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Holocene environment changes around the Sara Us River, northern China, revealed by optical dating of lacustrine–aeolian sediments

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ABSTRACT

The Sara Us River is located along the boundary of the Mu Us Desert and the Chinese Loess Plateau in northern China. The river has cut down through Quaternary sediments creating 70–80 m deep valleys with thick lacustrine/aeolian sequences exposed. We applied optical stimulated luminescence on sediments from a Holocene section of aeolian sand/lacustrine deposits in the top of the river valley. The dating results show that a humid period existed from 7.1 to 2.0 ka ago as evidenced by two layers of peat and lacustrine sediments. However, compared to other published Holocene sections in the Sara Us River valleys close to the section under studying, the local environment experienced very complicated changes during the Holocene. All of the sections recorded a period with drought and/or cold before the Holocene at around 13 ka, and an episode of aridity after about 2 ka ago as evidenced by the layers of aeolian sand. However, the ages of the lacustrine and peat layers in these sections are substantially different. Geomorphological analysis by digital elevation models does not support the existence of a mega lake covering the study area at 2 ka. The intricate environmental changes may have been caused by the meandering of the Sara Us River. Environmental changes also strongly affected human migration in this area, which is documented by Chinese historical records.

1. Introduction

The Sara Us River (SUR) runs along the boundary of the Mu Us Desert (MUD) and Chinese Loess Plateau (CLP) in northern China (Fig. 1). The MUD (37°28′–39°23′N, 106°10′–110°30′E) is distributed on the southeastern portion of the Ordos Plateau and adjacent to the CLP to the south. At the northern margin of the zone dominated by the East Asian monsoon, this region experiences a climate transition from arid to semi-arid from north to south. The mean annual temperature in the MUD ranges from 5.5 to 8.0 °C. The mean annual precipitation ranges from 200 mm in the northwest to 450 mm in the southeast with more than 60% falling between July and September (Sun, 2000). Stabilized and semi-stabilized sand dunes are widely distributed in the MUD, with ~64% of the area occupied by active sand dunes. The semi-arid CLP lies within 100 km to the south of the SUR, with an average of more than 400 mm of annual precipitation. Loess-soil deposits are the typical sediments in the CLP. Because of its unique geographic location, the environment around the SUR is both sensitive and fragile, providing an ideal study area for paleoclimatic and environmental reconstructions. In the historic record, human migration occurred frequently in this area in response to the dramatic environmental changes and historic documents provide additional insight into these environmental changes (Sun, 2000).

The SUR originates in the north piedmont of the Baiyu Mountain on the northern margin of the CLP. It flows northeastward through a depression at the southern margin of the MUD and then merges into the Wuding River, a branch of the Yellow River (Fig. 1). The SUR has cut down through Quaternary sediments and forms 70–80 m deep valleys throughout its length exposing thick aeolian/lacustrine deposits. Between year of 1983 and 2000, several studies investigated the deposits on the sides of these deep valleys; these studies reconstructed the climatic and environmental changes since the Late Pleistocene (Dong et al., 1983; Li et al., 1988, 2000; Shao, 1987). The ages determined by these studies were mainly based on radiocarbon and thermoluminescence (TL) dating. Su and Dong (1997) re-determined the sedimentary age of these strata by comparing the stratigraphy of two sections in the SUR valley. That comparison identified only five dates in the

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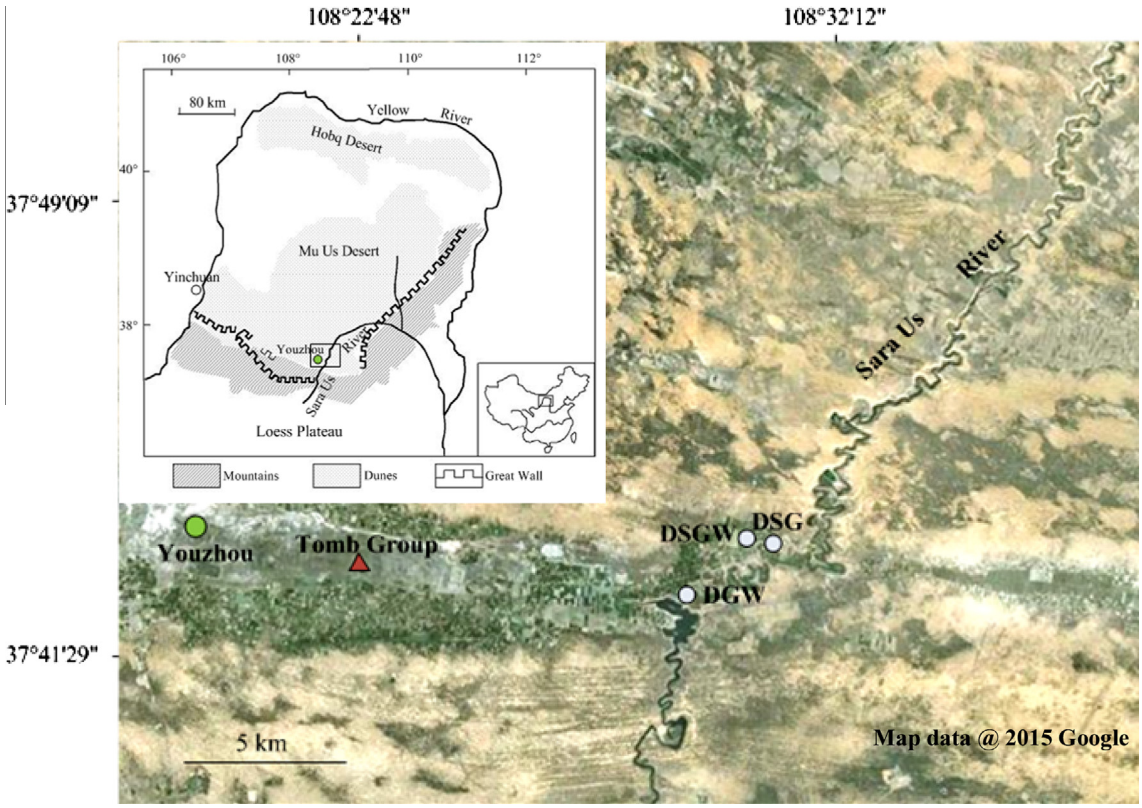

Fig. 1. Google Earth image of the study area. Index maps show the location of the image in north central China.

Holocene period. The age controls for the environmental/climatic reconstruction around the SUR for the Holocene are rather limited.

Pollen from a peat deposit section in Midiwan, about 11 km south of the SUR, was studied by Li et al. (2003), and detailed ^{14}C chronology, $\delta^{13}C$, and organic carbon analyses from the same section have also been carried out (Zhou et al., 1996, 1999). These studies suggested that the kinds of vegetation present in this study area oscillated rapidly during the Holocene under the influence of summer monsoon precipitation. Generally, a cold–dry climatic condition (11.2–10.0 ka ^{14}C yr BP) was found in the early Holocene, the Holocene optimum (10.0–7.5 ka ^{14}C yr BP) and another humid period (4.5–3.5 ka ^{14}C yr BP) were interrupted by a dry interval (7.5–4.5 ka ^{14}C yr BP). In the last 3 ka, dry conditions prevailed. However, Liu and Lai (2012) studied a Holocene section (the DSG section) in the SUR valley. They used both optical stimulated luminescence (OSL) and ^{14}C dating to build a chronologic framework for the section and they concluded that the wettest climatic conditions, evidenced by a lacustrine layer, occurred during the early Holocene at around 11 ka. In their study, the subsequent climate showed a trend of increasing aridity that led to continuous shrinkage and desiccation of the paleolake as evidenced by a shift in the lacustrine sediments to peat at about 3.2 ka. Finally, a sandy paleosol that formed between 1.8 and 1.0 ka indicated arid conditioned prevailed during the late Holocene. However, these conclusions are challenged by a study at another section in the SUR valley (called DGW) only about 2 km from DSG using OSL dating (Li et al., 2008a, 2012). After a detailed analytical program to obtain credible OSL dates, their results implied that a dry environment existed in the early Holocene before 8.35 ka followed by a wet environment that formed between 8 and 5 ka in the middle Holocene. The evidence was the presence of a lacustrine layer; the lacustrine deposits graded into fluvial deposits and reworked silty sediments indicating a dry late Holocene from 5 to 2 ka.

The studies mentioned above reached contradictory conclusions concerning the climatic changes around the SUR during the Holocene even though all of the studied sections are close to each other. Possible reasons for these contradictions include misinterpretation of the sedimentary records and misdating of the sediments. OSL dating can be applied to the Quaternary sediments using quartz or potassium-rich feldspar mineral grains to directly determine their deposition age (Wallinga et al., 2000; Wintle and Murray, 2006). This method has been successfully applied to both aeolian deposits (Li et al., 2002; Zhao et al., 2007) and waterlain sediments (Zhao et al., 2012; Chen et al., 2013) to reconstruct the Holocene environmental and climatic changes in northern China. All these successful applications of the OSL dating to Holocene samples indicate that the dating results of the published sections (DSG and DGW) are reliable. Hence, the contradictory conclusions are likely caused by misinterpretation of the sedimentary records and the deposits in the SUR valleys are therefore worthy of further study.

To this end, we investigated a new section (named DSGW) in the SUR valley less than 1 km from the DSG section. A series of OSL samples of lacustrine and aeolian sediments from the section were collected and their OSL ages determined. Based on these dates, the environmental changes and their effects on human migrations around SUR are explored and discussed.

2. Geological setting and stratigraphy

Dishaogouwan (37°43′16″N, 108°30′43″E) is one of the deep valleys with an elevation of 1298 m in the SUR (Fig. 1). It is the segment of the SUR that flows across the southeastern margin of the MUD and close to the north margin of the CLP (<100 km away). The SUR is upstream of the Wuding River and eventually flows about 300 km southeast into the Yellow River.