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Late Pliocene and early Pleistocene environmental evolution from the sporopollen record of core PL02 from the Yinchuan Basin, northwest China

Yanyan Tian [a], Mingjian Wei [a, *], Maotang Cai [b], Junping Wang [a], Xinling Li [a]

[a] College of Resource Environment and Tourism, Capital Normal University, Beijing 100048, China
[b] Institute of Geomechanics, Chinese Academy of Geological Sciences, Beijing 100081, China

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A B S T R A C T

To investigate the change of climate during the Pliocene-Pleistocene transition in the Asian interior, sporopollen records from the 567.3 m-247.9 m depths (ca. 2.87−1.52 Ma) of the core PL02 in the Yinchuan Basin were studied, which could be regarded as an excellent archive of vegetation and climate changes. The results indicated that the climate of the Yinchuan Basin was relatively warm and humid with a desert steppe environment before 2.6 Ma. At the beginning of the early Pleistocene, the pollen content of xerophytic plants (*Nitraria* and Chenopodiaceae) increased sharply, the climate became drier than that of the late Pliocene, and the environment obviously worsened. However, from 1.99 Ma to 1.73 Ma, xerophytic plants in the pollen content decreased for a short time, and the climate became more humid. After 1.73 Ma, the pollen content of herbaceous plants continually increased, and the vegetation type shifted from desert steppe to desert, which reflects a cold and dry climate. In the study region, the vegetation change suggested an aridification trend in Central Asia inland since the late Pliocene, which might be related to global cooling and the uplift of the Tibetan Plateau.

1. Introduction

The transition from the late Pliocene to the early Pleistocene represented an interval with dynamic environmental change (Bailey et al., 2012). Generally, the emergence of the interval occurred at approximately 2.58 Ma, which marked the termination of the Pliocene warm period and the start of the increasing climate extremes in the Pleistocene (Andreev et al., 2016; Andreev, 2012). During this transitional period, glacioeustatic sea-level changes obviously increased in amplitude in response to the potentialization of northern hemisphere glaciation (Mudelsee and Raymo, 2005; Naish et al., 2009; Pollard and DeConto, 2009; DeConto et al., 2008). The increase of eolian dust flux in deep sea sediments of the North Pacific Ocean was regarded as an indication of a drying Asian interior (Rea et al., 1998). Furthermore, the global climate changes during the late Pliocene-Pleistocene transition have generally been linked to the uplift of the Tibetan Plateau, global cooling and the evolution of the East Asian monsoon (Fang et al., 2003). Hence, terrestrial sediment records that continuously recorded beyond the Pliocene/Pleistocene boundary were required for a better understanding of the climate changes in the Asian interior during this transition.

Pollen assemblages in the east-northern border of the Tibet Plateau provided an interesting record of the terrestrial palaeoflora, which complemented the intensive regional tectonic movements during the late Pliocene and early Pleistocene. The Yinchuan Basin is located in the arid and semi-arid climate transition zone, as shown in Fig. 1a. The region is particularly sensitive to climate change, which has become a research focus for the East Asian monsoon and global climate change (Wang et al., 2015; Li et al., 2017). The Cenozoic fault basin continued to sink and collect eroded materials from the surrounding mountains and the Tibetan Plateau, which formed thick sediments during the Cenozoic. The paleoclimate changes in Central Asia and the effect of the Tibetan Plateau uplift could be studied by the sediments in the Yinchuan Basin (Zheng and Liu, 1994). Until now, most studies of vegetation histories from the Yinchuan Basin have focused on the middle Pleistocene, late Pleistocene or Holocene (Tong et al., 1995, 1998). However, there have been few investigations of the climate changes during the late Pliocene and early Pleistocene. This paper presents a

* Corresponding author.
E-mail address: weimj@cnu.edu.cn (M. Wei).

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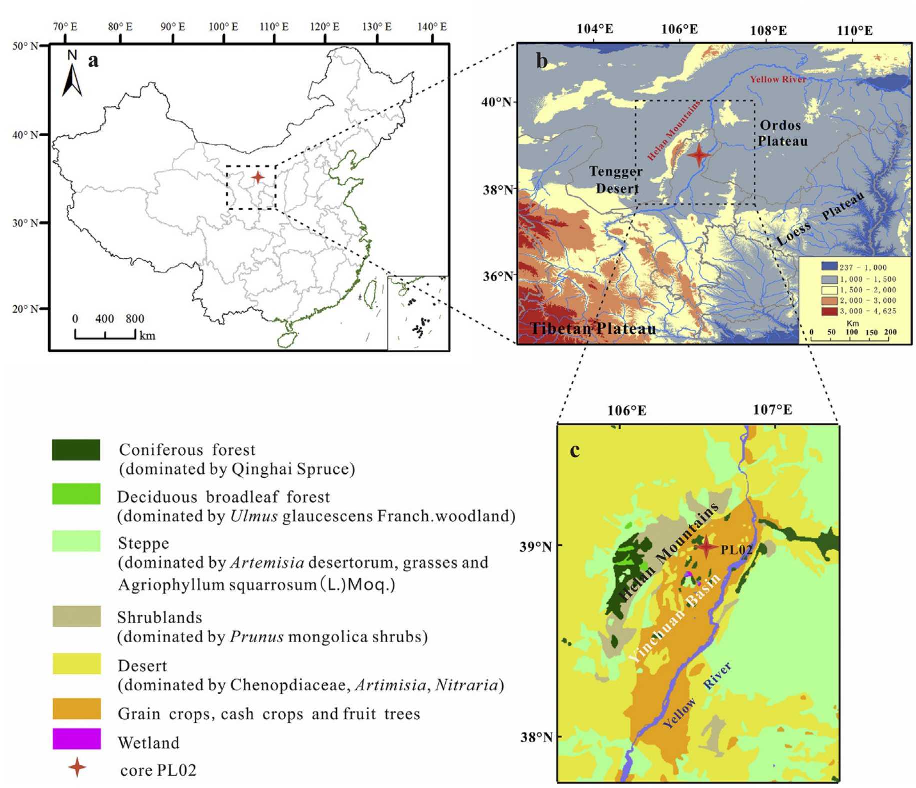

Fig. 1. a. Map of China and the study site; b. Digital elevation map of northwestern China (Yinchuan Basin); c. Vegetation map showing the location of the core PL02 (Revised from the Vegetation Map of China, 2008).

detailed sporopollen record from core PL02 from the Yinchuan Basin during the late Pliocene and early Pleistocene. This data can be used to understand the relationship between vegetation change and climate fluctuation in the Yinchuan Basin and northwestern China.

2. Geography and geological environment

The Yinchuan Basin is located to the east of Helan Mountains to the west of the Ordos Plateau, and is covered by desert in the north and loess in the south. The Yinchuan Basin is also known as the Yinchuan Graben with respect to geological tectonics. In geological time, tension and occlusion processes have occurred many times in this region, with a series of magmatic activities occurring in the Yinchuan Basin. Therefore, the thickness of the accumulated Cenozoic sediments has reached more than 7000 m (Molnar and Tapponnier, 1975; Zhang et al., 1990; Zhou et al., 1993; Wang, 2008). Quaternary sedimentation began at 2000 m, according to the speculation of geophysical prospecting (NBGMR, 1989). The Yellow River originating in the Tibetan Plateau, runs through the Yinchuan Basin from south to north and carries a large amount of debris, such as mud and sand. The main topography units from west to the east include the Helan Mountains, piedmont pluvial floodplain (composed of many pluvial fans) and alluvial floodplain (the Yellow River valley) (Fig. 1b).

The climate of the Yinchuan Basin is dry and cold in winter and is sunny in summer due to the temperate continental climate. In the study area, the annual temperature range is very large, and the mean temperature of the warmest month reaches 25.1 °C, while that of the coldest month drops to −7 °C. Precipitation is concentrated in the summer due to the Asian monsoon, and the annual average precipitation is approximately 170 mm–200 mm (NBGMR, 1989).

The dominant vegetation of the Yinchuan Basin is the desert steppe type, characterized by xerophytism, and is composed of short families and genera (such as *Salsola passerine, Stipa breviflora, Cleistogenes caespitosa* and *S. glareosa*). The composition and distribution of modern vegetation are seriously affected by precipitation and soil moisture (Gao and Dai, 1988). The constructive components are dominated by plexus-born small grasses, followed by some strong xerophilous and super xerophilous shrub plants. The vegetation of the Helan Mountains, located at the western margin of the Yinchuan Basin, is complicated due to the great absolute elevation and relative elevation. Hence, the vertical distribution of vegetation on the mountains is notable, as shown in Fig. 1c. This vegetation is composed of xerophilous shrub steppe zone in the shady slope of the mountain (at elevation of 1500 m–1800 m), gray elm woodland (at elevation of 1800 m–2000 m), pine and spruce mixed forest (at elevation of 2000 m–2200 m), Qinghai spruce forest (*Picea crassifolia*) (at elevation of 2400 m–3100 m) and an alpine shrub and alpine meadow belt (above the elevation of 3100 m) (Tong et al., 1995).

3. Materials and methods

In this study, a 720 m drill core with an average recovery rate of 94.7% was taken from the Yinchuan Basin (38°55′26.62″N, 106°36′3.82″E, 1103 m) in September 2013. The location of core PL02 was approximately 11 km from the Yellow River and 22 km from Helan Mountain, as shown in Fig. 1b. The sampling drilling was performed on the alluvial floodplain, located on the eastern side of the Yinchuan-Pingluo fault. The sediments of the core mainly contained medium sand, fine sand and clay.

The determination of the chronostratigraphic sequence of the core was based on paleomagnetic stratigraphy. The sedimentation

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