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Sandy desertification cycles in the southwestern Mu Us Desert in China over the past 80 years recorded based on nebkha sediments

Jinchang Li [a,*], Yanfang Zhao [a], Haixia Liu [a], Zhizhu Su [b]

[a] Institute of Loess Plateau, Shanxi University, Taiyuan 030006, China
[b] Historical Culture School, Shanxi University, Taiyuan 030006, China

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ABSTRACT

Sandy desertification (SDN) cycles in the southwestern Mu Us Desert since the late 1920s were recorded based on the evolution of *Nitraria tangutorum* nebkhas. Particle size changes of the nebkha excavated during the study, together with AMS ^{14}C and ^{137}Cs dating controls, indicated that the SDN of the study area was reverse on the whole over the past 80 years, but multiple SDN cycles also occurred. SDN mainly occurred during the late 1920s to the early 1940s, late 1940s to early 1950s, late 1950s to early 1960s, mid- and late 1980s, and early 2000s. The formation of nebkhas in the study area was triggered by severe SDN caused by extreme drought events that occurred in the 1920s to the 1930s. Over the past 80 years, the general SDN trend in the southwestern Mu Us Desert was mainly controlled by the westerly circulation strength, and severe SDN resulted mainly from extreme drought events in a large spatial scale, whereas slight SDN cycles were mainly due to local climate fluctuations and human activities.

1. Introduction

The Mu Us Desert on the southern Ordos Plateau lies at the northern margin of the modern Asian summer monsoon, covering an area of 38,940 km^2, and is an important component of the farming and pastoral zones in Northern China (Fig. 1a). In the UNEP map (1992), the desert is identified as a region of intense sandy desertification (SDN). The main form of SDN in the desert is the evolution of anchored dunes into semi-anchored and mobile dunes, and the main form of reversal is the evolution of mobile dunes into semi-anchored and anchored dunes (Wang et al., 2008a). Given the fragile natural environment and hydrothermal sensitivity of the desert, the historical and modern SDN cycles in the region have received considerable attention over the past several decades (e.g. Huang et al., 2009; Wang et al., 2005).

The SDN cycles in arid and semi-arid regions are mainly presented as the degradation and recovery of vegetation (Thomas and Elias, 2014; Li and Yang, 2014), and is closely associated with regional aeolian activities (Zhang et al., 2012; Yan et al., 2011). Previous studies have also suggested that aeolian activities are important in the development of the aeolian morphology and regional ecological environment (Yizhaq et al., 2013; Wang et al., 2014). Therefore, the variation in the aeolian activities strength can reflect the SDN trend, and the historical SDN cycles can be reconstructed based on the aeolian activity sequences recorded with the aeolian sediments in the arid and semi-arid regions of China (Wang et al., 2008b; Lang et al., 2013a). However, because of the difficulty in acquiring high-resolution aeolian sediments, and the lack of aerial photos and Landsat images before the 1970s, the SDN cycles during the early stage of the previous century remains poorly understood in China.

Our field investigation has found that nebkhas (also referred to as coppice dunes, nabkhas, or vegetated dunes) have developed in the southwestern Mu Us Desert. Nebkhas are produced from aeolian activities (Li et al., 2014), and *Nitraria tangutorum* is found in the nucleus of nearly all the nebkhas in the region. As an incipient nebkha form, *N. tangutorum* traps aeolian sediments, which enlarges the nebkha, and regional environmental changes can be recorded through these sediments (Seifert et al., 2009; Wang et al., 2010; Lang et al., 2013b), thus, the regional SDN cycles can be reconstructed by analysing the sediments deposited within nebkhas. This study uses the particle size of the sediments sampled from a nebkha in the southwestern Mu Us Desert to reconstruct the SDN cycles (with a resolution of one year) of the region over the past 80 years and discuss the association of these cycles with climate change.

* Corresponding author at: No. 92 Wucheng Road, Xiaodian District, Taiyuan, China. Tel.: +86 351 7010700.
E-mail address: lijch@lzb.ac.cn (J. Li).

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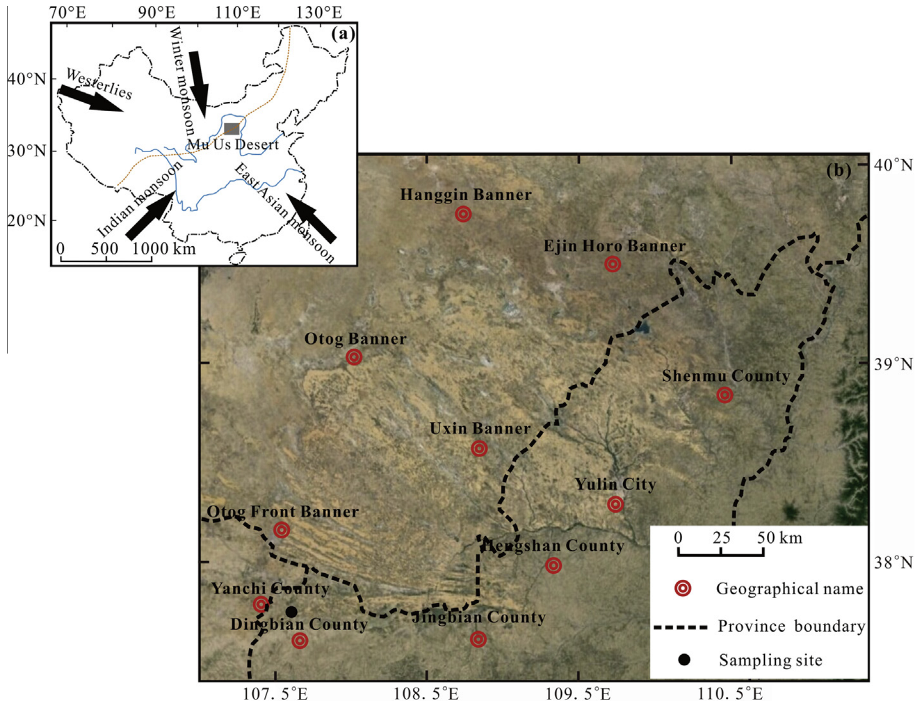

Fig. 1. Location of the study area and sampling site. (a) Mu Us Desert (grey rectangle); the dashed line shows the present limit of the Asian summer monsoon influence, while the blue lines represent the Yellow River and Changjiang River. (b) Google earth screenshot of Mu Us Desert and the sampling site. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Data and methods

2.1. Sampling site

Mu Us Desert has a typical arid and semi-arid continental monsoonal climate with an annual precipitation of 200–400 mm, evaporation of 1800–2500 mm, and aridity of 1.0–2.5 (Liu et al., 2014). This desert currently has a low to moderate wind-energy environment with a ground surface that is dominated by semi-anchored, anchored, and mobile dunes (Wang et al., 2004b). Nebkhas are one of the main types of semi-anchored and anchored dunes in the southwestern Mu Us Desert.

Our sampling site belongs to Dingbian County of Shaanxi Province based on the administrative division (Fig. 1b). According to the instrumental records in the county that has begun in 1976, the mean annual temperature, precipitation and wind velocity are 8.7 °C, 301.5 mm, and 2.5 m s^{-1}, respectively (averaged over the period of 1976–2013), as shown by the trends in Fig. S1 (Supplementary information). In this sampling site, *N. tangutorum* nebkhas extensively develop on the dry riverbeds and previously arable lands, and are almost circular-shaped, aggregative, and clustered (Fig. 2a). The vegetation cover of the nebkhas is approximately 80% to 90% during the growing season (April–October) and 50–60% during the other seasons. The occurrence of wind erosion on the surfaces of the nebkhas is unclear, but previous studies have suggested that when the vegetation cover of the dunes exceeds 14%, the amount of aeolian deposits is greater than the extent of erosion (Wiggs et al., 1994, 1995). In addition, Deng et al. (2007) have suggested that highly obvious environmental changes have not occurred in the desert in recent centuries. Therefore, despite the variations in the vegetation cover during different periods, the regional environment has ensured the continuous development of the nebkhas since the initial formation of these sandy dunes.

On June 14, 2013, we have sampled a *N. tangutorum* nebkha located on a dry riverbed (latitude 37.75°N, longitude 107.61°E, altitude 1306 m). Considering that aeolian sand deposits occur mainly in spring (March–May) in Northern China, the surface sediments of the nebkhas in the region are products of the current year (2013). The nebkha sampled is 240 cm high, 12.2 m in diameter, and round-shaped. The vegetation cover is approximately 80% even at the end of the growing season in late October, and the cover on the southeastern side of the nebkhas is greater than on the other sides because the prevailing winds blow from the northwest. We have excavated the dune to reveal a clean vertical profile through the full depth of the northwestern side. From the crest of the dune toward the bottom, the sediments noticeably consist of aeolian sands entirely (Fig. 2b). We have collected the aeolian sands at 5 cm intervals throughout the profile, and a total of 48 samples has been collected.

2.2. Analytical methods

The *N. tangutorum* litter in the samples at the profile depths of 40, 90, 140, 190, and 240 cm were separated through sieving via accelerator mass spectrometry (AMS) ^{14}C dating. Particle size analysis was performed using a Mastersizer Laser 2000 (Malvern Co. Ltd, Malvern, UK; sample range 0.02–2000 μm in diameter) at the Key Laboratory of Western China Environmental System (Ministry of Education). Before obtaining the particle size measurements, each sample was weighed at 3 g, and the sediments were immersed in 10% H_2O_2, and then in 12.7% HCl to remove any plant debris and disperse the aggregates within the sediments. The sample residue was finally treated with 10 ml of 0.05 M $(NaPO_3)_6$ in an ultrasonic vibrator for 10 min to facilitate the dispersion prior to the particle size analysis. Only slight differences (0.5%) are found in the repeated particles size measurements on each sample.

The AMS ^{14}C dating was performed at the Xi'an AMS Center, Chinese Academy of Sciences. The dating methodology, instrumentation, and calculation of measurement errors as described by Zhou et al. (2007) were followed. The ^{14}C age of each sample was calculated using the methods of Stuiver and Polach (1977), and the ages