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Eolian origin of the Miocene loess-soil sequence at Qin'an, China: Evidence of quartz morphology and quartz grain-size

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Recent study revealed that the so-called Neogene Gansu System in the western Loess Plateau contains loess-soil sequences of Miocene age[1]. A most complete sequence (QA-I) covers a time interval from ~22 to ~6.2 Ma BP, consisting of more than 230 visually definable paleosols interbedded with loess layers[1]. A loess-soil sequence of late Miocene-Pliocene age, synchronous with the Hipparian Red Clay in the eastern Loess Plateau, was also recognized[2], and extends the Miocene sequences into the Pliocene, ~3.5 Ma BP. Recently, Miocene eolian deposits were also reported from the high terraces near Xining[3].

Eolian origin of the Miocene sequences near Qin'an is supported by several lines of evidence, including micromorphological, sedimentological and geochemical data[1]. Here, we further examine the morphology and sedimentological characteristics of more samples covering the entire QA-I sequence, to provide additional evidence of the eolian origin.

Quartz is a dominant mineral component of eolian dust deposits[4,5]. Because of its stable physical and chemical properties under surface conditions, grain morphology of the quartz is usually used to determine the sources, transportation dynamics and post-depositional modifications of the sediments[1,4−6]. Grain-size of the quartz fraction is also better reflective to that of the original eolian dust as quartz is resistant to post-depositional chemical weathering in the semi-arid/semi-humid loess regions[7,8]. In this study, grain-morphology and grain-size distributions of the quartz fraction from the QA-I sequence are examined, and compared with those of the typical eolian deposits of Quaternary age from the Xifeng site.

1 Materials and methods

The quartz fraction of 150 samples (75 from loess layers and rest from soil layers) from QA-I and 30 samples from Xifeng was extracted using the sodium pyrosulfate fusion-hydrofluorosilicic acid method[7]. X-Ray diffractions of the extracted fraction indicate a quartz purity of more than 95%. Scanning electronic microscopy (SEM) analyses were performed on 36 quartz samples (20 from loess layers and 10 from soil layers of QA-I; 3 from Xifeng loess layers and 3 from Xifeng soil layers), using an LEO 1450VP unit. Grain-size of these 180 quartz samples and the corresponding bulk samples were analyzed using a Malvern Mastersizer-2000 grain-size analyzer.

2 Morphology and grain-size of the quartz fraction

SEM observations showed that a majority of the quartz grains from QA-I are finer than 100 μm in diameter, mostly ranging from 10 to 30 μm. Grains >60 μm represent a very small fraction. Most of the quartz grains have irregular and angular shapes and many are characterized by sharp edges and conchiform fractures (Fig. 1). These grain-morphology features are highly similar to those of the Xifeng Quaternary eolian samples (Fig. 1), and also to those of the Quaternary and Pliocene eolian deposits elsewhere[4−6,9]. They are considered characteristic of eolian dust deposits[10,11]. The angular grains resulted from mechanical collisions, salt disintegration and freeze-thaw weathering in the desert regions[10−12], as eolian dust in northern China was mainly deflated from the northwestern desert lands[1,4]. Because dust was transported by wind in suspension, their angular sharps were not abraded.

Grain-size analyses (Fig. 2(a)) show a particle range of the quartz fraction between 0.3 and 120 μm. Although the presence of larger quartz grains (up to 1-2 mm) were noted during field descriptions within a few layers at the lower parts of the outcrops, they were not detected in this study because of the extremely scarce occurrence. This feature, usually observable in Quaternary loess sections over terraces, is attributable to local wind deflation or rain-splash transportation from the

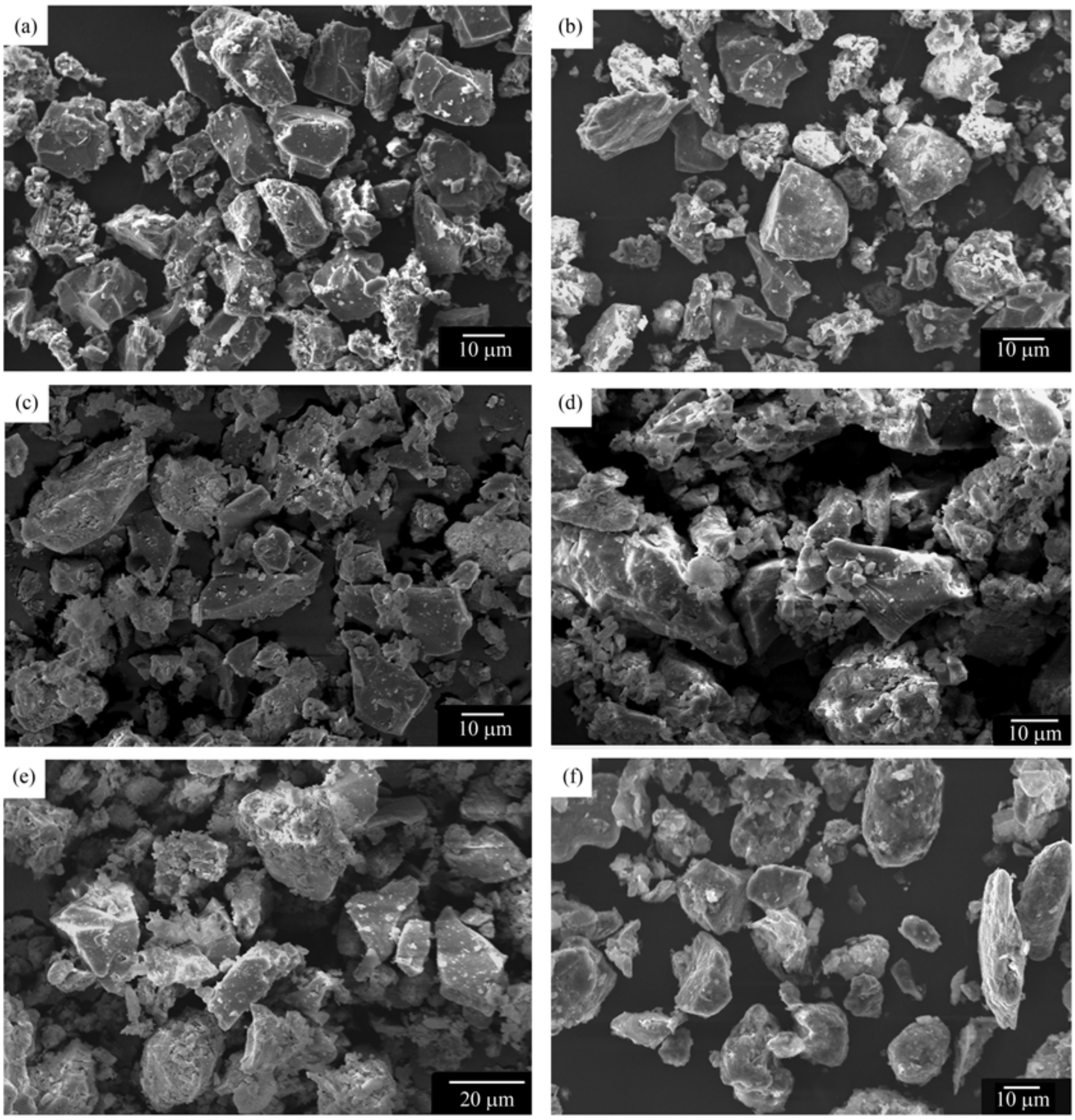

Fig. 1. Scanning electron microscopic photos from loess and paleosol layers in the QA-I and the Xifeng sections. (a) Quaternary loess, Xifeng, L1, × 480; (b) Quaternary paleosol, Xifeng S5, × 640; (c) Miocene loess , QA-I, 92.4 m depth, × 1000; (d) Miocene paleosol, QA-I, 62.3 m depth, ×1000; (e) Miocene loess, QA-I, 172.8 m depth, × 800; (f) Miocene paleosol, QA-I, 109.2 m depth, ×760.

nearby rocky highlands or river valleys. Overall, grain-size distributions of the analyzed samples are positively skewed with an asymmetric unimodal pattern, an average skewness of ~0.7, and a sorting coefficient of 1.5. The fraction of 10-30 μm is dominant and the fraction < 20 μm accounts for 60%—80%. The grain-size distribution models of the QA-I samples are therefore strongly similar to those of the Quaternary loess-soil sequence at Xifeng, characteristic of eolian deposits.

3 Grain-size variations in the QA-I sequence

We calculated the contents of five quartz-grain fractions (<2 μm, 2—20 μm, 20—50 μm, 50—63 μm and >63 μm) that are usually used in the study of dust dynamics[13,14]. Their variations in the QA-I sequence are shown in Fig. 2(b). The fraction <50 μm represents about 80.7%—98.9% with an average content of 93.4%. The fraction of 2—20 μm is dominant in the silt fraction (2—50 μm). The content of the <20 μm fraction averages 63% in the sequence. The >63 μm sandy fraction accounts for 12% in maximum and only 3% in average. The maximum quartz diameter, defined as the grain-size corresponding to 99% cumulative percentage,

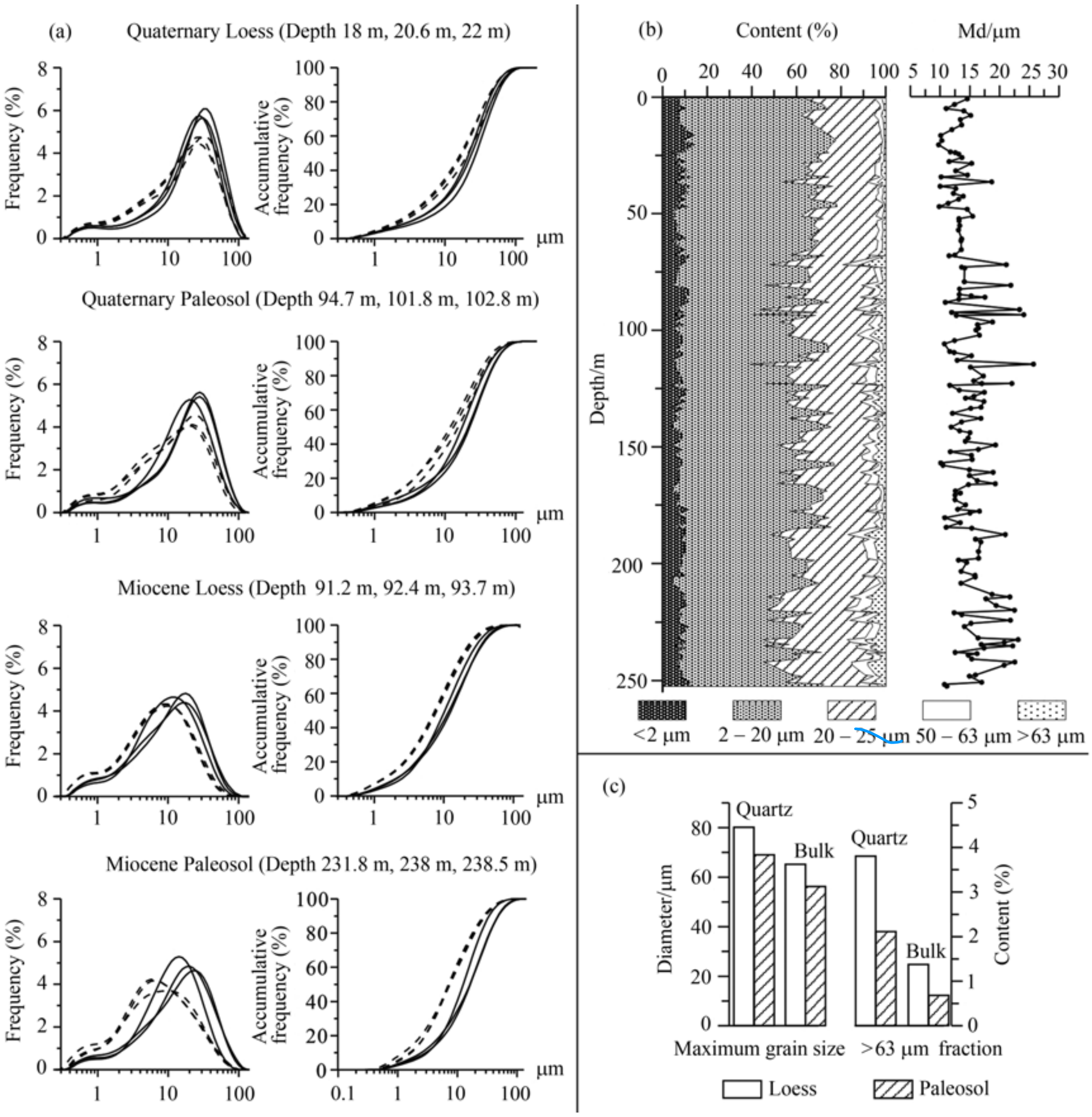

Fig. 2. Grain-size data of the quartz fraction and bulk samples from the QA-I and Xifeng loess-soil sequences. (a) Comparison of quartz (continuous line) and bulk sample (dotted line) grain-size distributions between the Miocene QA-I samples and the Quaternary Xifeng samples; (b) variations of quartz grain-size in the QA-I loess-soil sequence; (c) comparison of grain-size features of quartz and bulk samples between loess and paleosol layers in the QA-I section.

varies from 50 to 120 μm. This homogeneous grain-size dominated by silt fraction along the sequence is characteristic of wind-blown deposits[4]. The grain- size variations in the QA-I sequence therefore strongly support an eolian origin. Any other dynamics would be unable to generate such homogenous textural features along a 253-m thick sequence with a time span of about 16 million years containing several hundreds of paleosols.

Grain-size analyses on both quartz and bulk samples consistently indicate a pattern of coarser grain-size in loess, finer grain-size in soils (Fig. 2(c)), similar to that of the Quaternary loess-soil sequences. The maximum quartz grain-size of the 75 loess samples from QA-I averages 80 μm with the maximum values of 120 μm. That of the soil samples averages 70 μm with the maximum value of 97 μm. The fraction > 63 μm averages 3.8% for loess samples, 2.1% for soil samples. These suggest that the paleosols are accretionary soils, i.e. finer dust continued to deposit during the soil formation. Otherwise, there would not be any significant distinction of quartz grain-size between the soils and the underlying loess layers. The finer quartz grain-size in soils indicates weaker wind strength during the soil-forming intervals comparer with that of loess. From this sense, the presence of a paleosols simply indicates that dust deposition was less intense and pedogenic processes were predominant. The presence of a loess layer indicates the inverse. Continuous dust accretion to soil profiles may lead to upward migration of soil genetic horizons, and thicker calcareous horizon (Ca), in such a way that the upper part of the Ca usually occupied a lower portion of the weathering horizon (B), as is also characteristic of the accretionary paleosols in the Quaternary loess-soil sequences in northern China.

The quartz morphological features and grain-size distributions therefore provide new evidence of an eolian origin of the Qin'an Miocene sequences[1]. These are consistent with the malacological data[15] showing that the mollusks are all land-snails without any aquatic component. The well correlative stratigraphy and magnetic susceptibility of the Miocene sequences between distant sites[16] are also characteristics of eolian deposits. Our results also demonstrate the advantages of using quartz morphology and grain-size parameters to study the origin of eolian deposits. Although loess is a sediment on positive topographies under sub-aerial conditions, every level was exposed to ground surface, and hence subjective to post-depositional affections, such as pedogenic, biological, groundwater, micro-relief induced processes, etc, as observed for the Pleistocene and Miocene sequences, they are not able to significantly affect the basic features of the quartz fraction. Comparison of quartz grain-size between the soil and loess layers indicates that the paleosols in the Miocene sequence are also accretionary soils, resulting from the interactions of pedogenic and dust-deposition processes. The finer texture of the soils implies weaker wind strength during the soil-forming intervals comparer with that of loess. Because eolian accretion during soil-forming periods requires two alternative circulations, one is moisture carrier and the other is responsible for dust transportation, eolian accretionary soils can be regarded as an indication of monsoonal climate system.

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