Quaternary International xxx (2017) 1–12

Contents lists available at ScienceDirect

Quaternary International

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

A multi-proxy record of environmental changes during the Holocene from the Haolaihure Paleolake sediments, Inner Mongolia

Jin Liu [a, b, c, d], Yang Wang [c, d, e, *], Yong Wang [a, **], Youyi Guan [f], Jin Dong [a], Tingdong Li [a]

[a] Institute of Geology, Chinese Academy of Geological Sciences, Beijing, 100037, PR China
[b] China University of Geosciences, Beijing, 100083, PR China
[c] Department of Earth, Ocean, and Atmospheric Science, Florida State University, Tallahassee, FL, USA
[d] High National Magnetic Field Laboratory, Tallahassee, FL, USA
[e] Institute of Hydrobiology, The Jinan University, Guangzhou, Guangdong Province, 510632, PR China
[f] Hubei Earthquake Administration, Wuhan, Hubei Province, 430071, PR China

A R T I C L E I N F O

Article history:
Received 7 June 2016
Received in revised form
1 December 2016
Accepted 8 December 2016
Available online xxx

Keywords:
Stable isotopes
Holocene paleoclimate
Asian Summer Monsoon
Haolaihure Paleolake
Climate event

A B S T R A C T

The east Central Inner Mongolia is located near the present-day limit of the Asian Summer Monsoon (ASM) influence and therefore sensitive to both regional and global climate change. Here, we present the high-resolution proxy record of regional paleoclimate evolution over the past 12.2 cal ka BP, based on analyses of grain size and organic geochemical proxies (i.e., TOC, TN, C/N, $\delta^{13}C$ and $\delta^{15}N$) preserved in sediments from the Haolaihure Paleolake. The multi-proxy record reveals a cool and dry period from 12.2 to 8.7 cal ka BP and a relatively warm and wet stage from 8.7 to 2.2 cal ka BP, interrupted by a short interval of reduced precipitation at 4.6–3.7 cal ka BP. After 2.2 cal ka BP, the regional environment deteriorated as climate shifted to generally cooler and drier conditions in the area, with a brief return to a warm and wet climate during the Medieval Warm Period. The record also indicates severe drought in the region during the Younger Dryas event. Comparison with other proxy paleoclimate records in Inner Mongolia, South China and central Asia suggests that the environmental conditions in the east central Inner Mongolia were primarily controlled by the ASM in the early to mid-Holocene while the Westerlies appeared to be a major driver of environmental changes in the late Holocene. Six of the eight cool and dry events recorded in Haolaihure Paleolake sediments are in phase with the ice-rafting events in the North Atlantic, and were possibly caused by weakening of both the ASM and the Westerlies.

1. Introduction

The Westerlies and the Asian Monsoon (AM) are two major climate systems influencing the environmental conditions in China. The Westerlies provide a major source of atmospheric moisture (originating from the North Atlantic) for the arid northwestern region of China (Wang et al., 2005a; Chen et al., 2008). The Asian Summer Monsoons (ASM), including East Asian Summer Monsoon (EASM) and Indian Summer Monsoon (ISM), bring warm and moist air from tropical oceans to inland and provide the much needed precipitation to the south and east China during summer months. The position of ASM limit is controlled by the ASM strength and varies on various time scales in response to changes in global climate (Yang et al., 2015). The decadal mean locations of the ASM limit for 1968–1978 and 1978–1998, determined from the modern meteorological data (Qian et al., 2007), were approximately along the Great Khingan Mountain and the central and eastern Inner Mongolia (Fig. 1A). The transitional zone between the Westerlies and ASM regimes is particularly sensitive to climate change. Although many studies have investigated the paleoenvironment in the region (Xiao et al., 2006; Chen et al., 2010; Chu et al., 2014; Tang et al., 2015; Zhang et al., 2016), long-term climatic history in this region remains poorly understood. Some studies suggested that the humid condition occurred in the mid-Holocene (Feng et al., 2006; Xiao et al., 2006; Wang et al., 2013a), while others thought that the region was humid in early and mid-Holocene (Jiang et al., 2006, 2010; Wang et al., 2012). The controversies over both the timing and duration of the Holocene climatic optimum may be partly caused by the uncertainties in proxy interpretation and dating and

* Corresponding author. Department of Earth, Ocean, and Atmospheric Science, Florida State University, Tallahassee, FL, USA.
** Corresponding author. Institute of Geology, Chinese Academy of Geological Sciences, Beijing, 100037, PR China.
E-mail addresses: ywang@magnet.fsu.edu (Y. Wang), wangyong@cags.ac.cn (Y. Wang).

http://dx.doi.org/10.1016/j.quaint.2016.12.015
1040-6182/

Please cite this article in press as: Liu, J., et al., A multi-proxy record of environmental changes during the Holocene from the Haolaihure Paleolake sediments, Inner Mongolia, Quaternary International (2017), http://dx.doi.org/10.1016/j.quaint.2016.12.015

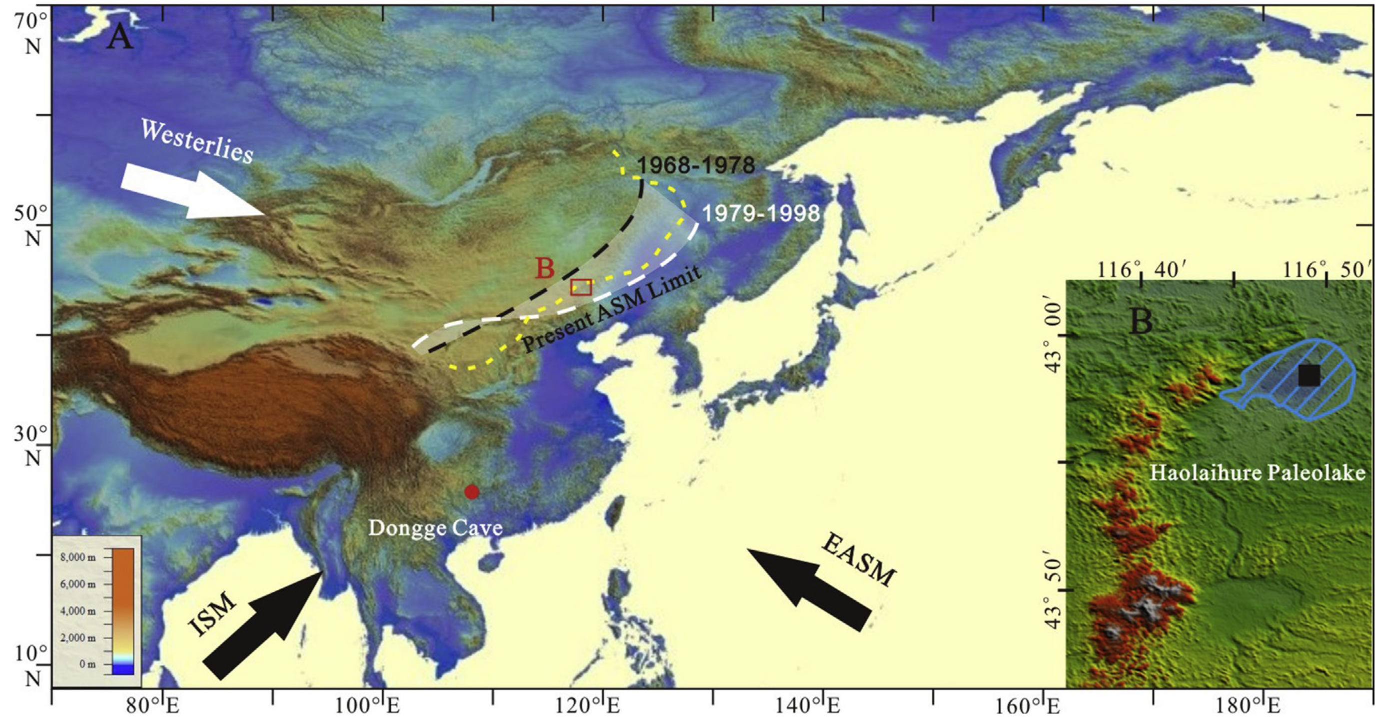

Fig. 1. Location of the Haolaihure Paleolake and dominant circulation systems in China. The dash lines represent decadal mean locations of the ASM limit for the year 1968–1978 (black) and 1978–1998 (white), respectively (from Qian et al., 2007). The yellow dash line is the boundary of modern vegetation zone between warm-temperate broadleaved deciduous forest and steppe (Sun and Wang, 2005). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

by differences in geographic locations of the various proxy records (Tang et al., 2015). Moreover, high-resolution paleoclimate records from ice cores, tree rings, speleothems and marine sediments from other parts of the world have revealed abrupt changes in climate over the 13,000 years (Stuiver et al., 1995; Bond et al., 1997; Cheng et al., 2006). But, only a few climatic events have been noted in the Westerlies-ASM transitional zone due to the relatively low resolution of the existing paleoclimate records (Wang et al., 2001; Liu et al., 2002; Sun et al., 2006). Well-dated high-resolution records from this transitional region are needed to provide detail information about paleoenvironmental conditions, and to help fully understand the regional climate history and offer an insight into future climate changes (An et al., 2000).

In this paper, we present a well-dated lacustrine sediment record from the Haolaihure Paleolake in east Central Inner Mongolia located in the Westerlies-ASM transitional zone. The new record spans a time interval from 12.2 cal ka BP (thousands of calibrated years before present; 0 years BP = 1950 CE) to the present, with a resolution of ~22 years. Grain size character and organic geochemical signatures of the sediments, including percentage contents and isotope ratios of carbon (C) and nitrogen (N) and $(C/N)_{atomic}$ ratio, were examined to reveal the past changes in environmental conditions in the area. The results were compared with other paleoclimate records in China as well as the record of ice-rifting events in the North Atlantic region to elucidate the possible drivers of environmental changes in the region.

2. Study area

The study section of the Haolaihure Paleolake (42°57′2″N, 116°47′37″E, 1295 m above sea level, m a.s.l.) is located in the southeastern Otindag Desert in the east Central Inner Mongolia, China (Fig. 1). The paleolake has dried out and since been covered by an eolian sand layer. The present-day climate in the area is characterized by a dry windy spring, a wet short summer and a cold long winter (Li, 1993). The average annual temperature is 0–1 °C, with the highest of ~16 °C in July and the lowest of ~ -23 °C in January; the annual precipitation is ~250 mm concentrated in July and August brought by the ASM, and evapotranspiration is more than 1300–1900 mm (Li, 1993). The area is in the ASM-Westerlies transitional zone and also in the transition region of modern vegetation zones, with the temperate deciduous and mixed forest biomes in the south and east and temperate steppe in the north and west (Liu, 1988; Sun and Wang, 2005) (Fig. 1). The area around the lake is dominated by a mosaic of *Artemisia*–*Betula*–*Chenopodiaceae* woodlands and grasslands. A mixture of *Betula*–*Pinus*–*Artemisia* and *Betula*–*Artemisia* woodlands and grasslands are distributed in the Great Khingan Mountain in the east, and *Artemisia*–*Chenopodiaceae* steppe in the west (Liu et al., 2002).

3. Materials and methods

3.1. Lithology and chronology: radiocarbon and OSL

The Haolaihure profile is 545 cm thick and can be divided into five sections based on the lithology: (1) light green clay from 545 to 503 cm depth, with a light grey fine sand layer at 526–514 cm depths; (2) black clay with lamination from 503 cm to 406 cm; (3) dark grey clay with lamination from 406 cm to 210 cm; (4) light grey clay from 210 cm to 30 cm; (5) light yellow fine sand from 30 cm to 0 cm.

Since no visible terrestrial plant debris was found in the lake sediment layer, we collected a total of 12 bulk organic matter (OM) samples from the strata with relatively abundant organic materials for accelerator mass spectrometry (AMS) ^{14}C dating. Three of them (HL12-35, HL12-40, HL12-70) were measured at Beta Analytic Inc., Miami, USA, and the rest of the samples were analyzed in the Institute of Heavy Ion Physics School of Physics at Peking University,