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Geochemical characteristics of surface dune sand in the Mu Us Desert, Inner Mongolia, and implications for reconstructing the paleoenvironment

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ABSTRACT

We present a new dataset from 28 active and 13 stabilized–semi stabilized dunefields in the Mu Us Desert to report the geochemical macroscale properties as well as reveal the relationship between various chemical ratios and modern climate conditions among different types of Mu Us sandy landscapes. We find that several chemical-weathering indexes, such as CIA, CIW, CPA, and WIP, can be used for the reconstruction of the paleoclimate and servel conditions. One should be cautious in interpreting the weathering intensity using these chemical ratios at a given deposition site when the geochemical background is unknown. This preliminary geochemistry study shows that stabilized–semi stabilized dunefields, which are influenced by Asian summer monsoon (ASM) precipitation, are analogous to buried paleosols, whereas active dunefields, which are controlled by Asian winter monsoon (AWM) wind, resemble paleo-dune sand. The comparison with the geochemical results from an excellent dune–paleosol succession implies that stronger ASM and AWM periods could have recurred 8–9 times in the Mu Us Desert during the early Holocene.

1. Introduction

Massive dunefields cover up to 810,000 km^2 of northern China (Wu, 2009; Zhu et al., 1980). The Mu Us desert (also be called Mu us sandy land) is one of the key regions for studying the history of eolian sand activity and the evolution of the desert in northern China (Dong et al., 2002). Dong et al. (1983) identified ancient eolian sands for the first time in the Mu Us region. And then they attributed the multiple alternations of the eolian dune sand and lacustrine deposits observed in the Salawusu Basin of the Mu Us Desert to the orbital-scale paleomonsoon strength (Dong et al., 1998; Li et al., 2000). The loess–eolian sand sequence at the southern margin of the Mu Us Desert confirmed the link between the enlargement and reduction of the dunefield and the paleomonsoon strength further (Ding et al., 1999; Li et al., 2005; Liu and Sun, 2002; Sun et al., 1999). In the past few decades, a growing number of optically stimulated luminescence data derived from dune sand–paleosol records have provided good chronological knowledge of the servelal changes in the Mu Us region (He et al., 2010; Jia et al., 2015; Li et al., 2012; Liu et al., 2014; Liu and Lai, 2012; Lu et al., 2005; Wen et al., 2016; Xu et al., 2015a). However, the link between dunefield formation and insolation forcing is not always straightforward (Lu et al., 2005) and is inconsistent with other dune records form other locations (Thomas and Burrough, 2013), which may demonstrate a nonlinear relationship between climate change and dune system response (Duller, 2016; Halfen et al., 2016; Lancaster et al., 2013; Li and Yang, 2016). While the lack of an independent climate proxy in coarse-grained dune sand

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(Fitzsimmons et al., 2013), such as the pollen spectrum (Lu et al., 2012), hinders the quantification/semi-quantification of specific paleoenvironment changes in sand region (Lancaster, 2008; Telfer and Hesse, 2013; Thomas and Burrough, 2012). Some geochemical proxies obtained from eolian loess–paleosol deposits provide useful information regarding the reconstruction of the paleoenvironment (Li et al., 2008; Wang et al., 2008; Yang et al., 2006), however, because source detritus, grain size variation and sediment transport process could alter the geochemical composition, especially in the desert, the uncertainty of the reconstruction of the paleoenvironment and climate sometimes increase to a level at which the interpretation is no longer valid.

The goal of this study is to characterize the chemical properties of active and stabilized dunefields of the Mu Us Desert to develop a modern analog for reconstructing servel and paleoclimate. We investigated chemical properties of active and stabilized dunefields of the Mu Us Desert as well as the regional variation at the macroscopic scale by presenting a new dataset from 28 active (MMD) and 13 stabilized–semi stabilized (MFD) dunefields in the Mu Us Desert. And revealing the relationship between various chemical weathering indexes and modern climate conditions among different types of Mu Us sandy landscape. We find several potential parameters for using in the reconstruction of the paleoclimate and servel conditions.

2. Area description

The Mu Us sandy region is located between the Ordos Plateau and Loess Plateau and mainly lies in the southeastern depression. Some dunefields cover the Ordos Plateau and partly expand into the northwestern margin of the Loess Plateau. This desert, covering more than 40,000 km^2, is one of the four largest sandy regions in eastern China (Wu, 2009). Fully active and vegetation-stabilized dunes coexist, as indicated by a remote sensing image (Fig. 1). It shows active dunefields occupying the uplands and stabilized dunefields predominating low-lying depressions, valleys, and lake margins. The active dunes are composed of crescent barchanoid ridges and parabolic, honeycomb, and nabkha dunes.

The current weather in the Mu Us Desert is strongly influenced by the Asian summer monsoon (ASM) and Mongolia–Siberia high-pressure cell systems. The mean annual precipitation of the southeastern sector is 400–450 mm and declines to 250 mm toward the northwestern sector, while the mean annual temperature of the region ranges between 6 °C and 9 °C (Xu et al., 2015b). It is warm and semi-humid in summer and cold and dry in winter. During summer and fall, the southeasterly winds of the ASM prevail and semi-humid conditions support a healthy ecosystem. During winter and spring, northerly and northwesterly winds of the Asian winter monsoon prevail and drier, colder, windier, and dustier conditions inhibit plant growth. Wind erosion and eolian transportation mainly occur during winter and spring.

3. Methods and material studied

We collected 28 surface sand samples from active dunefields and 13 samples from stabilized and semi-stabilized dunefields. Active dunefield samples were recovered from barchan sand dunes at the upper apex of the upland, and stabilized and semi-stabilized samples were recovered from the top of nabkha sand dunes in low-lying depressions and basins. All samples were collected at a depth of 1–5 cm below the land surface. We used differential GPS (mode: S750-G2) to record the geographic coordinates and elevation and employed an ArcGIS10 projection of the location (Fig. 1).

The elemental concentrations of 41 samples were measured using a polarized energy-dispersive X-ray fluorescence spectrometer (mode: Epsilon 5). All samples were dried in a low-temperature (38 °C) oven for 72 h, passed through a 2-mm sieve, and ground to < 75 μm (200-mesh) using a ZHM-1A shatter box for 90 s. Six grams of each pulverized sample was compacted into a disc with a diameter of 3.2 cm using 30-ton pressure for 30 s. A calibration curve was developed using 27 Chinese national soil reference materials (GSS2 to GSS28), 6 fluvial sediment reference materials (GSD2a, GSD7a, and GSD9 to GSD12), and 6 rock reference materials (GSR1 to GSR6). The repeatability of the elemental measurements was evaluated through duplicate analyses of the National Standard soil reference GSS17. The experimental analytical uncertainty of the major elements was ±5% and that of the trace elements was less than 10%. The major elements are given in the form of oxides in wt%. The analytical results are shown in Table 1.

Particle size analysis was performed using a Mastersizer 2000 M

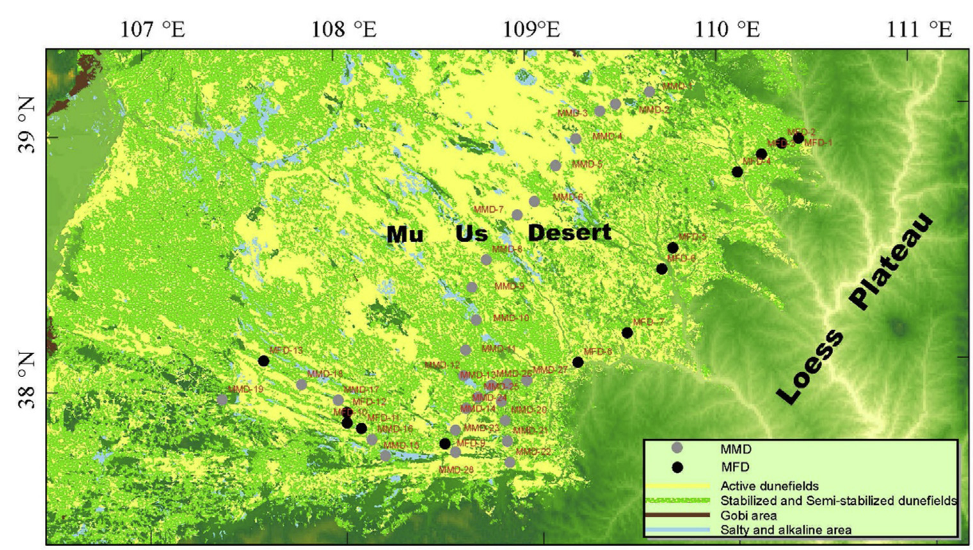

Fig. 1. Locations of dune sand samples in the Mu Us Desert. The satellite image data are provided by the International Scientific & Technical Data Mirror Site, Computer Network Information Center and the Chinese Academy of Sciences.