Quaternary Science Reviews 128 (2015) 69–80

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Environmental changes in the Ulan Buh Desert, southern Inner Mongolia, China since the middle Pleistocene based on sedimentology, chronology and proxy indexes

Guoqiang Li [a,*], Ming Jin [a], Xuemei Chen [a], Lijuan Wen [a], Jiawu Zhang [a], David Madsen [a], Hui Zhao [b], Xin Wang [a], Tianlai Fan [a], Yanwu Duan [a], Xiaokang Liu [a], Duo Wu [a], Fangliang Li [a], Fahu Chen [a]

[a] Key Laboratory of Western China's Environmental Systems (Ministry of Education), College of Earth and Environmental Sciences, Lanzhou University, Lanzhou 730000, China

[b] Key Laboratory of Desert and Desertification, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China

A R T I C L E I N F O

Article history:
Received 19 June 2015
Received in revised form
3 September 2015
Accepted 10 September 2015
Available online 29 September 2015

Keywords:
Ulan Buh Desert
China
Environment change
Pleistocene
Drill cores

A B S T R A C T

The Ulan Buh Desert (UBD), in southwestern Inner Mongolia, is one of the main dune fields and dust source areas in northern China. The formation of the desert and associated environmental changes since the middle Pleistocene are still unclear due to a lack of depositional records and environmental proxy index analyses. In this study, quartz and K-feldspar optical dating, environmental proxy indexes of grain size, loss on ignition, pollen, and ostracod analysis were employed to supplement the sediment record of a 120.5 m drill core, WL12ZK-1, from the southern UBD. In combination with previous stratigraphic records obtained from drill cores WL10ZK-1 (35 m deep) and WL10ZK-2 (32 m deep) from the northern UBD, and drill core WL12ZK-2 (80 m deep) from the northeastern UBD, these proxies indicate there has been essentially an arid environment in the UBD, with desert or steppe vegetation, since the middle Pleistocene, and that sand dunes were widely distributed in the UBD beginning at least ~230 ka ago. The Yellow River filled a freshwater paleolake beginning ~15 ka ago that covered both the UBD and the adjacent Hetao Plain. The paleolake lasted until ~87 ka, and was associated with wetlands along its margins. Steppe vegetation was present in the surrounding region. An arid environment appeared again after ~87 ka, and there is no evidence of a large stable lake in the UBD at any time thereafter. Sand dune deposition and a very arid desert environment were present throughout the last glacial period and lasted into the early Holocene. During the Holocene these arid conditions were interrupted by minor wetland intervals. Deserts in southern Inner Mongolia formed at least since the middle Pleistocene, expanded during the last glaciation and into the early Holocene and again after ~2 ka. We suggest that a combination of tectonic activity and climate change may be responsible for desert formation and environmental changes in southern Inner Mongolia since the middle Pleistocene, with additional human influence exacerbating these conditions in the late Holocene.

1. Introduction

Sand deserts characterized by active dunes in China include the Taklimakan, Kumtag, Qaidam, Badain Jaran, Tengger, Ulan Buh, and Hobq deserts, while sandy lands characterized by fixed or semi-activity dunes include the Gurbantunggut, Mu Us, Otindag, Keerqin, and Hulunbeier regions. The sand deserts and sandy lands in the arid and semiarid regions of northern and northwestern China cover ~1,000,000 km^2 (Zhu et al., 1988), accounting for a large portion of the deserts in the middle latitudes of the Northern Hemisphere. These sand deserts and nearby fluvial/lacustrine deposit provide huge amounts of atmospheric dust and aerosols, influencing global atmospheric circulation and climate change (Biscaye et al., 1997; Uno et al., 2009). Lacustrine deposits found

* Corresponding author. College of Earth and Environmental Sciences, Qilian Building 607A, Lanzhou University, 222 Tianshuinanlu, Lanzhou 730000, China.
E-mail address: gqli@lzu.edu.cn (G. Li).

http://dx.doi.org/10.1016/j.quascirev.2015.09.010
0277-3791/

over all sand deserts from east to west suggest that extensive lakes occurred in desert areas of northern and northwestern China during the Quaternary (Pachur et al., 1995; Hövermann, 1998; Yang et al., 2003; Yang 2006; Yang and Scuderi, 2010; Yang et al., 2012). Understanding past environmental changes in these sand deserts is of importance for clarifying climatic changes in mid-latitudes terrestrial regions (Yang et al., 2010, 2012; Li et al., 2014a, b).

The Ulan Buh Desert (UBD), located just northwest of the Helan Mountains, is one of the main sand deserts in China, and consists of active high dunes in the south and fixed low-dunes in the north. This area experienced frequently lake/desert changes during the late Quaternary, and paleoshorelines and lacustrine deposits in the region indicate a Mega-paleolake covered the UBD and the Hetao Plain before ~50–60 ka (Chen et al., 2008a), and the modern UBD formed after the paleolake regression (Chen et al., 2014). The Yellow River, the second longest river of China, lies on the east of UBD. The shifting of the Yellow River channel during the late Pleistocene to early Holocene was also considered to be the driving force for UBD formation (Yang et al., 1991). Other studies suggested that the modern northern UBD desert formed during early to middle Holocene, and is the latest cycle of lake/desert changes responding to climatic variation (Jia et al., 2003; Chun et al., 2008; Zhao et al., 2012). Still others argued that the northern UBD to have formed during and after the Han Dynasty (200 BC) as the result of human activity (e.g. farming and overgrazing) (Hou and Yu, 1973; Fan et al., 2010a). These studies have explored episodes of desert formation at different time scales and have focused on the northern UBD. However, environmental changes in the UBD, especially the southern UBD, at long time scales (e.g. since the middle Pleistocene) are still poorly understood due to a lack of sedimentary outcrops and a well-defined depositional sequence.

In this study, quartz single-aliquot regenerative-dose protocol and potassium feldspar (K-feldspar) multi-elevated-temperature post infrared (post-IR) infrared stimulated luminescence (IRSL) (Met-pIRIR) (Li et al., 2014a) optical stimulated luminescence (OSL) dating methods were employed to establish the chronology of the drill core WL12ZK-1. Environmental proxy indexes of grain size, loss on ignition (LOI), pollen and ostracod were applied to the fluvial-eolian-lacustrine sequence from drill core. We combine the lithology and chronology with results from drill core WL10ZK-1 and WL10ZK-2 in the northwestern UBD (Chen et al., 2014), and drill core WL12ZK-2 in the northeastern UBD (Chen et al., 2014; Zhang et al., 2014) to explore environmental and vegetation changes in the UBD since the middle Pleistocene. We then evaluate possible mechanisms and processes of deserts formation in southern Inner Mongolia.

2. Geological setting

The ~11,000 km^2 UBD (Wang, 2003) is located in southwestern Inner Mongolia. The UBD is surrounded by the Yellow River, the Langshan Mountains, the Bayan Urals Mountains, and the Helan Mountains, and the locations of these surrounding featuress are illustrated in Fig. 1. The UBD is part of the Hetao basin, a Cenozoic fault basin surrounded by the Ordos Plateau, the Helan Mountains and the Yinshan Mountains. The high dune zone in the southern UBD is composed of ~100 m high star-type dunes and compound reversing dunes (Chun et al., 2008), while the northern low dune zone is dominated by ~10 m high fixed and semi-fixed dunes separated by now dry interdunal ponds and even older lake sediments. Quaternary lacustrine sediments are extensive in the northern UBD (Geological and Mineral Bureau, 1991; Chen et al., 2008a; Zhao et al., 2012). Jilantai Salt Lake, the second largest salt lake in China, lies on the western margin of the northern UBD. The UBD area has a continental climate typical of areas to the north and west of the main East Asian summer monsoon-dominated region (Fig. 1). At present the average annual precipitation in the area is 103 mm, with 65% falling in the summer (Wang, 2003). The area has typical desert vegetation, is on the boundary between arid and semi-arid China, and is one of the main Chinese dust storm regions (Qin, 2002).

3. Material and methods

3.1. WL12ZK-1 core drilling and sampling

Core WL12ZK-1 (39°42′09.3″N, 106°08′21.7″E, 1093 m; Fig. 1) was drilled to a depth of 120.5 m in a depression among complex sand dunes at 1093 m elevation in the southern UBD by using a XY-2200 m machine drilling system with a single pipe sampling system. According to the ratio of the collected sample depth to drilling depth, core retrieval exceeded 95% for the clay and sandy clay units and more than 75% for the sand units. The recovered sediments consist mostly of clay, silt, and fine sand, but medium to coarse sand in some sections could not be collected completely because the sands were unconsolidated and fell easily from the core barrel. Samples of the uncompact sand were collected at ~10 cm intervals in the field, while compacted and cemented core sections were transported and sampled at 2 cm intervals in the laboratory. OSL dating samples of eolian sand collected in the field were taken from drill tubes inside an opaque shield to avoid sunlight bleaching. OSL samples of lacustrine sandy clay or clayey sand were collected from the core in the darkroom of a luminescence laboratory with red light. A total of eleven OSL samples were collected at different depths of the core WL12ZK-1 (Li et al., 2014a). Depths of these samples are list in Table 1.

3.2. The analysis of grain size, loss on ignition, pollen and ostracods

A total of 800 grain size samples from core WL12ZK-1, collected at intervals of ~4 cm for clay and sandy–clay and ~20 cm for sand, were measured. The samples were pretreated with 10 ml of 30% H_2O_2 to remove organic matter and then 10 ml of 10% HCl with heating to remove carbonates. Deionized water was then added and each sample was kept in suspension for 24 h to remove acidic ions. Finally, the sample residue was dispersed with 10 ml of 0.1 mol/l $(NaPO_3)_6$ using an ultrasonic vibrator for 10 min to facilitate dispersion (Peng et al., 2005). Grain sizes were measured using a Malvern Master Sizer 2000 at Lanzhou University, with a range of 0.02–2000 μm and a mean measurement error of ~2%.

An additional 461 samples from core WL12ZK-1, collected at intervals of ~40 cm for sand and ~8 cm for sandy–clay and clay, were used for LOI weight analysis to roughly estimate the organic and $CaCO_3$ content of the sediments. LOI, following a method proposed by Heiri et al. (2001) and Santisteban et al. (2004), was measured by sequential heating of samples in a muffle furnace and weighed using a balance with 0.0001 g accuracy. Each sample was first dried in a crucible for 8 h at 105 °C to remove water, and then the dried sample was heated at 550 °C for 4 h to remove organic materials. The residual sample was then heated at 950 °C for 2 h to decompose any $CaCO_3$. Finally, the sample was weighed at room temperature after each heating reaction. The percentages of different weights of each sample between 105 °C and 550 °C were calculated to roughly estimate the organic content. The $CaCO_3$ content was estimated by the percentage weight difference between the 550 °C and 950 °C heating steps (Heiri et al., 2001).

Forty-one pollen samples weighing ~20 g were taken at approximately 0.5 m intervals from clay and silty clay sediments of core WL12ZK-1. Pollen samples were not collected from pure eolian sands in the upper and basal portions of the core, as no pollen has