas and in the transitional zone between loess and desert. In the gully areas, the planting of trees and shrubs is appropriate for reducing soil erosion caused by human activities.

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1. Introduction

The Chinese Loess Plateau (CLP), occupying an area of ~4.4 × 10^5 km^2 in north-central China, is a major archive of continental climatic change spanning at least the last 22 Ma (Guo et al., 2002; Liu, 1985). Increased soil erosion, low tree survival rate, severe water shortages and deep soil desiccation (Normile, 2007; Wang et al., 2007, 2009) present tremendous challenges to the continued socioeconomic development of this relatively impoverished region. A major reason for this is the lack of knowledge of the past natural vegetation distribution on the CLP. In addition, it is especially important to understand the spatiotemporal patterns of vegetation change during the most recent geological epoch, i.e., the Holocene (the past ~12,000 years), because projected global changes associated with ongoing climatic warming will occur under similar natural boundary conditions. In additional, the mid-Holocene was a more significant Megathermal (warm and wet interval) than the present (Feng et al., 2004; Kaufman et al., 2004; Marcott et al., 2013; Shi et al., 1992), and a more comprehensive understanding the vegetation distribution on the CLP during this interval may suggest strategies for promoting vegetation recovery in a warmer future (Intergovernmental Panel on Climate Change, 2013).

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The vegetation distribution on the CLP during the Holocene has been studied using various proxy records and archives (e.g., Guo et al., 1994; Jiang et al., 2013a; Li et al., 2003). However, the findings are controversial. For example, based on historical documents and archaeological materials, several researchers have suggested that relatively dense forest was present over a large area of the CLP prior to its destruction by human activity (He and Tang, 1999; Shi, 1981, 1991; Zhu, 1983, 1994). In contrast, others have argued that climatic conditions on the CLP since the last glacial were only suitable for grassland (e.g., Guo et al., 1994, 1998; Jiang and Ding, 2005; Li et al., 2003; Liu et al., 1996; Sun et al., 1997; Zhou et al., 2009). Recent studies have pointed out that the different topographic units should be considered when reconstructing the vegetation distribution of the CLP during the Holocene (e.g., Jiang and Ding, 2005; Jiang et al., 2013a, 2014; Lu et al., 2003; Shang and Li, 2010; Zhang and An, 1994). However, several uncertainties remain. For example, previous synthesis studies were based on a relatively small number of sites, many lacked reliable age control, and many of the sections were geographically located in the Yuan areas (one of the major topographic units in the CLP). Consequently, an increased number of reliable and well-dated proxy records are required to provide an improved understanding of the spatial distribution of the vegetation of the CLP during the Holocene.

Pollen analysis is an effective tool for reconstructing the vegetation and climate history of arid and semi-arid environments (Sun and Feng, 2013; Xiao et al., 2002; Zhao et al., 2011), including the CLP region (e.g., Jiang et al., 2013a; Li et al., 2003; Sun et al., 1997). In the present study, we used the quantitative biomization method to reconstruct Holocene vegetation of the CLP based on a synthesis of fossil pollen data. The aims of the study were: (1) to determine the vegetation types in different topographic units on the CLP during the Holocene, (2) to discuss the characteristics of the Holocene vegetation distribution and evolution in the various topographic units, (3) to determine the main factors controlling the Holocene vegetation distribution on the CLP, and (4) to provide a basis for determining the most appropriate strategies for promoting future vegetation recovery.

2. Regional setting

The main body of the CLP is located in the middle reaches of the Yellow River (Fig. 1a). The CLP can be divided into three parts by the Liupan Mountains and the Luliang Mountains: an eastern part (located east of the Luliang Mountains), a central part (located between the Liupan and Luliang Mountains), and a western part (located to the west of the Liupan Mountains). From the geomorphic units, the CLP is mainly divided into the following areas: mountains, loess "Yuan", loess hill, and valley plain. In additional, the characteristics of the boundary area between the CLP and the northern sandy land are different from the geomorphic units listed above. Here, combined with the terrain and material composition of the underlying surface, the geomorphic units are divided into four main types: (i) Mountainous areas (comprising bare bedrock or bedrock with a thin loess cover), (ii) Yuan areas (flat-topped loess highlands, covered with thick loess deposits), (iii) Gullies (one or two river terraces), and (iv) the transitional zone between loess and desert. Because of the interaction between the winter and summer monsoon, the modern climate of the CLP exhibits a distinct SE-NW gradient. Both mean annual temperature and precipitation decrease gradually from southeast (13 °C and 650 mm) to northwest (7 °C and 250 mm) (Wan et al., 2014), whereas the aridity (ratio of evaporation to precipitation) increases from southeast (1.0) to northwest (3.0).

The vegetation distribution closely follows the aridity gradient: broad-leaved deciduous forest occurs in the southeastern corner of the CLP, forest-steppe in the south-eastern part, steppe in the northwestern part, and desert-steppe in the northwestern corner (Zhang, 2007) (Fig. 1b). The tree species comprising the forest community mainly consist of *Pinus taulaefor*, *Quercus liaotungensis*, *Platycladus* sp., and *Populus tremula*. Shrubs exhibit a relatively high species diversity, and are dominated by *Rosa hugonis*, *Hippophae rhamnoides*, *Prinsepia uniflora*, and *Ostryopsis davidiana*. The natural steppe vegetation is dominated by *Stipa bungeana*, *S. breviflora*, *S. grandis*, *S. kryocii*, *Thymus mongolicu, Artemisia gmelinii* and *A. frigida*.

3. Material and methods

3.1. Pollen data and site selection

Numerous Holocene pollen records with varying data quality are available for the region. Due to the many records with low temporal resolution and/or depositional hiatuses, we first conducted an assessment of the data quality in order to select the most suitable datasets. The following criteria were used for selecting

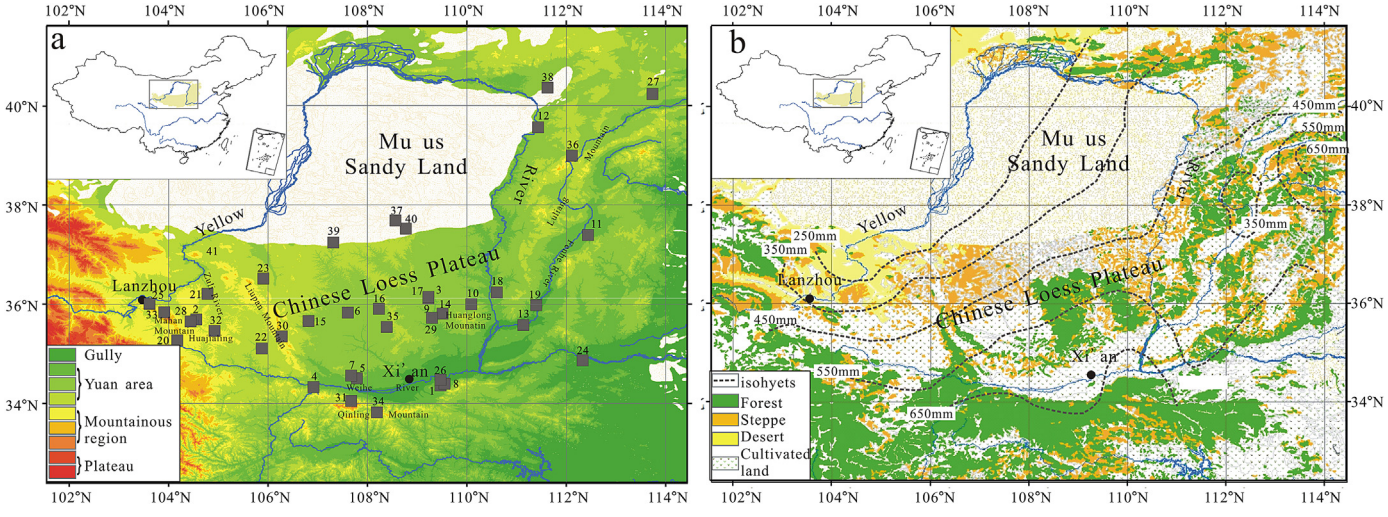

Fig. 1. Location of the Chinese Loess Plateau. (a) 41 studied pollen sites (dark brown squares) in the CLP. (b) The distribution of modern vegetation (Zhang, 2007) and mean annual isohyets (gray lines) across the Chinese Loess Plateau from Wan et al. (2014).

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