Journal of Asian Earth Sciences 127 (2016) 267–280

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Full length Article

Clay mineralogical and geochemical constraints on late Pleistocene weathering processes of the Qaidam Basin, northern Tibetan Plateau

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ARTICLE INFO

Article history:
Received 31 December 2015
Received in revised form 9 June 2016
Accepted 14 June 2016
Available online 27 June 2016

Keywords:
Clay minerals
Weathering process
Major-element geochemistry
Late Pleistocene
Qarhan Salt Lake
The Qaidam Basin

ABSTRACT

At the Qarhan Salt Lake (QSL) on the central-eastern Qaidam Basin, northern Tibetan Plateau, Quaternary lacustrine sediments have a thickness of over 3000 m and mainly composed of organic-rich clay and silty clay with some silt halite and halite. In this study, a 102-m-long sediment core (ISL1A) was obtained from the QSL. Combining with AMS ^{14}C and ^{230}Th dating, clay minerals and major-element concentrations of ISL1A were used to reconstruct the weathering process and trend of the QSL since late Pleistocene. The results reveal that the clay mineral from <2 μm fraction in ISL1A is composed of illite (47–77%), chlorite (8–27%), smectite (including illite-smectite mixed layers, 3–29%) and kaolinite (2–11%). Such clay mineral assemblages in ISL1A derived primarily from felsic igneous rocks, gneisses and schists of Eastern Kunlun Mountains on the south of the QSL. The abundance of illite mineral displays an opposite fluctuation trending with that of smectite, chlorite and kaolinite mineral in ISL1A, which is significantly different from the monsoon-controlled regions. Moreover, higher values of illite, kaolinite/chlorite and illite/chlorite ratios, and lower values of smectite, chlorite and kaolinite minerals occurred in 83–72.5 ka, 68.8–54 ka, 32–24 ka, corresponding to late MIS 5, late MIS 4, early MIS 3 and late MIS 3, respectively. These three phases were almost similarly changed with oxygen isotopes of authigenic carbonates and pollen records in ISL1A, which implies that stronger chemical weathering corresponds to higher effective moisture periods of source region in the Qaidam Basin. Based on chemical weathering index and (Al_2O_3-($CaO + Na_2O$)-K_2O) diagram, chemical weathering degree in this study area takes a varying process from low to intermediate on the whole.

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1. Introduction

The uplift of the Tibetan Plateau (TP) and its environmental effects during the Cenozoic have been widely studied since tectonic uplift–weathering hypothesis was proposed by Raymo et al. (1988). On the one hand, the uplift of TP fostered Asian monsoon climate systems and the evolution of river basins in East and South Asia; On the other hand, weathering or erosion process from these river basins on the TP plays a key role in surface processes and geochemical cycles in earth supergene environments, including global carbon cycle and chemical composition of the oceans (Berner et al., 1983; Raymo and Ruddiman, 1992; Kump et al., 2000). Previous studies have focused on main drainage basins around the TP, such as the Mekong drainage basin (Liu et al., 2004; Noh et al., 2009; Borges et al., 2008), the Salween drainage basin (Noh et al., 2009; Borges et al., 2008), the Yangze River catchment (Yang et al., 2006; Wang and Yang, 2012; Shao and Yang, 2012) and the Yellow River drainage basin (Li, 2003; Yang et al., 2004). And the results indicate that there is a strong relationship between weathering/erosion and the climate change during glacial and interglacial periods (Liu et al., 2004; Yang et al., 2006; Borges et al., 2008).

However, the research on weathering process in the source region of the Qaidam Basin on the northern TP is still limited and unclear due partly to limited numbers of long continuous paleoclimatic records. Most previous records in the Qaidam Basin extend only as far back as the late glacial or early Holocene (Zhao et al., 2007, 2008; Liu et al., 2008), although there are a few low resolution paleoclimate records extending back to the last glacial or the late Pleistocene (Chen and Bowler, 1986; Chen et al., 1990; Huang and Chen, 1990; Zhang et al., 1993; Yang et al., 1995). In recent works, high resolution pollen and oxygen isotope records of lacustrine sediments in ISL1A were obtained spanning the last glacial period (Fan et al., 2014a; Wei et al., 2015). The results show

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http://dx.doi.org/10.1016/j.jseaes.2016.06.013
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that three drier climatic intervals at 90–80 ka, 52–38 ka and 10–9 ka, correspond to the late MIS 5, middle MIS 3 and early Holocene, respectively, were identified based on the oxygen isotope record (Fan et al., 2014a). Fan et al. (2014a) also argued that "a uniform Qarhan mega-paleolake" spanning the period of ~44–22 ka mentioned by predecessors may not have existed because a relatively dry climate with high $\delta^{18}O$ values corresponded to this period. Furthermore, the pollen results reported that the identification of the primary wetter periods of late MIS 5, early MIS 4, early and late MIS 3 in the Qarhan Salt Lake (QSL) region (Wei et al., 2015).

Here we present a ~500-yr-resolution clay-mineral record in ISL1A to develop a better understanding of the paleoclimate information recorded in deposits of QSL in the Qaidam Basin. Because clay minerals in sediments present a record of weathering conditions in the watershed, they have often been used as a proxy in paleoclimate reconstructions (e.g., Chamley, 1989). In this study, we attempted to establish the relationship between weathering/erosion and the climate in QSL region since the late Pleistocene.

2. Regional setting

The Qaidam Basin is the largest intermontane endorheic basin on the northern TP (Fig. 1). It located at the northern TP with an average elevation of 2800 m a.s.l., and influenced by both of the East Asian summon monsoon, the Westerlies and the Siberian high (Fig. 1A). The basin area is ~120,000 km^2 and its catchment covers approximately 250,000 km^2. It is enclosed by three large mountain belts: the Aljun Mountains to the northwest, the eastern Kunlun Mountains to the south and the Qilian Mountains to the northeast. It contains 27 salt lakes, many of which were linked via thick salt beds and brines, and a very thick (>3000 m) sequence of Quaternary sediments deposited in the central Qaidam Basin (Chen and Bowler, 1986; Zhang, 1987; Liu et al., 1998) (Fig. 1B).

As the largest playa of the Qaidam Basin, QSL region is the depocenter of the Qaidam Basin during the Quaternary, covering an area of approximately 5856 km^2 (Chen and Bowler, 1985, 1986; Liu et al., 1998) (Fig. 1B). It has a surface elevation of 2675 m a.s.l. at the lowest point in the depression (Chen and Bowler, 1985). In contrast, the mountains surrounding the QSL reach an average elevation of 3500–4500 m a.s.l. (Zhang, 1987), which results in the basin-and-range topography in the study area (Fig. 1B). From west to east, the QSL is divided into four sections: Bieletan, Dabuxun, Qarhan and Huobuxun (Fig. 1C). There are 9 residues brine lakes with different sizes scattered in the playa, and field investigation indicates that there are 18 rivers originating from the Kunlun Mountain to feed into the QSL (Yuan et al., 1995) (Fig. 1C).

The QSL area is also one of the driest places in the world with a mean annual temperature of 5.2 °C, the mean annual precipitation level is approximately 24 mm, while the mean annual evaporation level reaches 3564 mm (Yang et al., 1993; Fan et al., 2014a). However, the mean annual precipitation on the northern slopes of the Kunlun Mountain is slightly greater than that of QSL. Additionally, the average wind speed is 4.3 m/s and relative moisture is 27.7% (Yu et al., 2009).

The landscapes of the QSL area can be divided into 6 major types (Yang et al., 1993) (Fig. 1C): (1) Mountains are present primarily on the north and south sides of the lake. The Eastern Kunlun Mountains, located along the south side of the lake, are underlain primarily by Proterozoic gneiss and schist, and lower Paleozoic greenschist and carbonate rocks that were widely intruded by polyphasic granitic rocks of the Caledonian, Variscan, Indosinian and Yanshanian orogenies. The Xitieshan and Amunike Mountains, located on the north side of the lake, are underlain primarily by Proterozoic gneiss, schist and marble and Paleozoic biotite schist with intermediate–mafic to felsic volcanic rocks and volcaniclastic rocks that were intruded by polyphasic ultrabasic to felsic igneous rocks of the Caledonian, Variscan and Indosinian orogenies. Fissures in the bedrock produce local bedrock aquifer. (2) Gobi zones are located primarily on the south side of the piedmont and consist of ancient alluvial–pluvial fans. The lithology of this region is dominated by glutenite and gravel strata, which constitute the main phreatic aquifer of the piedmont clinoplains. (3) Alluvial–pluvial plains are primarily distributed as east–west–trending belts with widths of 10–15 km on the south side of QSL. These plains are used for farming and grazing and contain numerous springs. Sand, gravelly sand, clayey sand and clay are the primary lithologic types in this area and constitutes the overlapped artesian aquifer of the alluvial–lacustrine plains. (4) Lacustrine plains are primarily along the east, south and west sides of QSL and have widths of several to tens of kilometers. Centripetal radial networks of dry gullies extend across this area, and the lithology is primarily composed of silty sand, clayey sand and clay soil. (5) Playas dominate the flat, saline desert landscapes of the QSL region. The surfaces of playas are covered with various types of salt crust composed primarily of halite. There are also intercrystalline brine deposits. (6) Brine lakes dominate the western, southern and eastern edges of the playas and formed primarily in the convergence areas of rivers (including intercrystalline brine deposits) and lakes.

3. Materials and methods

3.1. Sediment core and dating

The core ISL1A (37°3′50″N, 94°43′41″E) was obtained from the Bieletan section of Qarhan playa (Fig. 1B). The lithostratigraphy of the core alternates primarily between evaporite layers and silt-clay sediment layers from 0 to 51.1 m, and between silt and organic-rich clay sediments from 51.1 to 102 m (Fig. 2).

Twelve clay samples containing dark organic matter were collected from the upper 54.5 m of the core for accelerator mass spectrometry (AMS) ^{14}C dating, and eight halite samples were collected from the upper 46.0 m of the core for ^{230}Th dating. An assessment and comparison of these ^{230}Th and AMS ^{14}C ages have been discussed in detail by Fan et al. (2014b). In addition, three carbonate samples were collected from 64.5 to 98.9 m of the core for isochron ^{230}Th dating. The impure carbonate samples were dissolved with 0.1 M HCl, 1 M HCl and HF-$HClO_4$, respectively, to obtain isochron ^{230}Th ages. Chemical procedures followed those described by Ma et al. (2004, 2010). ^{230}Th ages of carbonate deposits were determined using an Octête® plus alpha spectrometer, with a vacuum of 20 mT and an energy resolution (FWHM) of approximately 25 keV at 5.15 MeV. Analyses were conducted at the U-series Dating Laboratory of The Institute of Geology and Geophysics, Chinese Academy of Sciences.

3.2. Clay mineralogy analysis

A total of 154 samples were taken at intervals of approximately 50 cm from the core for clay mineral analysis. Of these, 53 samples were taken from the evaporation sequence, and the rest were taken from lacustrine silt-clay sedimentary strata. The clay fraction (<2 μm) were isolated from deflocculated suspensions using Stoke's Law in a setting beaker. Relative clay mineral contents in the core samples were determined with X-ray diffraction (XRD) according to the procedures and methods described in detail by Petschick et al. (1996) and Liu et al. (2004). All clay samples were processed on oriented mounts of non-calcareous clay-sized (<2 μm) particles (Holtzapffel, 1985). And three XRD runs were performed, following air-drying, ethylene-glycol salvation for 24 h, and heating at 490 °C for 2 h. The measurements were conducted on PANalytical X' Pert PRO diffractometer with CuKα

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