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Landscape evolution of the Ulan Buh Desert in northern China during the late Quaternary

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ABSTRACT

The evolution of arid environments in northern China was a major environmental change during the Quaternary. Here we present the dating and environmental proxy results from a 35 m long core (A-WL10ZK-1) collected from the Ulan Buh Desert (UBD), along with supplemental data from four other cores. The UBD is one of the main desert dune fields in China and our results indicate the UBD has undergone complex evolution during the late Quaternary. Most of the present UBD was covered by a Jilantai-Hetao Mega-paleolake lasting until ~90 ka ago. A sandy desert environment prevailed throughout the UBD during the last glacial period and early Holocene. A wetland environment characterized by the formation of numerous interdunal ponds in the northern UBD occurred at ~8–7 ka, although a dune field persisted in the southern UBD. The modern UBD landscape formed after these wetlands dried up. During the last 2000 years, eolian sand from the Badain Jaran Desert has invaded the northern UBD, while farming and overgrazing resulted in the formation of the eastern UBD. We suggest that the formation of UBD landforms is related to the disintegration of the megalake Jilantai-Hetao and to summer monsoon changes during the last glaciation and Holocene.

Introduction

Sand deserts are a major landscape feature of the arid and semi-arid areas of the world. Northwestern China contains the largest desert dune fields in the central-east Asian dryland zone, and these deserts form one of the main dust storm and dust source areas in the world (Biscaye et al., 1997; Sun et al., 2001). The evolution of the major deserts in China's drylands is very important in understanding environmental and climatic changes in arid central-east Asia, partly because these deserts provide huge amounts of atmospheric dust and aerosols which influence regional and even global climate changes (Uno et al., 2009). These deserts also contribute much of the silt to the Chinese Loess Plateau (Liu et al., 1994; Sun et al., 2008; Li et al., 2009).

The Taklamakan Desert in western China, the largest desert dune field in China, was formed by ~5 Ma (Sun and Liu, 2006) or ~7 Ma (Sun et al., 2009). The Badain Jaran Desert, with the highest sand dunes on Earth (Yang et al., 2011), and the Tengger Desert on the southern Mongolian Plateau are thought to have formed since the Tertiary Period (Yan et al., 1992; Yang et al., 2006). However, it is generally believed that the sandy lands on the central and eastern Inner Mongolia Plateau and on the Ordos Plateau developed only during the late Holocene (Qin, 2002), possibly as recently as during the last 2000 yr, due to improper human land use including overgrazing and farming (Hou, 1979; Jing, 2001).

The Ulan Buh Desert (UBD), on the western Inner Mongolia Plateau, one of the main desert dune fields in China, is located at the margin of the present Asian summer monsoon (Fig. 1), and the landscape there is thus sensitive to changes in the intensity and northern limit of the summer monsoon. This area experienced dramatic environmental changes during the late Quaternary (Chen et al., 2008a), as well as frequent human disturbances in the late Holocene (Hou and Yu, 1973). Chen et al. (2008a), Yang et al. (2008) and Fan et al. (2010a) have investigated the serial shorelines and lacustrine deposits around Jilantai Salt Lake and the Hetao Plain. On the basis of Optically Stimulated Luminescence (OSL) dates, Chen et al. (2008a) proposed that a so-called Jilantai-Hetao Mega-paleolake (JH paleolake) covered the whole Jilantai Salt Lake basin, and most of the modern UBD and the Hetao Plain, with the highest water levels reaching ~1080 m above sea level (asl). OSL dating suggested that the megalake formed before 50–60 thousand yr ago (ka), with the UBD forming sometime after the paleolake disappeared. Using archeological methods and historical records, including the identification of abandoned cultivated fields, the remains of ancient cities/towns, and the location of tombs, Hou and Yu (1973) concluded that the UBD only formed after the Han Dynasty (beginning about 2200 yr ago) as the result of intensive human activity in the low wetlands of the eastern UBD. However, recent research indicates the UBD developed much earlier, before the historical period. Yang et al. (1991) believed that the desert formed during the late Pleistocene to early Holocene

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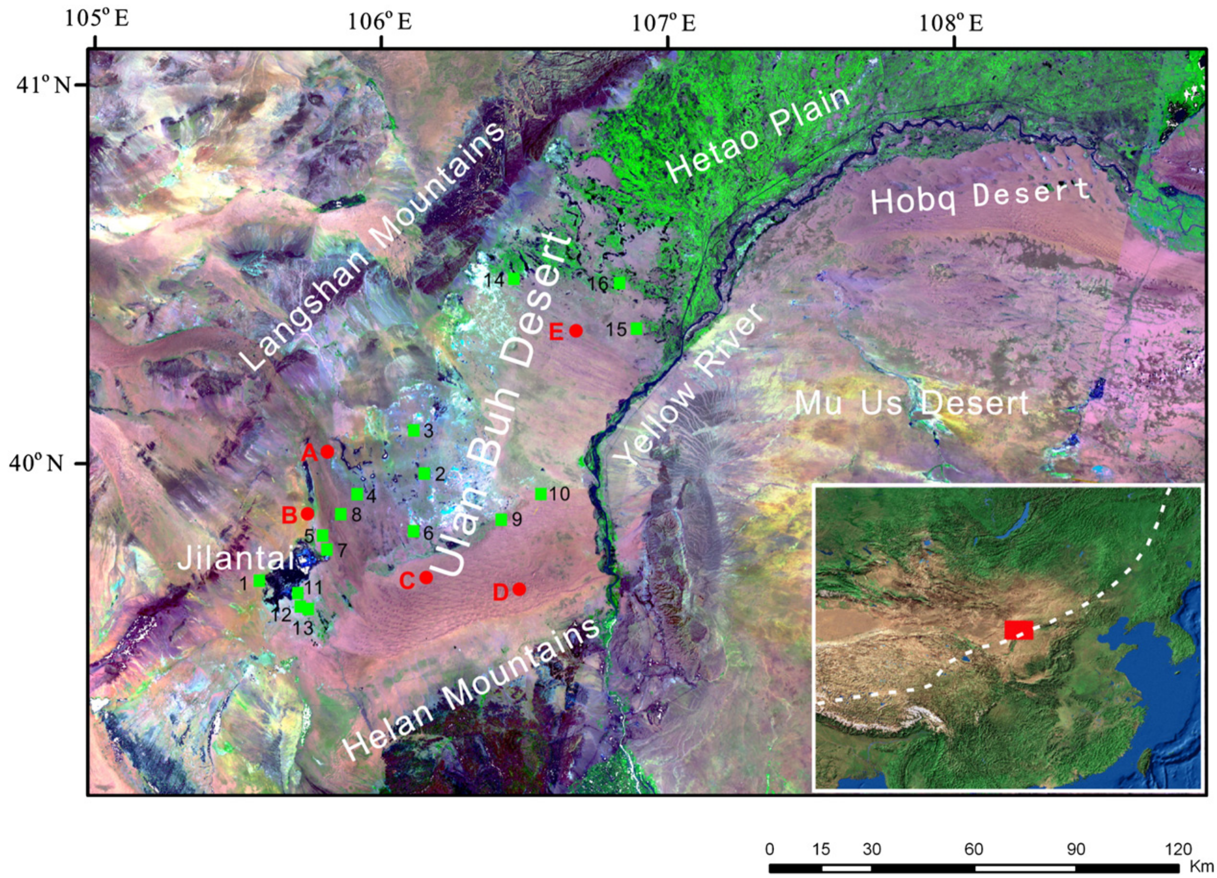

Figure 1. Remotely sensed image of UBD and its surrounding areas. Drill cores A, B, C, D and E are shown by circles. A — core A-WL10ZK-1; B — core B-WL10ZK-2; C — core C-WL12ZK-1; D — core D-WL11ZK-1; and E — core E-WL12ZK-2. Correlative sections or cores are marked by squares with the numbers 1 to 16. Number 1 — FAN section (from Fan, 2008); 2, 3, 4, 5, 6 and 14 — Sections QJD-2, QJD-3, QJD-4, QJD-5, QJD-6 and TSZ respectively (from Zhao et al., 2012); 7, 8, and 9 — Cores WLD07A, WLD07D and WLD07B respectively (from Fan et al., 2010a); 10, 11, 12, and 13 — Sections BS6, BS2 and BS4 respectively; 15 and 16 — Sections TSZ-1 and TSZ-2 (from Jia et al., 2003). The insert box is the remote-sensing image of the physical geography of East Asia showing the location of the study area (filled square) and the modern monsoon limit (dashed line) (modified from Chen et al., 2008b).

and, based on geomorphological evidence, suggested that the driving force was a change in the course of the Yellow River. In addition, Jia et al. (2003) investigated eolian–lacustrine deposits in the UBD, and, based on several ^{14}C dates agreed that the desert formed before the Han Dynasty.

It is still not clear when and how the UBD developed, and in this study, we present the lithology, chronology and selective proxy analyses of core A-WL10ZK-1 collected in the northwestern UBD, along with ancillary data from four other cores (B-WL10ZK-2, D-WL11ZK-1, C-WL12ZK-1 and E-WL12ZK-2), drilled in different areas of the UBD (Fig. 1). Quartz OSL dating and potassium feldspar (K-feldspar) IRSL dating were used to establish a chronology. Grain size, loss-on-ignition (LOI) and pollen analysis were used to reconstruct environmental conditions for the UBD during the late Quaternary. Based on these data we discuss possible mechanisms behind these changing conditions.

Environmental and geological setting

The UBD, with an area of ~11,000 km^2 (Wang, 2003), is situated in the southwestern portion of Inner Mongolia in northern China. As shown in Figure 1, the desert is surrounded by the Yellow River (east), the Langshan Mountains (north), the Bayan Urals Mountains (west), and the Helan Mountains (south). The UBD is essentially part of the Hetao basin, a Cenozoic fault basin surrounded by the Ordos Plateau, the Helan Mountains and the Yinshan Mountains. It consists of a high-dune zone in the south, a low-dune zone in the west, a dry wetland and lake-bed zone in the north and a sand zone in the east. The high-dune zone is composed of ~100 m high pyramid dunes and compound mega dunes (Chun et al., 2008). The low-dune zone in the west, separating Jilantai Salt Lake from the UBD, is dominated by ~10 m high fixed and semi-fixed dunes. Quaternary lacustrine sediments are extensive in the northern UBD (Geological and Mineral Bureau, 1991; Chen et al., 2008a; Zhao et al., 2012). The sand zone in the east is characterized by low linear dunes near the mountains and by relatively high pyramid dunes further away from the mountains. The UBD area has a continental climate typically found away from the main region dominated by the East Asian summer monsoon. At present, the average annual precipitation in the area is 103 mm with 65% in summer (Wang, 2003). The area is on the transition zone between arid and semi-arid China, on the limit of the present summer monsoon (Fig. 1). It is characterized by typical desert vegetation (Chun et al., 2008).

Materials and methods

Coring and sampling

Five cores were drilled in different zones of the UBD. The 35 m long core A-WL10ZK-1 (40°02.448′N, 105°46.66′E, 1026 m asl) was drilled on a gray sandy clay surface surrounded by small dunes in the northern dry wetland and lake bed zone of the desert. B-WL10ZK-2, a 32 m long core (39°52.29′N, 105°42.92′E, 1020 m asl), was drilled on a gray sandy clay surface between two dunes in the western small dune zone. D-WL11ZK-1 (39°38.24′N, 106°29.77′E, 1310 m asl) was drilled in the high sand dune zone, and a 16 m long core was obtained after ground penetrating radar (GPR) detected a 50 m thick eolian sand deposit. Core C-WL12ZK-1 (39°42.16′N, 106°08.36′E, 1093 m asl) was drilled on a low area of compound dunes and, although this core was drilled to a depth of 120 m, only the top 80 m of the record is reported here