Science of the Total Environment 598 (2017) 797–804

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Moisture variation inferred from a nebkha profile correlates with vegetation changes in the southwestern Mu Us Desert of China over one century

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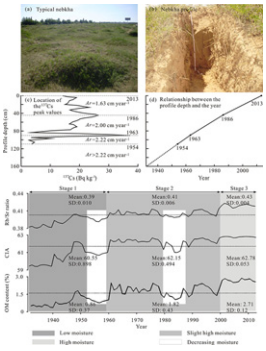
HIGHLIGHTS

- We inferred moisture changes during the past 80 years in the Mu Us Desert.
- Our study revealed that moisture levels increased during the study period.
- Key factor determining moisture variations was different during different periods.
- Moisture variations controlled vegetation recovery or degradation of the desert.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 October 2016
Received in revised form 13 March 2017
Accepted 16 March 2017
Available online 27 April 2017

Editor: D. Barcelo

Keywords:
Moisture variations
Nebkha
Rb/Sr
CIA
Mu Us Desert

ABSTRACT

We inferred moisture variations from the early 1930s to the early 2010s in the southwestern Mu Us Desert of China using Rb/Sr ratio, chemical index of alteration (CIA), and organic matter (OM) content in a nebkha profile. Our results showed that the variations in moisture may have been the main factor that controlled vegetation recovery or degradation, and we believe that gradual vegetation recovery was notable throughout the study area during the past 80 years, despite two notable degradation stages during the mid-1950s and the mid-1980s. The Rb/Sr ratio, CIA, and OM content revealed that moisture levels increased during the study period, though with large interannual variations. During the early stage of nebkha formation, the moisture variations were controlled by unusually low precipitation. Thereafter, the precipitation, pan evaporation and temperature determined together moisture variations, but the key factor determining moisture variations was different during different periods. The moisture variations trend revealed in this study may not be restricted to this region as it was similar with the adjacent Mongolian Plateau.

1. Introduction

China's Mu Us Desert is located in the desert-loess transition zone at the margin of the East Asian summer monsoon, and is an ideal region for studying past environmental changes due its sensitive climatic responses (Jia et al., 2015). Thus, many climate-related studies have

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http://dx.doi.org/10.1016/j.scitotenv.2017.03.145
0048-9697/

been carried out in the desert. For example, Chen et al. (2015) quantified precipitation during the late Quaternary; Si et al. (2014) described climate fluctuations in the late Last Glacial; Jia et al. (2015) and Liu et al. (2014a) reconstructed the history of aeolian activity and moisture variations, respectively, during the Holocene; and Huang et al. (2009) explored desertification trends during the last two millennia. However, the time spans of these studies were long and the resolutions were relatively low. Because of the difficulty in acquiring high-resolution profiles of aeolian sediments and a lack of aerial photos, Landsat images, and meteorological data before the 1970s, the climatic and environmental changes in the Mu Us Desert during recent centuries, especially during the early and middle 1900s, remains poorly understood.

The main shrub in the desert is *Nitraria tangutorum*, which belongs to the *Nitraria* genus in *Zygophyllaceae*. It can resist the region's salinity and alkalinity, drought, wind and dust, and can efficiently fix moving sands and decrease wind speed (Yang and Furukawa, 2006). Nebkhas (which are also referred to as coppice dunes or vegetated dunes) have developed in the southwestern Mu Us Desert, and *Nitraria tangutorum* is the nucleus of most of the nebkhas in the area. As a major factor in the development of nebkhas, shrub traps aeolian sediments, thereby enlarging the nebkha, and regional environmental changes can be recorded in these sediments (Seifert et al., 2009; Lang et al., 2013; Wang et al., 2014).

Geochemical elements and organic matter (OM) content were often used to reconstruct the palaeoclimatic and palaeoenvironmental condition in the loess, aeolian sand and other deposits (Wu et al., 2006; Chen et al., 2008; Liu et al., 2014a). In this paper, we investigated the Rb/Sr ratio, chemical index of alteration (CIA), and OM content in a nebkha profile in the southwestern Mu Us Desert. These environmental proxies are often used to indicate the moisture variation (e.g. Liu et al., 2014a, 2014b; Su et al., 2015). The specific objectives of this study were to reveal the moisture variations (with a resolution of approximately 1 year) of the study area during the past century and discuss the association of these variations with regional vegetation changes.

2. Data and methods

2.1. Sampling site

The Mu Us Desert (37°27′N to 39°22′N, 107°20′E to 111°30′E, altitude between 1100 and 1500 m asl) covers an area of 38,940 km^2 (Fig. 1) (Lu et al., 2005). It has a typical arid to semi-arid continental monsoonal climate, with an annual average temperature of 6.0 to 9.0 °C, precipitation ranging from 200 to 400 mm, and pan evaporation of 1800 to 2500 mm; 70% of the rainfall occurs in the summer (Liu et al., 2014a). In the dry winter and spring, northwest winds are dominant and frequent dust storms occur, whereas southeast winds prevail in the summer, during the period of abundant rainfall, so dust storms are rare (Jia et al., 2015). The modern vegetation is temperate steppe and desert steppe type, mainly *Setariaviridis*, *Salsolacollina*, *Caraganamicrophylla*, *Ixeridiumgramini folium*, *Artemisia frigida*, and *Chloris virgate* besides *Nitrariatangutorum*. This desert currently has a low to moderate wind-energy environment, and the surface 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 is located in the southwestern Mu Us Desert, in Dingbian County of Shaanxi Province (Fig. 1b). Meteorological records for Dingbian County (from about 5 km from the sampling site) were used to calculate averages from 1976 to 2013 for mean annual

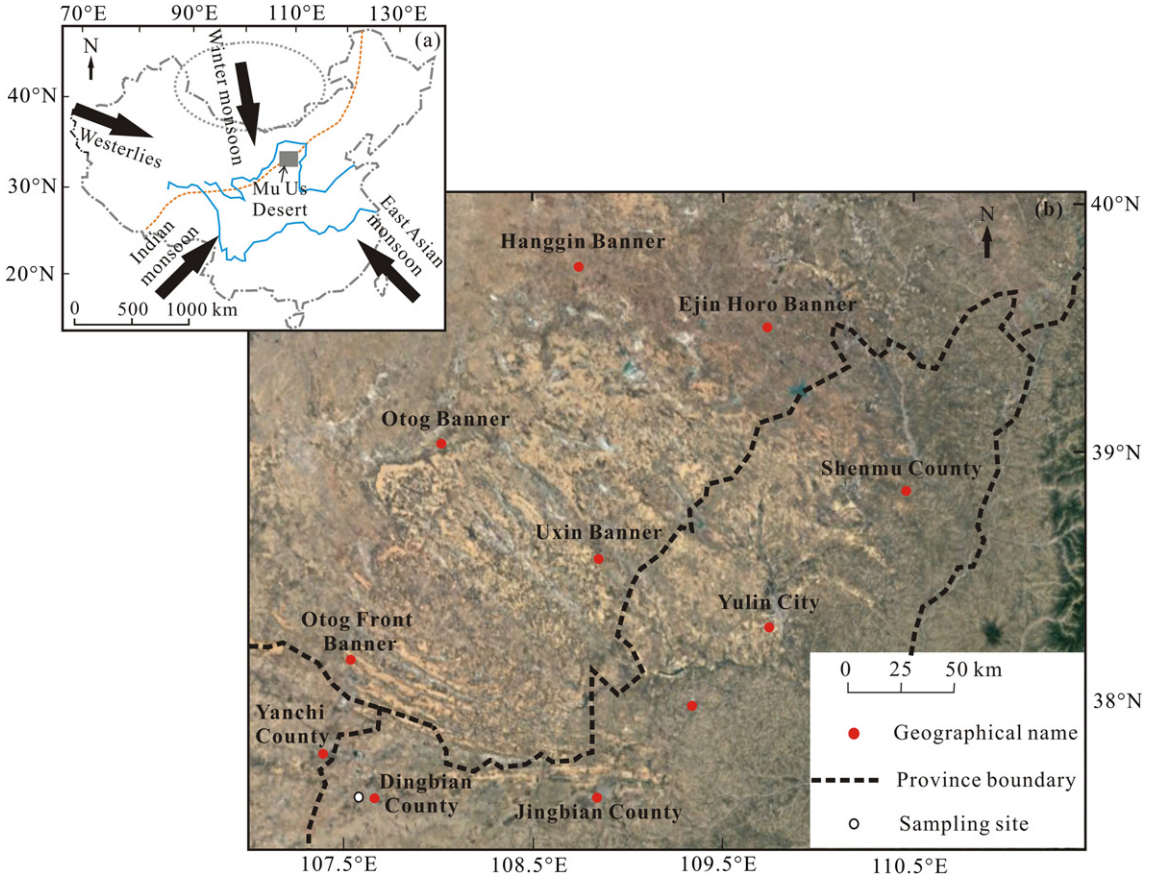

Fig. 1. Location of the study area and the sampling site. (a) Location of the Mu Us Desert (grey rectangle); the line running from southwest to northeast shows the present limit of the East Asian summer monsoon influence, and the blue lines represent the Yellow River (north) and Changjiang River (south); the black oval shows the Mongolian Plateau. (b) Google Earth image of the Mu Us Desert and the location of the sampling site.