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Paleoclimate interpretation in northern Ordos Basin: Evidence from isotope records of groundwater

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ABSTRACT

The hydrogen and oxygen stable isotopes are the indicative evidences of paleoclimate change. δD and $\delta^{18}O$ composition of groundwater is commonly used to provide information on the climate record. This study focuses on the isotopic evidences of paleoclimate variations in the Northern Ordos Basin, where the Cretaceous groundwater have different ages since the middle age of Late Pleistocene. The hydrogen/oxygen stable isotopic compositions are analyzed and groundwater age is calculated by 14C based on 59 groups of data collected from 16 boreholes in the study area. The δD and $\delta^{18}O$ data indicate that the temperature is relatively low in the middle age of Late Pleistocene, and it became to get warmer since the Holocene, which coincides with the variation of global scale. It is also found that the δD and $\delta^{18}O$ could be divided into two groups in terms of groundwater age, the Holocene (<15 ka BP) and the middle stage of Late Pleistocene (31–19 ka BP). There exists a remarkable gap of groundwater age in the late stage of Late Pleistocene (19–15 ka BP), which corresponds to the last glacial maximum (LLM), it is concluded that this gap may be caused by the periglacial covered over the northern of Ordos Basin in these period when the groundwater recharge from precipitation is prevented by ice sheet or frozen soil. The results obtained in this study will provide useful insights for paleoclimate reconstruction in Ordos Basin.

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1. Introduction

Stable isotope geochemistry has been used as an indicator of palaeoclimate since the work of McCrea (1950) and Urey et al. (1951) highlighted the potentials of oxygen isotope compositions to be used for palaeotemperature reconstruction. Climatic factors govern the stable isotopic content of precipitation, and the relationship between the specific parameters such as temperature or precipitation amount and precipitation isotopic content allows the reconstruction of past climate from paleoclimatic archives. Globally, tree rings, pollen records, corals, speleothems, peat bogs, ice cores, and marine and lake sediments are the important paleoarchives used for paleoenvironmental studies. The resolution of these paleoenvironmental records depends on the quality of these natural archives (Martinez-Ruiz et al., 2015; Streletskaya et al., 2011). Numerous studies have attempted to infer paleoclimate information from the isotopic composition (δD and $\delta^{18}O$) of paleoprecipitation preserved in natural archive materials, such as glacial ice, tree rings, lake sediments, freshwater mollusks, pedogenic carbonates, fluid inclusions in speleothems, and speleothem calcite (Thomas and Burrough, 2013; Duller, 2016; Li et al., 2016; Rybin et al., 2016; Shu et al., 2017). Variations of δD and $\delta^{18}O$ in water and ice cores are important indicators of present and past hydrologic processes and climate. The record of these isotope variations in polar ice cores is certainly one of the most detailed and important pieces of information on climate conditions over glacial and interglacial (Luz et al., 2009; Lacelle, 2011). The validity of using the isotopic composition of paleowater (e.g., from deep ice cores or lake sediments) for inferring paleotemperatures has been reviewed in the articles principally focusing on Greenland ice core data (Jouzel et al., 1982; Jouzel and Merlivat, 1984). The last global glacial age is estimated about 24–14 ka BP according to the isotopic data from the ice core, stalactite, sediment fossil, and subsequent 14–12 ka BP was Bolling-Allerod warm stage, 12–10 ka BP appears a cold stage, i.e., Younger Dryas climate event. Afterwards, Holocene almost is dominated by warm climate, during which short cold climate event occurred in different areas (Lu et al., 2013a; Shackleton et al., 2004; Rohling et al., 2009; Wan et al., 2010). In North china, paleoclimate was predominantly determined by ice edge and Quaternary deposit

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of loess. Li et al. (2016) presented a leaf wax n-alkane records from northwest-southeast loess transect in the Chinese Loess Plateau since the Last Glacial Maximum (LGM). Lu et al. (2013b) has performed an investigation of East Asian monsoon precipitation in the area of Chinese loess deposits, which included Ordos Basin. Cui and Xie (1984) and Cui et al. (2004) found the south boundary of permafrost in the last glacial period. However, there exists some controversy for confirmation of permafrost or seasonal frozen soil. Therefore, thorough evidence is required to reconstruct the environmental evolution.

The objective of this study is to provide isotopic evidence for interpretating paleoclimate variations in the Ordos Basin, for this purpose, the stable isotopes of Hydrogen and Oxygen (^{2}H and ^{18}O) of the samples obtained from the boreholes located at different depths were analyzed, at the same time ^{14}C age dating investigation was conducted. The observed isotopic compositions and groundwater age demonstrate that there exists permafrost in northern Ordos Basin during 19–15 ka BP, indicated by the absence of groundwater recharge. This research illustrates how stable isotope studies contribute to an understanding of climate changes, which provides useful insights and implications for reconstructing paleoclimate.

2. Description of study area

The Ordos Plateau is a large-scale sedimentary basin in China, located at the interior of Eurasia. The Northern Ordos Basin lies between 37°10′N and 40°30′N, and 106°45′E and 110°08′E, extending 360 km in the N–S direction and 210–260 km in the E–W direction, covering an area of 81,000 km^2. The elevation of the Ordos Basin decreases from 1400 to 1500 m above sea level (asl) along the central Sishi Ridge to 1100–1200 m asl along the eastern, western, and northern margins. The Baiyu Mountain at the southern margin has an elevation ranging 1500–1800 m asl (Fig. 1).

Ordos Plateau belongs to eastern Eurasia temperature zone, and the climate is characterized with East Asian Monsoon climate, also called arid to semi-arid climate, a long cold winter and short warm summer result in a scare rainfall and intensive evaporation. Seasonal variations in temperature and precipitation are evident, mainly occurs from March to October, and approximately 60–80% of rainfall concentrate in July, August and September, with a value about 420 mm/yr in the southeast to 160 mm/yr in the northwest. Precipitation record from 1988 to 2012 showed there were 72 precipitation events per year, of which 6 events with rainfall

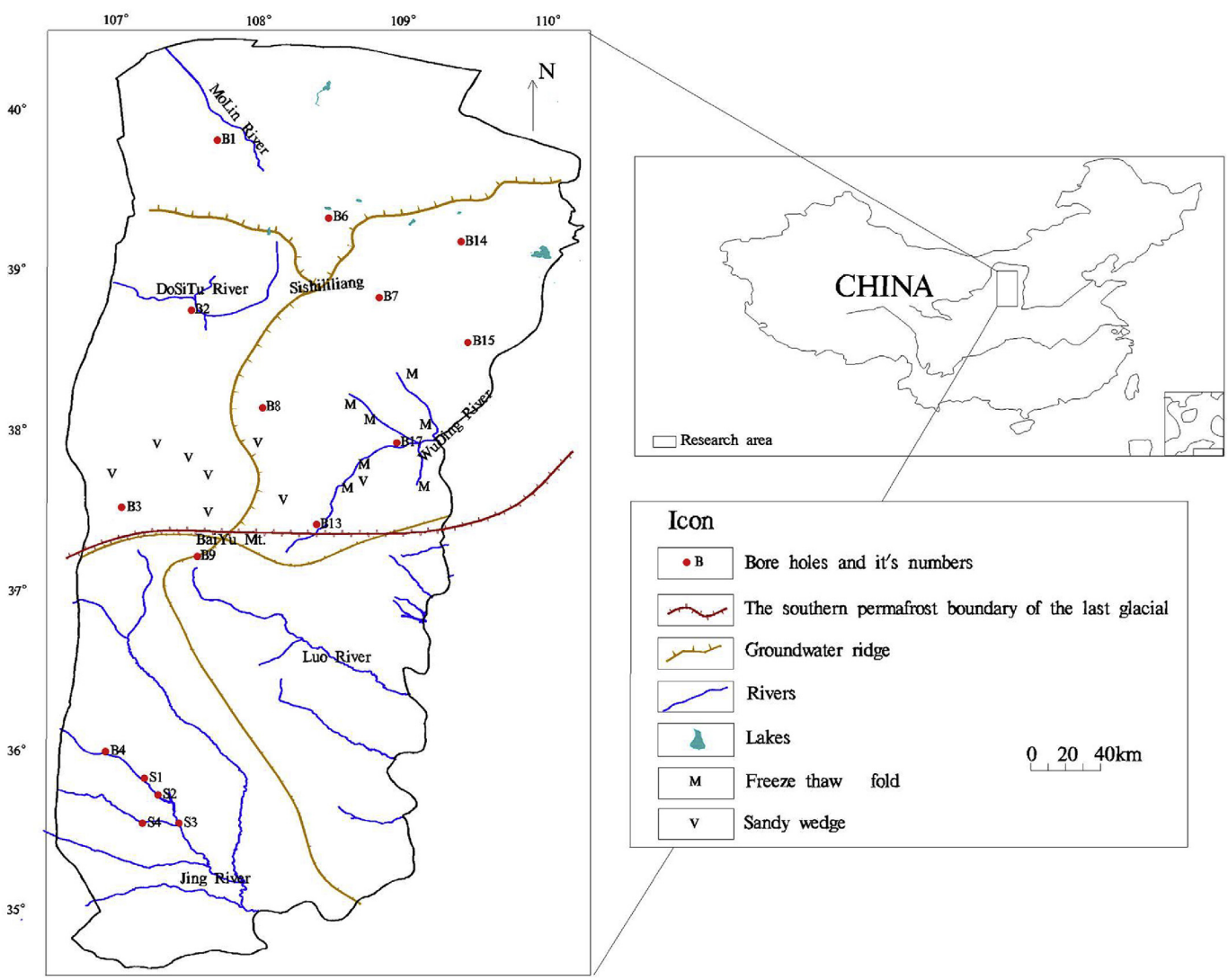

Fig. 1. Outlined location map of study area (South boundary of permafrost of last glacial from Cui et al., 2004, Frozen-thawed drape and soil wedge from Dong et al., 1985).

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