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Holocene aeolian activities in the southeastern Mu Us Desert, China

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ABSTRACT

Aeolian deposits from three sites in the Mu Us Desert were used to reconstruct the history of aeolian activities during the Holocene. The results of the lithologies, chronologies and proxy indicators showed that aeolian activities occurred at ~9.96 cal ka BP, 7.9–6.9 ka BP, 6.4 ka BP and 3.8 cal ka BP~. The cold event that occurred around 6.4 ka BP interrupted the Holocene Optimum period, which is largely consistent with the findings from sediments in adjacent regions and the monsoon areas of China. Combined with punished OSL and ^{14}C ages of aeolian deposits samples in this region, the environmental changes in the Mu Us Desert were divided into four stages. Active sand dunes dominated before 11 ka BP. Aeolian activities occurred regionally from 11 to 8.5 ka BP and typical sandy paleosol widely developed with episodic aeolian activities between 8.5 and 4 ka BP. Dunes have reactivated and active sand dunes have gradually increased since 4 ka BP. Comparisons with the other paleoclimatic records indicated that the evolution of the Mu Us Desert was closely related to the East Asian monsoon. Paleosol development depended more on the precipitation brought by the East Asian summer monsoon (EASM). The stronger East Asian winter monsoon (EAMW) and higher isolation resulted in the aeolian activities in the early Holocene, while during the mid-Holocene the fluctuating EAWM played a more important role in inducing episodic aeolian activities. The environmental deterioration during the late Holocene can be related to weakened EASM or to increased anthropogenic influence.

1. Introduction

Aeolian deposits are important terrestrial archives of paleoclimatic and paleoenvironmental information that have been widely used to reconstruct climate and environmental changes in arid and semi-arid regions (An et al., 1991; Chen et al., 1997; Porter, 2001; Lai et al., 2009; Qiang et al., 2010; Stauch et al., 2012). One of the major concerns is the massive sedimentary deposits in the Chinese Loess Plateau (Maher and Hu, 2006; Porter, 2001; Sun et al., 2010; Xiao et al., 1995). In the arid and semi-arid regions in northern and northwestern China, desert and sand fields cover an area of approximately 1.0×10^{12} m^2 (Zhu et al., 1988), and provide valuable resources for aeolian deposits.

The Mu Us Desert, located in the desert/loess transition zone and in the margin of the East Asian summer monsoon, is an ideal region for studying past environmental changes due to its sensitive climatic response. The widespread occurrence of aeolian sediments in the Mu Us Desert has been already noticed since the last century (Ding et al., 1999; Dong et al., 1983a). In this region, aeolian deposits are characterised by interbedded well-sorted sand, paleosol and/or loess. Alternations in these sediment units provide us with excellent evidences about the evolution of the desert. Many studies on the desert evolution have been carried out by scholars in the Mu Us Desert (Sun et al., 1999; He et al., 2010; Xu et al.,2013). Most of researches reported consistent evolution patterns in the Mu Us Desert, showing that the Mu Us Desert experienced multiple expansions and retreats (Dong et al., 1983b; Gao, 1992; Li et al., 1998; Sun et al., 1999; He et al., 2010). However, previous studies focused more on the development process since the formation of the Mu Us Desert. The time spans of these studies are long but the resolutions are relatively low. The knowledge of environmental changes is far from satisfactory for understanding the evolution process of the Mu Us Desert at the millennial scale. To further understand paleoenvironmental changes at millennial scale in the Mu Us Desert, in this paper, aeolian deposits from three sites were investigated. The history of aeolian activities over the Holocene was reconstructed based on lithologies, chronologies and proxy indicators from these sites. The evolution process at the millennial scale and the relationships with the monsoon climate are discussed.

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2. Study area

The Mu Us Desert (107°20′E–111°30′E, 37°27′N–39°29′N) is located at the margin of the East Asian summer monsoon (EASM) on the Ordos Plateau and to the northwest of the Chinese Loess Plateau (Fig. 1), with an area of about 4.0×10^{10} m^2 (Huang et al., 2009). The mean annual temperature ranges from 5.5 to 8.0 °C and the mean annual precipitation ranges from 150 mm in the northwest to 450 mm in the southeast. Precipitation was dominated by the EASM, with more than 60% of the annual precipitation occurring from July to September (Sun, 2000). In the winter and spring, northwesterly winds are dominant and frequent dust storms occur, while southeasterly winds prevail in the summer accompanying abundant rainfall. The vegetation is dominated by *Artemisia*, *Salix* and *Hippophae*. At present, active sand dunes occupy 64% of the desert (Sun, 2000), and fully active dunes are generally barchanoid or transverse ridges with heights of 5–15 m (Lu et al., 2011). There are relict sand sheets and dune sediments in the sandfields characterised by alternating sandy loam soils and sand units.

3. Materials and methods

The ZBT, SDG and LJGW sections located at the southeastern margin of the Mu Us Desert were investigated (Fig. 1). The ZBT and SDG sections were found in a gully near the Yulin City, Shanxi Province and the LJGW section is located at the Salawusu River valley, which is a second-order tributary of the Yellow River. Five optically stimulated luminescence (OSL) samples and 11 radiocarbon dating samples were collected from aeolian deposits. The samples were taken from these three sections at 0.02-m, 0.05-m or 0.10-m intervals for measurement of the grain size and organic matter. The grain size measurements were performed using a Mastersizer 2000 with a size range of 0.02–2000 μm: organic matter and carbonates were removed using 10 mL of 30% H_2O_2 and 10 mL of 10% HCl, respectively; the acid residue was washed using distilled water; and 10 mL of 0.05 mol/L $(NaPO_4)_6$ was added to disperse the particles before measurement. The total organic carbon (TOC) was measured by a method of potassium dichromate–sulphuric acid oxygen titration: samples were milled to pass a 100-US mesh (0.150 mm) screen and then were preceded by 0.8 mol/L $K_2Cr_2O_7$ and 1.84 g/mL H_2SO_4 in an oil bath pot; the rest of the $K_2Cr_2O_7$ was titrated with 0.2 mol/L $FeSO_4$; and the organic matter (carbon) content was calculated using the amount of the consumed $FeSO_4$.

In the OSL laboratory, the materials at the middle part of the sample tube, which were not exposed to light, were used to equivalent dose (D_e) measurement. The pure quartz grains of 90–125 μm or 150–200 μm were extracted by using the procedure in the OSL laboratory of Peking University. D_e measurements were carried out using Risø DA-15 TL/OSL reader equipped with blue diodes ($\lambda = 470 \pm 10$ nm) and a $^{90}Sr/^{90}Y$ radioactive beta source. The luminescence was detected using a U-340 filter. The possible exposed-light materials at the each end of the tube were used to measure the concentrations of U, Th and K by neutron-activation-analysis (NAA). The water contents were measured by weighing the samples before and after drying.

The bulk organic matters were used to date for all ^{14}C samples. The ^{14}C samples from ZBT section were measured in Beta Analytic Radiocarbon Dating Laboratory using standard Accelerator Mass Spectrometry (AMS) delivery analysis. The pretreatment procedures of sediments can be found on the website of Beta Analytic (http://www.radiocarbon.com/ams-dating-sediments.htm). The Pretoria Calibration Procedure (Talma and Vogel, 1993) program has been chosen for these calendar calibrations. The calibration database used was INTCAL13 (Reimer et al., 2013). The ^{14}C samples from LJGW and SDG sections were measured by low-level liquid scintillation counter (Quantulus-1220, LKB) in the State Key Laboratory of Earthquake Dynamics, Institute of Geology (Zheng et al., 2005), China Earthquake Administration. The calibration program was OxCal v4.1 (Bronk Ramsey, 2009).

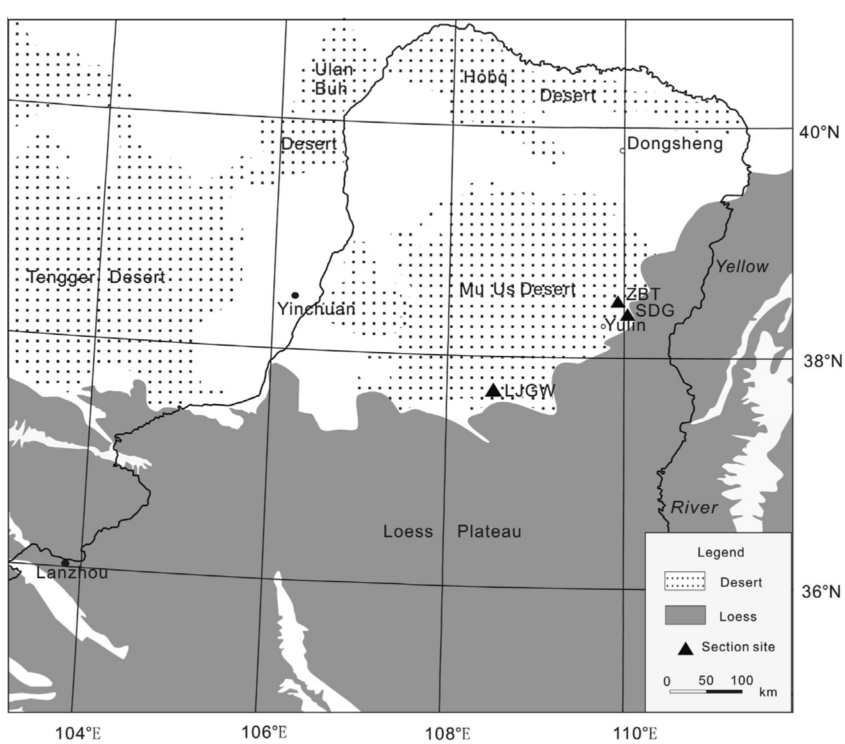

Fig. 1. Location of the Mu Us Desert and the section sites in this study.