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Micromorphology of the lower Pleistocene loess in the Iranian Loess Plateau and its paleoclimatic implications

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ABSTRACT

The loess deposits in Iran are a valuable archive of regional paleoclimatic and paleoenvironmental information. Extensive sedimentological and chronological studies have been carried out on the middle to upper Pleistocene loess successions during the past decades, but there is an absence of comparable research in the older loess deposits. Recently, a 19-m-thick loess-paleosol sequence was discovered in the central Iranian Loess Plateau (ILP), which was paleomagnetically-dated to ~2.4–1.8 Ma and thus represents by far the oldest loess known in northern Iran. Here, we present the results of a detailed micromorphological investigation of these lower Pleistocene loess-paleosol sequences ("red sequence") from the ILP. Our main findings are as follows: 1) The Agh Band red sequence deposits are an extremely thick soil complex comprising paleosols in different stages of development; 2) the micromorphological index of soil development (MISECA) suggests that the moderately- and well-developed paleosols in the red sequence formed in an environment with mean annual precipitation ranging from around 450 to 650 mm, respectively; and 3) MISECA suggests that the red sequence formed under a semi-arid to subhumid climate and thus under wetter and more favorable conditions than the overlying late Pleistocene loess and modern soils.

1. Introduction

Eolian deposits are a valuable archive of regional paleoclimatic and paleoenvironmental information, as evidenced by the Late Pleistocene loess deposits in Iran and elsewhere (Kehl et al., 2005; Frechen et al., 2009). Large areas of northern and northeastern Iran are covered by loess deposits, which are part of the Eurasian loess belt extending from northwest Europe to the Middle East, Central Asia and China (Frechen and Dodonov, 1998; Machalett et al.,, 2008). During Pleistocene cold stages, northern Iran consisted of a vast area characterized by increased dust accumulation and loess deposition (Pashaei, 1997; Frechen et al., 2009).

During the past decade, last interglacial/glacial loess-paleosol sequences and modern soils derived from loess have been studied in detail at several key sections along the Caspian Lowland. Kehl et al. (2005) studied three loess-paleosol sequences recording a significant climatic change from dry cool to moist warm during the Late and Middle Pleistocene period. Khormali and Kehl (2011) described the morphology, physicochemical properties, micromorphology and clay mineralogy of modern soils derived from loess in Northern Iran and made a comparison with the paleosols described previously. Lauer et al. (2016) applied optically-stimulated luminescence dating of a loess-paleosol succession, and the results of spectroscopic and grain-size analyses of the deposits were used by Vlaminck et al. (2015) to reconstruct paleoclimatic changes.

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Locally, loess–paleosol sequences in Northern Iran are underlain by reddish deposits known as the Lower Pleistocene Loess (LPL); however, the mechanism of formation of these red deposits has received almost no attention. The red-colored deposits are most likely significantly older than the loess deposits described in previous studies. Sedimentological evidence suggests that these widespread red-colored sediments are of eolian origin, and the results of paleomagnetic dating indicate that they accumulated between ~2.4 and 1.8 Ma (Wang et al., inpress, 2016a). However, the pedogenic features and potential paleoclimatic record of the lower Pleistocene loess in northern Iran remain poorly understood.

Paleosols consist of soils formed under climatic conditions different from the present day (Ruhe, 1965; Yaalon, 1971), and their physical properties are used as an indicator for reconstructing past weathering and climate conditions (Retallack, 1990; Ayoubi et al., 2006). Micromorphological analysis is an important technique for determining whether or not a particular pedogenic feature reflects a paleosol or diagenetically-transformed sediments (Kemp, 1998, 1999). More recently, micromorphological studies of paleosols have been used to reconstruct past climate and soil-forming conditions (e.g. Khademi and Mermut, 2003; Khormali et al., 2003; Ayoubi et al., 2006; Rellini et al., 2009; Kehl, 2010; Dar et al., 2015b).

Khormali et al. (2003) established a Micromorphological Index of Soil Evolution in highly Calcareous arid to semiarid Conditions (MISECA), in which various micropedological features including the microstructure, b-fabric, and the presence of clay coatings, decalcified zones and Fe/Mn oxides, as well as the degree of alteration of mineral grains were used as criteria to reflect the degree of soil development and thus past climatic conditions and/or the duration of pedogenic processes. Each feature was quantified by the application of a simple grading system that represents the degree of pedogenic evolution, and the sum of the ratings for each horizon gives the value of the index. The MISECA index ranges from 0 to 24 with increasing grade of soil development.

A correlation between the MISECA index and soil properties was recognized along a precipitation gradient in northern Iran (Ghergherechi et al., 2009; Khormali et al., 2012). Shahriari et al. (2015b) studied three loess-paleosol sequences (the Agh Band, Mobarak Abad and Neka sections) along a climosequence in Mazandaran and Golestan provinces, in northern Iran to investigate the utility of the MISECA index in paleopedological studies. They concluded that the MISECA index clearly resolve pedological changes in different horizons of the studied sequences, and they also found a good correlation between the MISECA index and the amount of precipitation, suggesting its potential usefulness and applicability for paleoclimatic reconstruction.

No previous systematic study of the depositional processes and paleoenvironmental conditions of the ILP has been performed to date. Thus the objectives of the present study are: (1) To conduct a micromorphological investigation to find out the presence of paleosols in the red deposits; to study the degree of paleosol development; and (3) to reconstruct the paleoclimate using micromorphological characteristics.

2. Regional setting

The study was carried out at a section exposed in a limestone quarry located near the village of Agh Band in Eastern Golestan Province, northern Iran (latitude 37.688889 N and longitude 55.158333° E). The sequence underlies an Upper Pleistocene Loess-paleosol (UPL) sequence and covers the Pliocene limestone of the Akchagyl Formation (Fig. 1). The Akchagyl Formation mainly consists of marl and mudstone with thicknesses ranging from 3 m to more than 100 m in the Kopet Dagh sedimentary basin (Forte and Cowgill, 2013).

The present-day climate of the study area is semi-arid, with mean annual precipitation and temperature of ca. 300 mm and 17 °C, respectively. The soil moisture regime is Xeric–Aridic and the temperature regime is Thermic (SWRI — Soil and Water Research Institute of Iran, 2000; Soil Survey Staff, 2014).

3. Materials and methods

3.1. Field descriptions and sampling

The Agh Band LPL has a thickness of 19 m in the quarry under study. In a field campaign in autumn 2014 the morphological characteristics of the section were recorded. Based on field observations, the sequence has been subdivided into 24 units, designated consecutively as U1–U24 from the top of limestone to the bottom of the UPL (Fig. 1). From each unit, representative undisturbed samples for micromorphological analysis and additional bulk samples were taken for laboratory analysis.

3.2. Laboratory analyses

3.2.1. Physico-chemical analyses

After air drying and crushing the samples and sieving using a 2-mm mesh, the soil physico-chemical properties were investigated. Soil pH was measured in a 1:2.5 soil: water suspension using a Digital Conductivity Meter-CC 601 (Jackson, 1975). Organic carbon was determined by wet oxidation with chromic acid and back titration with ferrous ammonium sulfate (Nelson and Sommers, 1982). Equivalent calcium carbonate (CCE) was measured using a titration method (HCl 1 M) (Sparks et al., 1996) in the soil science laboratory of Gorgan University of Agricultural Sciences and Natural Resources of Iran.

3.2.2. Mineralogical analyses

The mineralogy of 24 bulk samples was determined by XRD of powdered samples using a Bruker D8 ADVANCE X-ray diffractometer. No chemical pre-treatment was used.

3.2.3. Micromorphological analyses

According to standard techniques described by Murphy (1986), 24 oriented clods were air-dried, impregnated under vacuum with resin, cut into slices, mounted on microscope slides, cut to about 500 μm thickness with a diamond-edged saw, and polished to a thickness of around 25 μm. The final size of the thin sections was approximately 5 cm × 7 cm. Micromorphological descriptions were done in plane polarised and crossed polarised light (PPL, XPL) using a polarizing microscope and the definitions based on Bullock et al. (1985) and Stoops (2003). The interpretation of micromorphological features followed the standards discussed in Stoops et al. (2010).

4. Results and discussion

4.1. Physico-chemical properties

The amount of equivalent calcium carbonate (CCE) in the section varies from 0 to 16.3% and the pH varies from 7.15 to 8.9. The average organic matter content is 0.36% (Table 1).

According to Wang et al. (2016b) the grain-size distribution of the Agh Band LPL section is dominated by fine-grained silts.

4.2. Morphological properties

The Agh Band LPL sequence was subdivided into 24 units in which two or more pedogenic B horizons can be distinguished in

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