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Loess deposits in Beijing and their paleoclimatic implications during the last interglacial-glacial cycle

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A B S T R A C T

Loess-paleosol sequences are important terrestrial paleoclimatic archives in the semi-arid region of north-central China. Compared with the numerous studies on the loess of the Chinese Loess Plateau, the eolian deposits, near Beijing, have not been well studied. A new loess section in the northeast suburb of Beijing provides an opportunity for reconstructing paleoenvironmental changes in this region. An optically stimulated luminescence (OSL) chronology yields ages of 145.1 to 20.5 ka, demonstrating that the loess deposits accumulated during the last interglacial-glacial cycle. High-resolution climatic proxies, including color-index, particle size and magnetic parameters, reveal orbital-scale climatic cycles, corresponding to marine oxygen isotope stages (MIS) 6 to MIS 2. In contrast to the loess deposits of the central Loess Plateau, loess near Beijing is a mixture of distal dust materials from gobi and sand deserts in the arid part of northwestern China and proximal, local alluvial sediments. Climatic change in Beijing during the last interglacial-glacial cycle was controlled primarily by the changing strength of the East Asian monsoon. Paleosols developed during the last interglacial complex (between 144.0 and 73.0 ka) and the interstadial of the last glaciation (between 44.6 and 36.2 ka), being associated with an enhanced summer monsoon in response to increased low-latitude insolation and a weakened Siberia High. Loess accumulation occurred during cold-dry stages of the last glaciation, in response to the intensified winter monsoon driven by the strengthened Siberia High and its longer residence time.

1. Introduction

Loess covers about 10% of the land surface of the Earth (Taylor et al., 1983; Liu, 1985; Tsoar and Pye, 1987). Chinese loess deposits consist of alternations of loess layers and paleosols. The loess layers are indicative of cold and dry climate, while paleosols developed during warm and humid climatic conditions (Heller and Liu, 1982, 1984; Liu, 1985; Kukla et al., 1988). Continuous loess-paleosol sequences associated with glacial-interglacial cycles during the Quaternary are among the most detailed terrestrial records of climate changes since ~2.6 Ma (Heller and Liu, 1984; Kukla and An, 1989). Various paleoclimatic proxies extracted from loess-paleosol sequences, such as magnetic susceptibility, particle size, stable isotopes, and pollen, are used to infer Quaternary climatic changes (e.g., Heller and Liu, 1982, 1984; Muhs, 2013).

In China, loess accumulates not only on the Loess Plateau, but also occurs in other arid and semi-arid areas, especially on the windward sides of mountain ranges. These piedmont loess deposits are also useful for inferring regional climatic changes. In an early study loess was reported in the Zhaitang Basin, in a northwestern suburb of Beijing, where the last-glacial-aged Malan loess was named (Liu, 1985). A few studies including chronology, composition, and texture have been performed on this section (e.g., Li, 1990; Wang et al., 1998). However, compared with the detailed work on the loess-paleosol sequences from the Loess Plateau, loess deposits in Beijing have not been well studied.

In recent years, a well-preserved loess section in a suburb of Beijing was found and is the subject of the present study. In examining this new loess exposure, we have three objectives: (1) to generate a chronology of this section using the optically stimulated luminescence (OSL) dating method; (2) to reconstruct paleoenvironmental changes using multiple climatic proxies; and (3) to discuss the provenance of the loess deposits and the forcing

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mechanism for the paleoclimatic change.

2. Geological setting

Beijing is situated in North China (Fig. 1a). The geomorphology of the Beijing region is characterized by a series of mountains in the north and the northwest, whereas alluvial plains are found in the south. The elevations of the mountains vary between 800 and 1500 m above sea level (asl), while the average elevation of the alluvial plain is 20–60 m asl (Bureau of Geology and Mineral Resources of Beijing Municipality, 1991).

Beijing has a typical temperate monsoon climate, which is characterized by distinctive seasonal changes in temperature, precipitation and wind direction. The mean annual temperature is 11–12 °C in the alluvial plain area and gradually deceases toward the mountain areas. The mean annual precipitation is about 630 mm, but most rainfall (more than 70%), transported by the southeast summer monsoon from the Pacific Ocean, occurs in summer season (from June to August) (Editorial Committee of Local Chronicles of Beijing, 1999). In winter, the climate is controlled by the Siberia High and the prevailing wind is northwesterly, a component of the winter monsoon regime.

The loess section studied here (40°20.16′N, 116°51.57′E) is located about 60 km to the northeast of Beijing, lying in a small, east-west, extension-derived intermontane basin (Fig. 1b). This basin is bounded by the Yanshan Mountains to the north with elevations ranging from 600 to 1500 m asl, and a relatively lower Nanshan Mountains to the south. The section is located on the windward (northwest) slope of the southern mountain range, where airborne dust accumulated as loess cover on the mountain slopes and accumulated on top of fluvial terraces, due to blocking of the prevailing northwesterly winter-monsoon winds by the mountain range (Fig. 2a).

3. Materials and methods

The loess section studied is about 12 m thick, consisting of loess and interbedded paleosols, and six units can be recognized (Fig. 2b). Detailed lithological features of each unit are shown in Fig. 3. The uppermost unit is a light-yellow reworked loess layer, with a thickness of about 0.5 m, the existence of intercalated angular gravels indicates a fluvial origin. This layer is unconformably underlain by a dull orange (7.5YR 6/4) loess bed which is about 1.5 m thick. Underlying this loess bed is a reddish brown (5YR 4/6) weakly developed paleosol with a thickness of 2.1 m. Another dull orange (7.5YR 6/4) loess bed conformably underlies this weak paleosol, which is about 4.9 m thick. Near the bottom of this section there is a well-developed bright reddish brown (5YR 5/6) paleosol with a thickness of 2.3 m. This paleosol is conformably underlain by a light-yellow loess bed whose base is not exposed.

Eight samples were collected for OSL dating (Fig. 3) by hammering stainless steel tubes into cleaned vertical sections. The tubes were sealed at both ends using black plastic bags, to prevent the samples from exposure to sunlight and to preserve their natural water contents. In the laboratory, the outer layers at both ends of the tube were extracted for water content and dose rate measurements. The remaining material for each sample was treated with 10% HCl and 10% H_2O_2 to remove carbonates and organics, respectively. Quartz and K-feldspar separates were prepared, using a combination of sieving, heavy liquid separation and HF etching procedures in subdued, safe red light conditions (Li et al., 2007). Particles between 63 and 90 μm were obtained by dry sieving. Quartz grains (density between 2.62 and 2.75 g/cm^3) and K-feldspar grains (density between 2.53 and 2.58 g/cm^3) were separated using sodium polytungstate heavy liquids. The quartz grains were then treated with 40% HF to remove remaining feldspars and outer layers irradiated by alpha particles, while the K-feldspar grains were etched by 10% HF to remove the alpha irradiated outer layers. HCl (10%) was used again to dissolve residual fluorides. Finally, the quartz and K-feldspar grains were mounted on 10-mm-diameter aluminum discs with silicon oil. For OSL dating of quartz grains, contamination with incompletely dissolved feldspars can affect the equivalent doses and the shape of the growth curves (Lai and Brückner, 2007), so infrared-stimulated luminescence (IRSL)

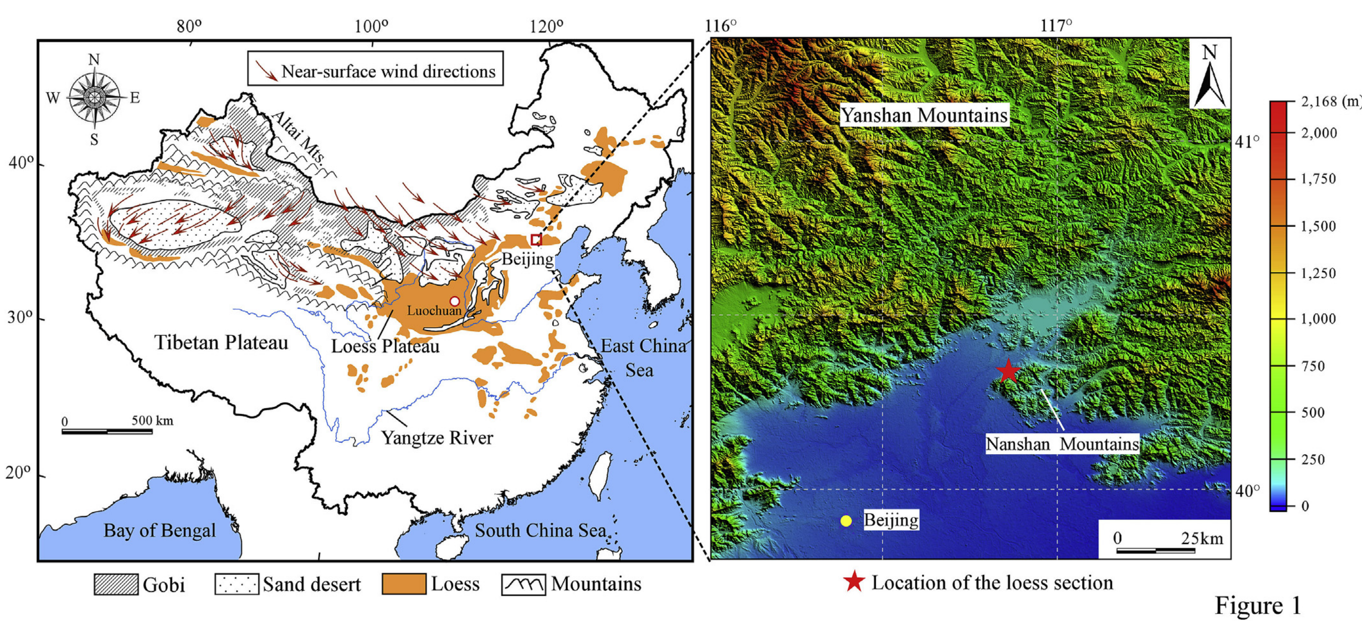

Fig. 1. (a) Map showing the mountain, gobi, sand desert and loess distributions in China as well as the locations of Beijing and Luochuan loess sections (after Sun and Zhu, 2010). The red arrows indicate directions of the prevailing near-surface winds. (b) Digital elevation model of the studied region in the northeast suburb of Beijing and the location of the sampling section. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)