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RESEARCH ARTICLE

Formation of Ulan Buh desert and its environmental changes during the Holocene

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Abstract Extensive investigations and studies on topography, sedimentary and chronology show new evidence for the formation and evolution of the Ulan Buh desert during early Holocene. Evidence on clay-sand strata and plant roots under interdune lowlands, lake shorelines covered by plenty of *Corbicula largillierti* and large amounts of dry salt lakes in the central region of the desert prove that many megalakes existed in the hinterland of Ulan Buh desert. Several OSL samples collected from Aeolian sands overlying lacustrine sediments in profiles around Jilantai Salt Lake and interdune lowlands in the southern Ulan Buh desert suggest that the desert began around 7 ka B.P.. The formation of Ulan Buh desert may have resulted from the shrinking of Jilantai megalakes and sands blown from exposed loose sediments.

Keywords Ulan Buh desert, palaeolake evolution, environmental evolution, aeolian deposition

1 Introduction

The formation and evolvement of Ulan Buh desert has been the focus of geologists and archeologist's interest. However, no agreement has yet been reached on the formation of Ulan Buh desert (Hou, 1965, 1973; Yang et al., 1991; Niu et al., 1999; Jing, 2001; Jia et al., 1997, 2003; Ren, 2003). The northern part of Ulan Buh desert was investigated by Hou Renzhi in the 1960s. Based on the tumulus site of the Han dynasty in the Hetao basin, he supposed that the desert was formed as a result of the wide-scale exploitation and abandonment of farmland by peasants in the Xi Han dynasty (Hou, 1965, 1973; Jing, 2001). However, according to the study on lake sediments and data of ^{14}C test in the northern Ulan Buh desert by professor Jia et al. (1997, 2003), the desert was formed between the late Pleistocene and early Holocene, and it was drought and climate evolution that led to the formation of the desert. The key to solve the contradiction of the two standpoints is to fix the age of Aeolian sand. However, because it is hard to preserve the materials needed for the ^{14}C test in the Aeolian sand, there is no such study about the determination of the desert age. On the other hand, the current studies just focus on the Hetao basin in the northern part of the desert; the hinterland of Ulan Buh desert has not been studied systematically as yet because of its complex landform and inconvenient traffic conditions. Since the formation and evolvement of the desert involves some significant scientific problems such as the response of arid regions of Central Asia to global changes, which is of high scientific value, a further study is necessary. Through an extensive field investigation and studies on the desert hinterland based on topography and sedimentary conditions, we will put forward in this paper some opinions about the formation time and environmental changes of the desert by means of OSL testing dates.

The Ulan Buh desert, located in the east of Alashan plateau, Inner Mongolia of China, covers an area of 9 900 km^2 (Wang, 2005). It has Jilantai salt lake on the west, Yellow River on the east and Hetao plain on the northeast. The desert borders the Langshan Mountain on the north and Helan Mountains on the south (Fig. 1). The desert basin is high in the southwest and low in the northeast, where it extends and connects to the Hetao basin. According to regional geology materials, the desert basin originated from rift-subsidence in the Jilantai–Hetao basin during the Eocene epoch. In the Quaternary, it violently sank and mountains around it were intermittently uplifted. As a result, an excellent environment for lake deposits with a regional gathering of waters formed. The Jilantai and the Linhe basins are located in the central

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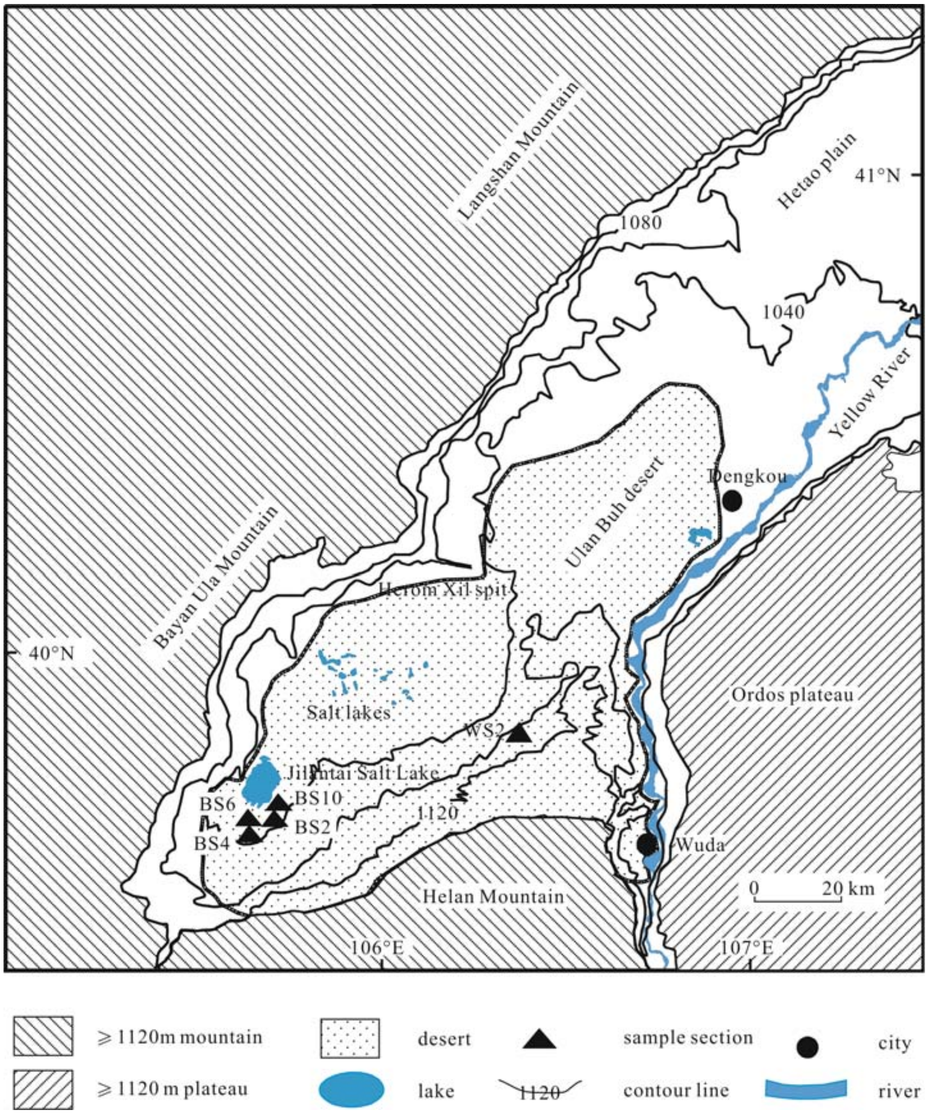

Fig. 1 Location of Ulan Buh desert and staple sample location

area of Jilantai–Hetao basin. The lake deposit that mainly consisted of fluvial-lacustrine clay and coarse sand was 300 m deep in the Jilantai area and 1 800 m deep in the Linhe basin (The Research Group on "Active Fault System around Ordos massif", State Seismological Bureau, 1988; Geological Mineral Bureau of Inner Mongolia Autonomous Region, 1991). The megalake environment extended to the Ulan Buh desert areas in the Pleistocene. However, because of drought and climate conditions, desert formation on a large scale in the early-middle Holocene led to the shrinking of megalake areas and extension of the desert area. Data from the Jilantai weather station show mean annual temperature from 1955 to 2003 was 8.6°C. Mean annual precipitation was only 107.8 mm. About 80% of the annual precipitation fell during June and September, with a peak value of 25 mm in July. However, mean evaporation was 2956.8 mm, which was 27.4 times annual precipitation. In this area, the climate in winter was controlled by the dry, cold northwesterly winter monsoon that brought frequent dust storms from late autumn to spring; whereas the summer climate was dominated by the warm, moist southeasterly summer monsoon that was responsible for most of the annual precipitation and rainstorms.

2 Methods

2.1 Field investigation

Investigations of the route show that dune type of Ulan Buh desert bore obvious regional characteristics, with large differences between the northern part and the southern part. Among them, mobile sandy desert mainly formed in the south and extended to the Jilantai–Wuda railway. Its dune type is compound and complex transverse dune, linear dune and star dune. The continuous accumulation of aeolian sand formed huge megadunes, with thin-bedded lacustrine deposits in the interdune lowland depressions and torrential deposits in the desert. Elevation of the huge megadunes is from 1080 to 1200 m. They are generally 10–150 m in height and scarcely found in other deserts of the world. However, dunes are small and low in the northern part but high in the eastern part of the desert. Those in the northern part are mainly fixed and half-fixed dunes, while those in the eastern part are complex. However, the western part of the desert is dominated by longitudinal dunes. The hinterland of the desert is composed of gray sandy clay lacustrine sediments, surrounded by widespread shells of plant root canals, *corbicula largillierti* and *radixau-ricularia*. A key difference of this desert from others is the existence of a palaeolake plain and salt lakes. Elevation of the palaeolake plain is from 1020 to 1040 m, and the hypsography is plain. It stretches to Hetao plain on the east, scattered by a number of salt lakes. Among them, the largest is Jilantai salt lake, surrounded by a series of lakeshore terraces, the highest of which is 60 m higher than the surface of the current salt lake. The lakeshore terraces accumulated on the northwest and southwest of Jilantai salt lake, and stretched south of Bayan Ula Mountain. The main sediment is beach sand of lakeshore, containing *corbicula largillierti*. There are more than thirty dependent salt lakes in different areas in the centre of the hinterland, including Hesion and Berdabusu. Although the palaeolakes are now deserts, multi-leveled lakeshore terraces can still be seen around the lakes. These lakeshore terrace deposits are mainly made up of beach sand, clay sand and aeolian sand, and they contain shells from the lake and *corbicula largillierti*.

There is also a sand spit from east to west in the Herom Xil in the desert hinterland (Fig. 1), with elevation stretching from 1052 m to 1035 m. The length of the sand spit is 11 km and the width is from 10 and 60 m. It is made up of gravel and sand and contains *corbicula largillierti* and *radixau-ricularia*.

2.2 Chronology data

We used the common testing method OSL technique to test the age of samples (Han et al., 1999; Zhao, 2003). The work is carried out in the key Laboratory of Desert and Desertification, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences. The early dispositions of samples involved washing, sieving, heavy-liquid separation, immersion of 30%, magnetic separation, and obtaining single mineral quartz particulate (Aitkea, 1998). The test was done with a Risoe TL/OSL DA-15 instrument, which measured Ed value by a POST-IR OSL single slice reconstruct and K, Rb, Th, U value with INAA, to obtain the age of sample data. The test by ^{14}C was completed in the Beta laboratory, America, and AMS ^{14}C data was converted to the calendar age.

3 Results and discussion

3.1 Sedimentary age of aeolian sand

The desert is the product of drought and climate conditions, and aeolian sand is the symbolic sediment of the desert environment (Dong et al., 1995). We collected samples of aeolian sand and beach sand inland around salt lakes and interdune lowlands to test the age of the desert. Fig. 2 shows that sediment sequences of each sections and stratum are identical. Except for section BS10, the surfaces of all other sections were deposited by gray clay-sand of up to 2 cm, which were typical of lacustrine sediments. Under the layer was aeolian sand deposit in all sections from 40 to 75 cm. The bottom of BS4 and BS10 sections is sandy-clay and coarse-sand, which typify lacustrine sediments. The beginning of OSL dating (6.73 $\pm$ 0.76) ka B.P. from BS4 section aeolian sand is identical to the formation times (6.77 $\pm$ 0.61) ka B.P. from sections BS6 aeolian sand and (6.82 $\pm$ 0.52) ka B.P. from sections WS2 aeolian sand, which shows that the formation time of Ulan Buh desert was synchronic. The start of the accumulation of beach sand was (6.71 $\pm$ 0.55) ka B.P. from the bottom of section BS10, which was earlier than that of aeolian sand sediment of other sections. But this slight error is within the permitted range of the OSL method. From the point of sedimentary formation, the connection between beach sand and aeolian sand proves the continuity of a sediment sequence and reflects the characteristic of alternating land and water environment fluctuation in the lakeshore area. AMS ^{14}C dating of this layer was (6.569 $\pm$ 0.56) ka B.P., with rich organic remains of bird eggs left on top, which was identical to the Aeolian sand date (6.42 $\pm$ 0.71) ka B.P. from section BS2. The AMS ^{14}C data suggest the security of OSL tested dates and further proves the lasting existence of drought conditions in the lake areas.

As proven by sediment character and test dates of sections, Aeolian sand has been accumulated since 7 ka B.P. in the southern Ulan Buh desert areas, showing that drought and climate led to the expansion of the arid area and drying up of inland megalakes, which finally resulted in the formation and development of the desert environment in early Holocene. Based on the evolution of salt lakes and related desert environment changes as well as the space-time distribution, we estimated that the Ulan Buh desert was formed in early-mid Holocene.

At that time, drought and climate conditions were not only distributed in the desert area on the Alashan plateau, but also extended to the margin of current monsoon areas. The high-resolution lake records show that the palaeoclimate was unstable in drought intervals during middle Holocene in China (Chen et al., 2001). The lake pollen records of Zhuyanze lake in Badain Jaran desert,

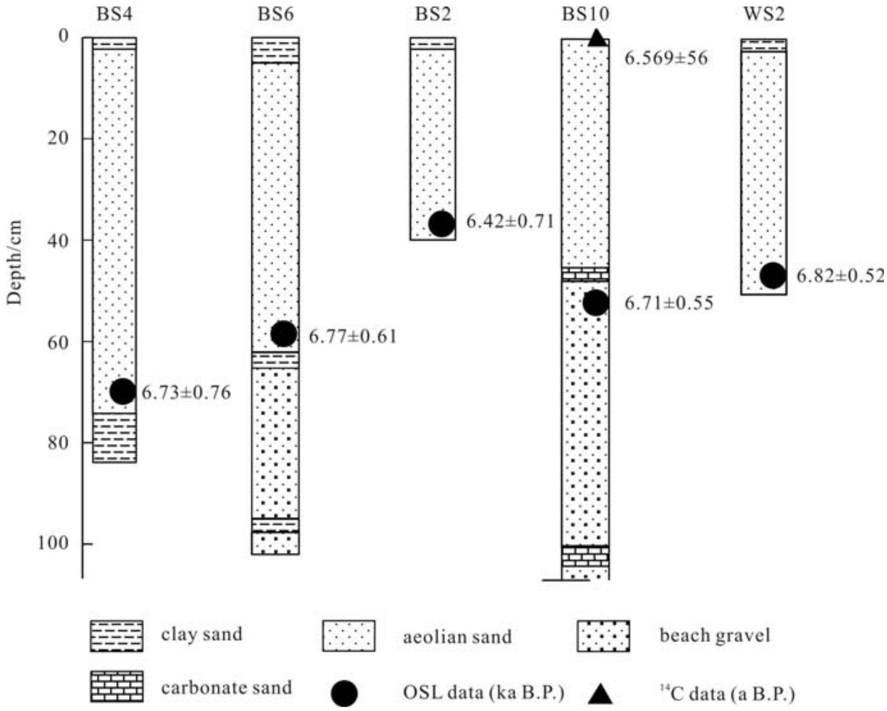

Fig. 2 Sample profiles in the Ulan Buh desert, southwestern regions

Zhuyanze lake basin between the Badain Jaran desert and Tengger desert, and lakes in the eastern Tengger desert such as Yamia lake, Toudaohu lakes, located in arid and semi-arid areas, show that these lakes shrank from 7 ka B.P. to 5 ka B.P. when the climate was arid with drought intervals in middle Holocene (Chen et al., 1999, 2003). The record of salt lake Yanhaizi sediment of Mo Us sand on the east of Jilantai shows that the lake level declined during the period of 8.3 − 4.3 ka B.P., when the lake sediment formed and content of the carbonate increased. Meanwhile, plants degenerated, the desert extended and lakes dried since 7 ka B.P. around the Dalai Nuuer in northern China (Geng and Zhang, 1988). At the same time, Otindag sandy plants degenerated and a warm-dry climate developed in central and eastern Inner Mongolia (Liu et al., 2001). These lacustrine sediment records of significant abrupt climate changes during the early-mid Holocene in northern China coincide with the formation time of the Ulan Buh desert. The coincidence further shows us the drought environmental background of the formation of this desert. The reason for the drought may be the decline of the summer monsoon (Chen et al., 1999, 2003), the increase of evaporation and the decline of precipitation in northern China (Chen et al., 2003).

3.2 Evolvement of desert environment

The Jilantai salt lake is located west of the Ulan Buh desert. The existence of a series of lakeshore terraces around it shows the previous presence of a high lake level in the Jilantai salt lake. The clay-sand strata, plant roots under interdune lowlands, lake shorelines covered by plenty of *Corbicula largillierti* and large amounts of dry salt lakes in the central Ulan Buh desert suggest that development of the desert environment is associated with palaeo lake–Jilantai evolution. Areal geology materials show that the Jilantai salt lake and surrounding area of Holobo (in the hinterland) had been silt and clay deposited from depths of 20 m to 50 m between the late Pleistocene and early Holocene, indicating the wide distribution of megalakes in the Ulan Buh desert areas (Geological Mineral Bureau of Inner Mongolia Autonomous Region, 1991). Based on the shoreline with elevation of 1042 m around Jilantai salt lake, the area of palaeo lake-Jilantai was estimated to be at least 1500 km^2 at that time. The palaeolake water extended to the eastern area of the Ulan Buh desert and connected Hoqin and Boerdabusu lakes. As a result, megalake-Jilantai was formed. Half of the Ulan Buh desert areas were then covered by palaeo lake water from the lake environment. According to the OSL testing dates of five sections and points, palaeo lake-Jilantai declined significantly around 7 ka B.P. in the Holocene. Therefore, the megalake disjointed and many smaller dependent lakes formed. Later, affected by the arid climate, they gradually transformed into salt lakes. At the same time, loose sediments around the drought lakes provided a major resource for the formation of the Ulan Buh desert. Thus, we suggest that the Ulan Buh desert environment evolved through eroded, transported and accumulated palaeo lake-Jilantai sediments in drought and climate conditions since 7 ka B.P.. The process of the formation and extension of the Ulan Buh environment was synchronous with the decline and salinization of the palaeo lake-Jilantai system in the Holocene.

The evolvement of palaeolake of the Ulan Buh desert is closely related to environment changes of the Alashan plateau. Studies show that the plateau had a water system of rivers-lakes from northwest to southeast in middle-late Pleistocene (Guo et al., 2000). In the MIS3 period, the Tengger-megalake extended Tengger desert areas in the west Ulan Buh desert and its palaeolake area was 20 000 km^2. Half of the Tengger desert areas were flooded by the palaeolake (Pachur et al., 1995; Zhang et al., 2004). At 31 ka B.P., megalakes developed and a high lake level appeared in the Badain Jaran desert (Yang et al., 2003). Since the Palaeoclimate was wet, plants grew abundantly in the desert area and dunes either declined or were fixed (Li et al., 2005; Zhang and Wang, 2005). These studies show the extensive existence of megalakes in the Alashan plateau. Therefore, we estimate that the megalake environment of the Ulan Buh desert may be associated with megalakes in neighboring areas in terms of water resources and the water system in the Alashan plateau.

4 Conclusions

The existence of salt lakes in the hinterland of the Ulan Buh desert, lakeshore terraces around salt lakes, evidence on clay-sand strata, plant roots under interdune lowlands and *Corbicula largillierti* show that the Ulan Buh desert was once a megalake environment. From the point of a coupling relation between palaeolake-Jilantai and the Ulan Buh desert, when the water level of the megalake rose and palaeolake areas extended, the desert area became smaller; on the contrary, the desert area extended and palaeolake region declined. Thus, we suppose that Ulan Buh desert developed on the basis of the declining, drying up and desertification of palaeolake-Jilantai. Testing data by OSL method of Aeolian sand from different regions shows that the Ulan Buh desert formed around 7 ka B.P. in early–middle Holocene and the desert environment has been maintained. However, the formation mechanism of the Ulan Buh desert's complex and involved many factors. The change of the Yellow River in Inner Mongolia and the movement of area geology construction are also important factors subject to further study.

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