Palaeogeography, Palaeoclimatology, Palaeoecology 454 (2016) 1–11

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

High-resolution enviromagnetic records of the last deglaciation from Dali Lake, Inner Mongolia

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ARTICLE INFO

Article history:
Received 31 October 2015
Received in revised form 25 March 2016
Accepted 11 April 2016
Available online 16 April 2016

Keywords:
Semi-arid East Asia
Dali Lake
Last deglaciation
Paleoclimate
Environmental magnetism

ABSTRACT

Detailed paleoclimate records during the last deglaciation are highly valuable for understanding rapid climatic changes and mechanisms during extremely variable conditions. High-resolution paleoclimate research in the semi-arid East Asian interior is essential due to its sensitivity to climate variability and importance for human inhabitance. A high-resolution environmental magnetic investigation has been performed on a sedimentary sequence from Dali Lake in central Inner Mongolia, which covers the period of 15.90–11.46 ka. Variable magnetic mineral sources are identified based on integrated rock magnetic analysis of both core sediments and catchment samples, complemented by scanning electron telescope and transmission electron telescope observation and X-ray diffraction analysis. The studied core is magnetically divided into four units: Magnetic minerals in Unit 1 (11.83–11.5 m, 15.90–15.32 ka) are mainly sourced from bedrock erosion of basalts in the catchment. This period corresponds to rapid climate fluctuations after the Last Glacial Maximum. In Unit 2 (11.50–9.50 m, 15.32–12.67 ka) and Unit 3 (9.50–8.59 m, 12.67–11.56 ka), pseudo-single domain magnetites from erosion of surface soils are the main magnetic carriers. These two units coincide within time error with the Bølling–Allerød warm period and the Younger Dryas cold period, respectively, and can be correlated with stalagmite and ice core records. Our findings reflect contrasting erosion processes during cold and warm periods in the lake catchment, which were ultimately controlled by climate changes during the last deglaciation.

1. Introduction

The last deglaciation represents the youngest transition from glacial to interglacial climate stages. Study of the last deglaciation is important for understanding the natural background during extreme climate changes (Ruddiman, 2014). Attention has been paid to rapid climate oscillations during the last deglaciation since the discovery of Heinrich events and Dansgaard–Oeschger cycles (Dansgaard et al., 1993; Heinrich, 1988). Although significant advance has been made based on archives in Greenland ice cores (Stuiver et al., 1995) and North Atlantic marine sediments (Bond et al., 1993), reports of these climatic oscillations in continental Europe (Thouveny et al., 1994) and East Asia (Yuan et al., 2004) suggest their global occurrence.

Semi-arid East Asia is of great interest for paleoenvironment and paleoclimate studies (An et al., 2015). Research in this region on tectonic (Guo et al., 2002), orbital (Deng et al., 2006; Ding et al., 2002; Hao et al., 2015; Heller and Liu, 1984) and millennial scales (Ding et al., 1998; Guo et al., 1996; Porter and An, 1995) has provided a wealth of information on global and regional climate changes. The climate instability during the last deglaciation in semi-arid East Asia was mostly reported in the Loess Plateau (Ding et al., 1998; Guo et al., 1996; Zhou et al., 1999). By comparing the Chinese loess grain size with Greenland Ice-core Project (GRIP) ice core $\delta^{18}O$ and *Neogloboquadrina pachyderma* (s.) abundance in North Atlantic sediments, Porter and An (1995) proposed teleconnection between East Asia winter monsoon and North Atlantic oceanic conditions during the last glaciation. Subsequently, Guo et al. (1996) further documented this climate teleconnection through analyzing chemical weathering indices of Chinese loess and extended this behavior into the penultimate glaciation. Recently, several high-resolution enviromagnetic records on lake sediments in the semi-arid East Asia depicted climate fluctuations during the last deglaciation and Holocene (Chen et al., 2013; Liu et al., 2011, 2015; Tang et al., 2015). Given their locations at the East Asian summer monsoon limit, these lakes are highly sensitive to climate changes. Therefore, detailed

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http://dx.doi.org/10.1016/j.palaeo.2016.04.030
0031-0182/

variations between climatic extremes documented in these records are essential to explore future global changes of both natural and anthropogenic origin.

In this study, we present a high-resolution Dali Lake sediment record of the last deglaciation in Inner Mongolia, northern China. The 11.83-m core DL04 was drilled in 2004. Results of the upper 8.5 m (0–11.5 ka) have been described in Liu et al. (2015), which documented a biomagnetic response recorded as magnetofossils to the Holocene Warm Period. Here, the lower part of the core was systematically studied using multi-parameter rock magnetic methods. Based on changes in magnetic mineralogy, concentration and grain size, we have investigated the magnetic mineral sources and depositional processes. We interpret these magnetic changes as representing rapid climate fluctuations during the last deglaciation.

2. Geological setting, sampling and chronology

Dali Lake (43°13′–23′ N, 116°29′–45′ E, ~1230 m a.s.l.) is an inland closed-basin lake in central Inner Mongolia (Fig. 1). It currently has an area of 238 km^2 and a maximum water depth of 11 m. The lake floor has a steep slope near the shore and an almost flat bottom toward the center. Given its location just at the modern limit of the East Asian summer monsoon (Fig. 1a), the lake sedimentation process should be highly sensitive to monsoon variability. Therefore, the lake sediments provide

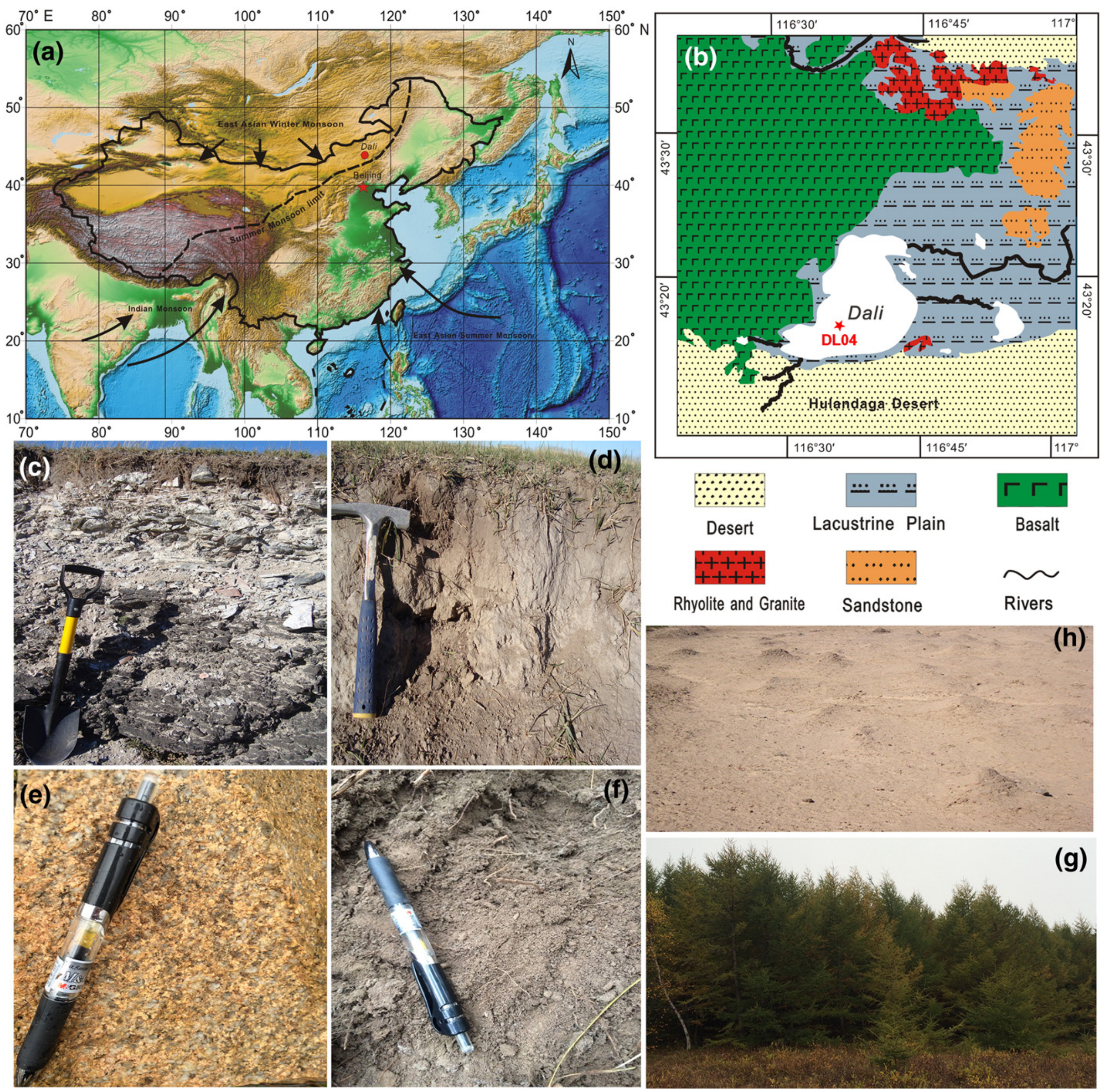

Fig. 1. Geological setting of Dali Lake, core position and catchment samples. a, Regional atmospheric circulations (arrows, the East Asian summer monsoon, East Asian winter monsoon and Indian Monsoon) and modern summer monsoon limit (dashed line); b, geological setting of Dali Lake; c–h, photographs of catchment samples. c, Basalt; d, grassland soils around the lake; e–g, granite, forests and forest soils at the Huanggangliang highland at the headwater areas. The Huanggangliang highland is about 80 km northeast of Dali Lake, with its peak at 43°34′ N, 117°37′E, ~1770 m a.s.l.; h, sand dunes in Hulandaga Desert.