Identification of aeolian loess deposits on the Indo-Gangetic Plain (India) and their significance

LIU XiuMing\textsuperscript{1,2}, MA MingMing\textsuperscript{1,2*}, WU HaiBin\textsuperscript{1,2} & ZHOU ZiBo\textsuperscript{1,2}

\textsuperscript{1}Institute of Geography, Fujian Normal University, Fuzhou 350007, China;
\textsuperscript{2}Key Laboratory for Subtropical Mountain Ecology, Ministry of Science and Technology and Fujian Province, College of Geographical Sciences, Fujian Normal University, Fuzhou 350007, China;
\textsuperscript{3}Department of Environment and Geography, Macquarie University, NSW 2109, Australia

Abstract  Aeolian loess deposits contain abundant information about the evolution of the paleoenvironment. For example, paleoclimate changes recorded in Chinese loess area obtained significant achievement in the past few decades. Compared to Chinese loess, research on Indian loess is lacking. Currently, most studies focus on the Kashmir area located in the southern Himalayas, and studies on other areas are rare. However, field observations demonstrate that the sediments around the New Delhi-Agra-Jaipur Plain are similar to Chinese loess-paleosol sequences. For example, the boundary between two strata is transitional and without horizontal bedding. Moreover, obvious pedogenic horizons developed among sediment sequences, probably indicating unrecognised aeolian deposits in the Indo-Gangetic Plain (IGP). To confirm this, pilot samples were obtained from the IGP and detailed indoor measurements conducted. The results indicate that the distribution patterns of particle size and rare earth elements (REE) of the pilot samples are similar to Chinese loess. Furthermore, the scanning electron microscopy (SEM) images of pilot samples show obvious conchoidal fractures, dash-shaped concavities, and abundant small pits that usually form through mechanical impact. These are typical characteristics of aeolian particles. In addition, environmental and rock magnetic measurements indicate that the dominant magnetic minerals in the pilot samples are magnetite and maghemite, and that they likely contain small amounts of hematite. Furthermore, conventional magnetic parameters are comparable with Chinese loess. Based on this, aeolian loess deposits are widely distributed in the IGP, which may have promoted the development of Indian farming and contributed towards the prosperity of ancient Indian civilisation. This study also provides a new and valuable record for the research on paleoclimate changes in the study area in the future.

Keywords  Indo-Gangetic Plain, Loess deposits, Particle size, SEM, REE, Environmental magnetism, Ancient civilisation


1. Introduction

Loess deposits have been important materials for the reconstruction of paleoclimate change (Heller and Liu, 1982; An, 2000; Geiss et al., 2008), because they continuously and accurately recorded the environment deposited and environmental changes after deposition. The longest history of climate change reconstructed by loess is up to ~25Ma B.P. (Chinese loess, Guo et al., 2002; Qiang et al., 2011) and can be correlated with the $\delta^{18}$O record of marine sediment. This confirms that loess is an excellent continental sediment for paleoclimatology studies.

Loess deposits in India have primarily been reported in Kashmir and the Son Valley in Uttar Pradesh. These detailed studies focused on chronology (Kusumgar et al., 1986; Singhvi et al., 1987), chemical properties (Lodha et al., 1987;
Ahmad and Chandra, 2013), magnetic properties (Gupta et al., 1991), micromorphological investigation (Pant et al., 1985; Dar et al., 2015), their sources (Ahmad and Chandra, 2013), and palaeoclimatic records (Gupta et al., 1991; Pant et al., 2005; Dar et al., 2015). Previous research revealed that loess-paleosol profiles could be correlated throughout the Kashmir Valley using magnetic measurements (Gupta et al., 1991) and micromorphological investigation (Pant et al., 1985), suggesting a similar origin. In addition, environmental magnetic analysis revealed the primary magnetic minerals as magnetite, maghemite, and haematite in central Himalayan loess deposits. Furthermore, the magnetic susceptibility curve of a loess-paleosol profile compares well to the $\delta^{18}$O record of sediments from the Arabian Sea (Pant et al., 2005). This suggests that loess deposits comprise the changing history of Indian southwest monsoons (Gupta et al., 1991; Pant et al., 2005).

India is divided into three areas according to physical geography and climate conditions: (1) the Himalayas mountain area in northern India, (2) IGP area in middle India, and (3) Deccan Plateau area in southern India (Ramakrishnan, 2008). The IGP is one of the largest plains in southern Asia, measuring a width of about 3000 km from north to south and a length of 250–300 km from east to west. The eastern area of the IGP is the Ganges Plain, the birthplace of ancient Indian civilisation, and the western area is the Indus Plain, which mainly comprises Thar Desert. The thickness of sediments in the IGP is generally 300 m, and the deepest area can measure up to 1800 m. These thick sediments were generally regarded as alluvium caused by the Ganges and Indus Rivers (Bhattacharya et al., 1995). However, the presence of Thar Desert, which is located in the junction area of north-western India and Pakistan, provides the western IGP area with dust, so there are likely unrecognised aeolian deposits here. In this study, pilot samples were collected from the western IGP near Thar Desert, and detailed indoor measurements (particle size analysis, geochemistry, SEM images, and magnetic methods) were conducted and compared to Chinese loess samples. The aims include: (1) confirming the aeolian origin of the pilot samples, (2) exploring the role of aeolian deposits in the development of ancient Indian civilisation, and (3) providing a new and valuable record for the research on paleoclimate changes in the study area in the future.

2. Materials and methods

2.1 Geological setting and sampling

The study area (27°14.313’N, 75°56.840’E, 424 m a.s.l) is near Jaipur (the capital of Rajasthan), which is located on the eastern boundary of Thar Desert (Figure 1) with an annual rainfall of about 600 mm (Verma et al., 2013). Thar Desert is the major source of dust storms in western India and eastern Pakistan (Pease et al., 1998; Washington et al., 2003; Prakash et al., 2013). The dominant wind pattern is south—south-westernly winds during the summer period (especially during the pre-monsoon season), which deposit a large volume of dust in the windward direction instates neighbouring the Thar (Yadav and Rajamani, 2006; Yadav et al., 2007). Therefore, dust and sand storms occurred regularly in the study area (Prakash et al., 2013; Verma et al., 2013). Here, the modern vegetation mainly comprises grasses with sparse trees (Figure 1a), which is similar to the central area of the Chinese Loess Plateau (CLP). Moreover, the naturally formed ‘steep terrain’ (Figure 1a) is also a common topographical feature on the CLP. Figures 1b–e show obviously transitional layered structures in the sediment sequence, which were likely caused through a pedogenic process, such as the Quaternary loess-paleosol and Neogene red clay sequences on the CLP. For example, three layers are obvious in Figure 1b: a relatively reddish layer is sandwiched between two yellowish layers, and the boundaries between them are transitional but not sudden. Furthermore, the reddish layer shows a slightly vermicular texture, indicating that it has undergone a strong pedogenic process. The texture of the whole sequence is uniform, loose, and silt-sandy without cementation and bedding. Moreover, obvious argic and Bt horizons can be distinguished. Figure 1c shows another profile nearby. Evident is many calcareous nodules with diameters of 1–2 cm around the foot of the profile and under the top soil layer (Figure 1d), suggesting significant leaching and depositing during pedogenesis. The top soil is loose and porous with a dark colour, similar to the Holocene black loam on the CLP (i.e. $S_1$ paleosol). However, the difference is that many calcareous nodules are generated (Figure 1d); therefore, the top soil probably corresponds to $S_0$. The bottom of the profile in Figure 1c corresponds to the reddish paleosol horizon in Figure 1b, which maybe correspond to L1S or S1 on the CLP. Meanwhile, from the perspective that it underwent a stronger pedogenic process than top soil, it should be $S_1$ rather than L1S. However, the paleosols in the study area underwent a stronger pedogenic process than did the CLP; for example, the calcareous nodules in $S_0$ and vermicular texture in $S_1$ may be related to more humid and warmer climate conditions. To confirm the aeolian origin of the sediments, three samples named Jaipur1 (top soil, 10YR 5/4), Jaipur2 (yellowish sediment, 7.5YR 6/4), and Jaipur3 (reddish sediment, 2.5YR 5/3) were collected from the profile in Figure 1c. As there is a hill less than 100 m away from the sampling site, the collected samples were likely mixed with coarse slope sediment.

2.2 Methods

Grain size was measured using a Mastersizer 2000 laser particle size analyser. This instrument has a measurement range