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Geochronology and Mineral Composition of the Pleistocene Sediments in Xitaijinair Salt Lake Region, Qaidam Basin: Preliminary Results

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ABSTRACT: Xitaijinair (XT) Salt Lake, located in the western Qaidam Basin, is significant for reconstructing the evolution of inland drying climate. However, the chronological and mineralogical records from this lake are rare. This study investigated the chronology (accelerator mass spectrometry (AMS) ^{14}C ages and optically stimulated luminescence (OSL) ages) and mineral compositions of sediment in the 240-cm-deep XT Section of the Xitaijinair Salt Lake region. The conclusions are drawn as follows: (1) Nine AMS ^{14}C ages, ranging between 33 and 40 cal ka BP, are obviously younger than the two OSL ages (57.9 and 69.1 ka). The ^{14}C ages probably reflect contamination with modern carbon. (2) Both ^{14}C and OSL ages indicate that the surface of Xitaijinair Salt Lake region has suffered erosion. (3) The sediments of XT Section are composed of silicates (quartz, muscovite, clinochlore and albite), carbonates (calcite, dolomite, and ankertie), halite and gypsum.

KEY WORDS: Qaidam Basin, Xitaijinair Salt Lake, geochronology, Pleistocene.

0 INTRODUCTION

Salt lakes are widely distributed in the Qinghai-Tibetan Plateau (QTP). As a product of climate change, salt lake deposits preserve valuable information about past environmental changes. Dating methods (^{14}C dating, luminescence dating, U-series dating and paleogeomagnetic dating) combined with geochemistry, sedimentology, mineralogy and micropaleontology methods have been applied to retrieve the past environmental information that is recorded in salt lake deposits (Fan et al., 2013; Han et al., 2013; Wang et al., 2013; Zheng et al., 2007). The evolution of salt lake in the QTP has been clearly affected by global climate change (Huang and Chen, 1990). The salt formation was controlled by intra-basinal tectonic movement, migration of paleo-rivers and climate drying during the Pliocene and Quaternary (Wang et al., 2013).

Salt lakes are extensively developed in the Qaidam Basin, northeastern QTP. The Qaidam Basin is the most important source of potash for Chinese agriculture. Investigations demonstrated that the depocenter of the Qaidam Basin migrated from the west in the Pliocene to the east in the Quaternary, induced by the formation of anticlines (Wang et al., 2013).

Xitaijinair Salt Lake, situated in the western Qaidam Basin, is surrounded by the Yiliping depression to the northwest, and the Dongtaijinair Salt Lake (Dongtai) to the southeast (Fig. 1). The paleoclimatic changes have been interpreted based on drill cores from Kunteyi playa (ZK3208) (Han et al., 1995) and the Qarhan salt playa (Liang and Huang, 1995; Huang and Chen, 1990). Recently, the chronology and environmental proxies of drilled cores from Qarhan Salt Lake (ISL1A) (Fan et al., 2014, 2013; An et al., 2012; Long, 2011), Dalangtan playa (Liang ZK02, Liang ZK05) (Hou et al., 2010; Shi et al., 2010), and Gahai Lake (DG-02) (He et al., 2014) have been studied. However, the conclusions of the climatic changes during the Late Pleistocene obtained by the same core ISL1A are contradicted (Wei et al., 2015; Fan et al., 2014). The U-series and OSL (optically stimulated luminescence) dating of the salt crusts in the west Qaidam Basin indicated that the salt crusts have an age of about 100 ka and that sediments beneath these salt crusts were protected from the wind erosion (Han et al., 2013). These results do not support the idea that many materials have been removed from the Qaidam Basin by wind erosion (Kapp et al., 2011).

Similar to other salt lakes in the Qaidam Basin, Xitaijinair Salt Lake is important in research of paleoenvironment. However, up to now, there is no report about the chronology and mineral compositions of the sediments in this lake. This study aims to investigate the chronology and mineral compositions of a section from the Xitaijinair Salt Lake region and their

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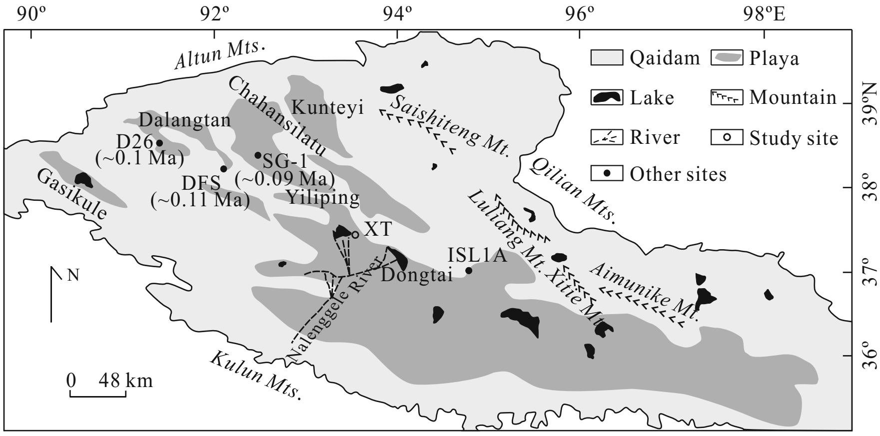

Figure 1. Location of the Xitaijinair Section (XT Section) in the western Qaidam Basin (ages under the sites are surface ages of the playas; revised from Han et al., 2013).

implications for geomorphic processes in the study region during the Late Pleistocene.

1 MATERIALS AND METHODS

1.1 Section Setting

Nalenggele River flows into the Xitaijinair Salt Lake. Huge alluvial fans have developed in the south of the Xitaijinair Salt Lake. Xitaijinair Lake Basin is a closed rift basin, presenting a triangular shape. The Late Pleistocene and Holocene strata are composed of clay, sands and salts (Zhang et al., 2007).

A lithologic section of the Xitaijinair Salt Lake region, named the XT Section (37°40'42.69"N, 93°32'47.73"E, 2 692 m a.s.l.), lies in the east part of the lake (Fig. 1). The section was excavated to a depth of 240 cm (Fig. 2). The lithology of the XT Section from the top to bottom is as following: 0–25 cm, red clay-silt; 25–47 cm, green silt; 47–185 cm, red clay-silt; 185–199 cm, green silt interbedded with red clay-silt; 199–240 cm, red clay-silt.

Two OSL samples at depths of 40 and 190 cm were obtained by using a steel tube (20 cm length, 5 cm diameter). Bulk samples were collected at 2 cm intervals.

1.2 Laboratory Analysis

Nine accelerator mass spectrometry (AMS) ^{14}C ages for bulk organic matter were analyzed in the Center for Applied Isotope Studies at the University of Georgia, USA.

OSL dating was conducted on an automated Risø TL/OSL DA-20 reader by method of Single Aliquot Regeneration (SAR) (Murray and Wintle, 2000) at the Qinghai Institute of Salt Lakes, Chinese Academy of Sciences. The quartz grain size for OSL dating is 90–125 μm fractions. U, Th and K concentrations were measured by neutron activation analysis (NAA) at the China Institute of Atomic Energy in Beijing. The procedure and calculation of OSL dating for this study are similar to those described in detail by Fan et al. (2010).

The mineral compositions of the 63 samples (about 4 cm interval) that were ground to powder (<75 μm) by ball mill were analyzed by X-ray diffraction (XRD) using a Panalytical X-pert Pro diffractometer at Qinghai Institute of Salt Lakes, Chinese Academy of Sciences. The relative volume percent of the mineral is calculated by a formula (Chung, 1974), based on the intensity of diffraction for the sample.

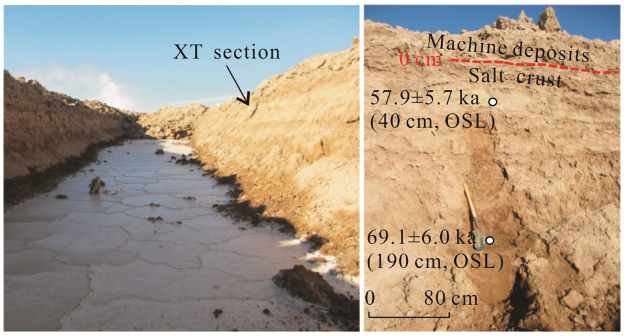

Figure 2. Photos of the XT Section in the Xitaijinair Salt Lake region.

2 RESULTS AND DISCUSSION

2.1 Chronology of Radiocarbon and OSL

Nine AMS ^{14}C ages are listed in Table 1. Calibrated ^{14}C ages were calculated using Calib 7.0.2 with INTCAL13 model (Reimer et al., 2013). All calibrated ages are in range of 33–40 cal ka BP. OSL ages have been shown in Table 2. The OSL decay curves and regenerative-dose growth curves fitted by sums of exponential and linear functions are presented in Fig. 3. AMS ^{14}C ages are obviously younger than OSL ages of sediments in the XT Section (Fig. 4). Due to the lack of plant remains and other more suitable radiocarbon dating material, bulk organic matter of the sediments was used for radiocarbon dating. ^{14}C ages except the one from the section base are nearly in accordance with the stratigraphic order from top to the bottom (Fig. 4). However, two OSL ages of the sediments in XT Section are 57.9 ka (depth at 40 cm) and 69.1 ka (depth at 190 cm), showing 25–30 ka older than ^{14}C ages from the same stratum.

The difference between radiocarbon dating and OSL dating is also found in other sites in the Qaidam Basin. The ^{14}C ages (bulk organic matter used as the dating material as well), and OSL ages are typically different in the Shell Bar (36.5140°N, 96.2021°E) that is located in the southeastern part of the Qarhan playa. The uncalibrated ^{14}C ages (TOC) are 22.11 ka BP (at depth 53 cm) and 30.51 ka BP (at depth 152 cm) (Zhang et al., 2008), whereas OSL ages (38–63 μm quartz as the dating mineral) are 99 ka (at depth 144 cm) and 113 ka (at depth 178 cm) (Lai et al., 2014). The younger ^{14}C ages of the sediments in the ISL1A core (Fan et al., 2013; Long, 2011) are

Table 1 AMS ^{14}C ages of the sediments in the XT Section

Sample	Depth (cm)	Material	$\delta^{13}C$ (‰)	^{14}C age (a BP)	^{14}C calibrated age (2σ) (cal a BP)*
XT0	0	TOC	-22.7	29 050±25	33 289±274 (33 015–33 563)
XT10	20	TOC	-21.7	31 170±100	35 039±304 (34 735–35 343)
XT30	60	TOC	-22.0	29 100±80	33 329±312 (33 017–33 640)
XT50	100	TOC	-21.9	29 590±90	33 775±209 (33 566–33 984)
XT65	130	TOC	-22.6	32 980±110	37 065±550 (36 515–37 615)
XT95	190	TOC	-21.4	32 660±100	36 568±330 (36 238–36 898)
XT105	210	TOC	-23.3	34 050±45	38 556±202 (38 354–38 758)
XT115	230	TOC	-23.3	35 170±120	39 734±393 (39 341–40 127)
XT120	240	TOC	-23.4	30 110±90	34 149±258 (33 891–34 407)

*Calibrated by software Calib 7.0.2 (Reimer et al., 2013).

Table 2 OSL ages of the sediments in the XT Section (quartz 90–125 μm)

Sample	Depth (cm)	K (wt.%)	Th (ppm)	U (ppm)	Water content (%)	Dose rate (Gy/ka)	De (Gy)	OSL age (ka)
XT1	40	1.55±0.06	6.35±0.37	6.92±0.33	10±5	3.55±0.27	205.92±12.99	57.9±5.7
XT6	190	1.63±0.07	8.11±0.50	3.03±0.26	10±5	2.83±0.22	195.42±7.50	69.1±6.0

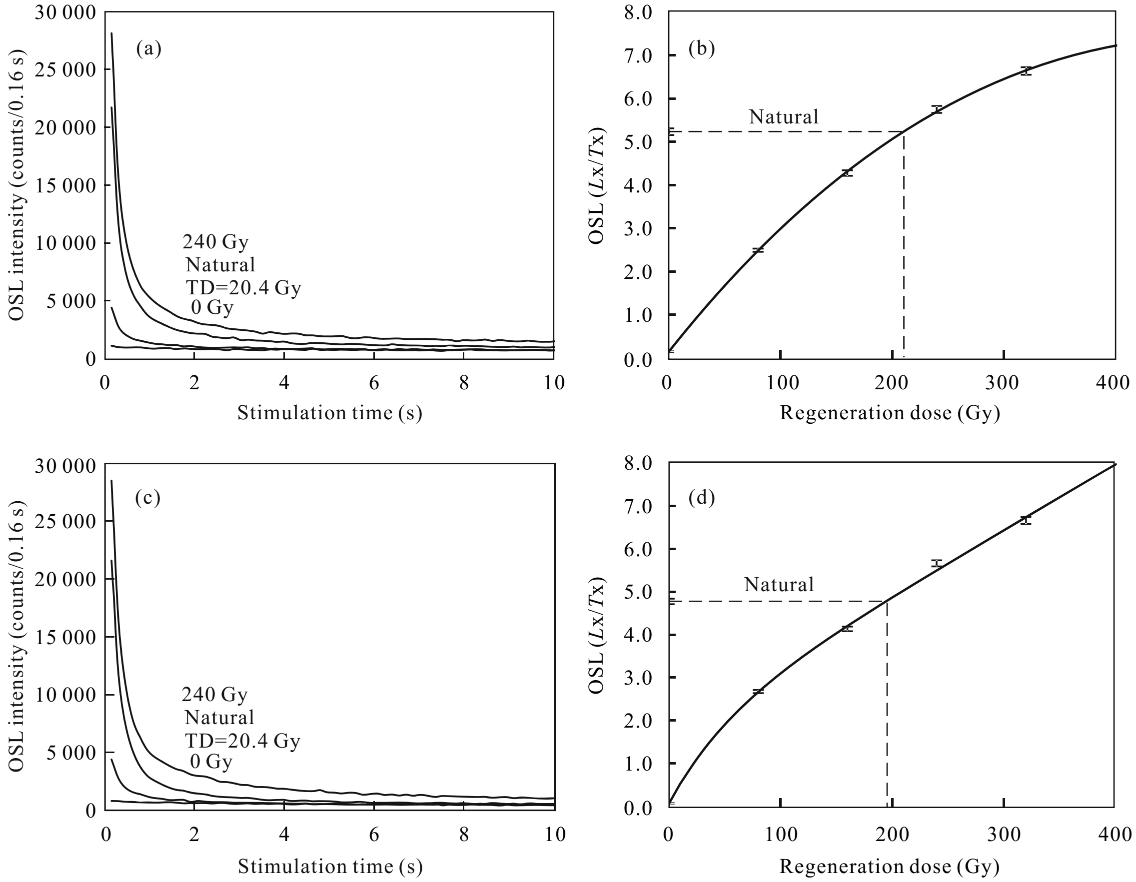

Figure 3. OSL decay curves and regenerative-dose growth curves for samples XT1 (a), (b) and XT6 (c), (d). *L*x. Regeneration dose; *T*x. test dose.

inconsistent with the older OSL ages (Long, 2011).

Fan et al. (2013) postulated that the organic carbon of the sediments in the ISL1A core may be contaminated by ground water that comes from the eastern Kunlun Mountains and surface water that is supplied to deep brines during the exploitation of deep brines for fertilizer. Long (2011) and Long and Shen (2015) concluded that the underestimated ^{14}C ages for the ISL1A core are caused by contamination with modern carbon after deposition or during sampling and preparation for dating. The postulated contamination of the organic carbon in lacustrine sediments in the Qaidam Basin indicates that the source of organic carbon may be very complicated.

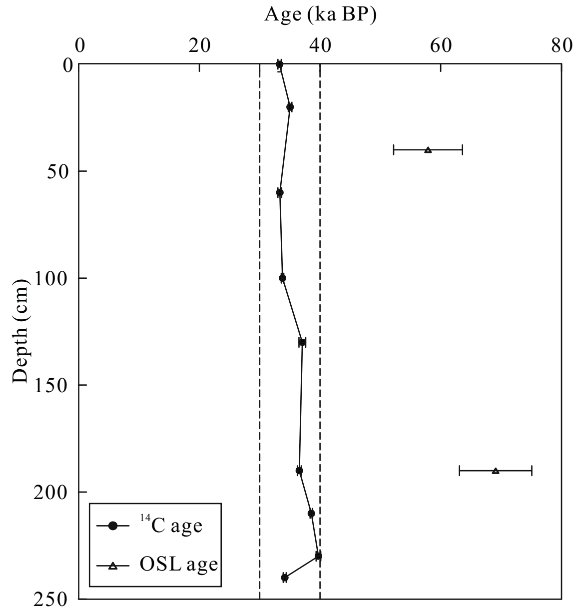

Figure 4. AMS ^{14}C ages and OSL ages of the sediments in the XT Section.

Based on comparative study between ^{14}C ages and OSL ages for the Shell Bar in the Qaidam Basin, Lai et al. (2014) proposed that the ^{14}C dates on the Shell Bar are severely underestimated by sample contamination during burial, diagenetic alteration, and even sample mixing during laboratory processing. Impact of 2% contamination with modern carbon for a 60-ka-old sample could yield an age estimate of about 30 ka BP (Pigati et al., 2007). Most OSL ages of paleoshorelines in northwestern China fall between 70–120 ka, whereas ^{14}C ages for the same shorelines concentrate between 30 and 40 ka BP (Lai et al., 2014). The above differences between OSL ages and ^{14}C ages indicate that the ^{14}C ages are probably severe underestimates. Therefore, ^{14}C ages older than 25 ka BP of lacustrine sediments in arid regions should be re-investigated (Lai et al., 2014).

Because bulk organic matter may be contaminated by modern carbon from the ground water that comes from the eastern Kunlun Mountains and surface water that is usually supplied to deep brines during the exploitation of the brines for fertilizer in the Xitaijinair Salt Lake region, ^{14}C ages of sediments in the XT Section are probably underestimates. The result of this study supports the conclusion that the ^{14}C ages larger than ~30 ka BP are severe underestimates in the Qarhan Salt Lake (Long and Shen, 2015; Lai et al., 2014; Fan et al., 2013; Long, 2011).

OSL dating method as a new approach to the salt lake deposits has been applied to date strata containing salts in the SG-1 core, western Qaidam Basin, and the reliability of OSL ages are confirmed by U-series dating results (Han et al., 2013). However, whether the OSL ages in sediments of the XT Section are more reliable than ^{14}C ages in this section is unclear, because the bleaching of quartz during deposition and unstability of the dose rate in these sediments containing salts would affect the accuracy of the OSL ages.

2.2 Erosion in the Xitaijinair Region, Qaidam Basin

Assuming the sedimentation rate is constant and the preliminary OSL ages are more reliable than ^{14}C ages, the surface age of the XT Section is about 55 ka. This age indicates that the XT Section experienced erosion during the Late Pleistocene, in agreement with other studies (Lai et al., 2014; Han et al., 2013).

Nearly 80% of the surface area has been covered by playas in the Qaidam Basin (Fig. 1; Han et al., 2013). The U-series dating results of the Dafengshan (DFS) pit section, and the U-series dating and OSL dating results of the SG-1 core show that the surface of the playas has an age of about 100 ka (Han et al., 2013). U-series dating of gypsum from the D26 Section at Dalangtan playa plain placed the playa plain formation at about 100 ka (Ma et al., 2011). The extrapolation of magnetostratigrapy dating results of the sediments in the Liang ZK05 core also indicate the surface age at Dalangtan playa is about 111 ka (Shi et al., 2010). The OSL age of the surface sediment in the XT Section is about 50 ka younger than the above ages of the playa formation ages (Han et al., 2013; Ma et al., 2011; Shi et al., 2010). Both OSL and ^{14}C ages of the XT Section indicate that the surface of the Xitaijinair region has been eroded. Additionally, some evidence shows that the lithologies of the yardangs in the western Qaidam are composed of Tertiary mudstone, siltstone and sandstone (Niu et al., 2011; Halimov and Fezer, 1989). Large areas of the yardangs distributed in the western Qadiam Basin imply that wind erosion is the main transport mode in the Qaidam Basin. Thus, the erosion of the surface of the Xitaijinair Salt Lake region was probably caused by wind erosion. Erosion of the Qaidam Basin has been concluded by Bowler et al. (1987), Kapp et al. (2011), Han et al. (2013) and Lai et al. (2014). Lai et al. (2014) re-interpreted the Shell Bar as a remnant of a river channel and proposed that the wind erosion has left the fluvial channel sediments topographically inverted. An et al. (2012) proposed that the possibility that the Qaidam Basin can contribute dust from the basin to the Chinese Loess Plateau, whereas Sun (2002) suggested that it was unlikely that the Qaidam Basin could be the dust source of the Chinese Loess Plateau. The chronology of the XT Section, which is close to the Shell Bar, also shows the erosive nature of the landscape during the Late Pleistocene.

2.3 Mineral Compositions

The mineral compositions of the sediments in the XT Section are summarized in Fig. 5. The sediments in the whole XT Section are composed of quartz (volume%, 11%–44%, average 32.76%), muscovite (20%–40%, average 30.97%), clinochlore (4%–29%, average 11.25%), albite (0%–23%, average 4.84%), calcite (3%–13%, average 7.62%), dolomite (0%–6%, average 1.68%), ankerite (0%–4%, average 0.32%, occurred at depth 136–168 cm and 204 cm), halite (0%–15%, average 5.14%), gypsum (0%–29%, average 5.00%), and also aragonite, magnesite, bromargyrite and hexahydroborite.

Silicates (quartz, muscovite, clinochlore and albite) and carbonates (calcite, dolomite, ankerite, aragonite and magnesite) are in ranges of 60%–92% and 4%–18%, respectively (Fig. 5). The contents of muscovite and clinochlore are relatively lower in the coarse sediments (depth at 25–47 and 185–199 cm) than those in the other part of the section. However, the content of albite is relatively higher in the coarse part of the section (Fig. 5).

Feldspars are thought to be the most abundant of the labile

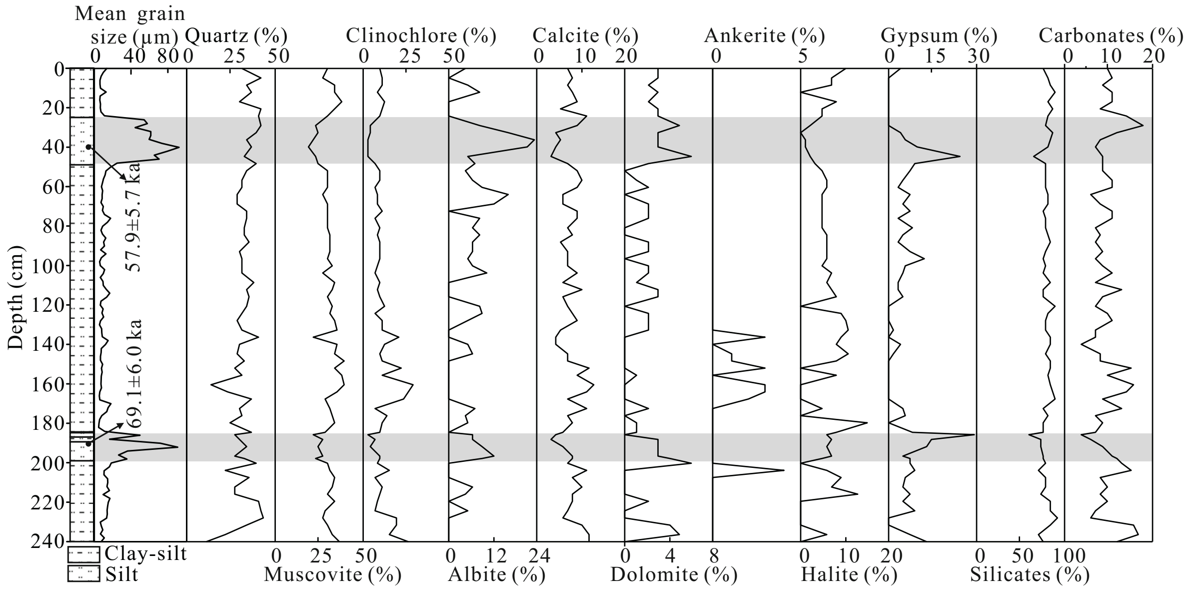

Figure 5. Mineral compositions of the sediments in the XT Section (the shaded boxes show the coarse sediments).

minerals (Nesbitt and Young, 1982). As one of three endmembers of the feldspars, the albite ($NaAlSi_3O_8$) can be transported by rivers after the weathering and leaching of the rocks. The albite of the sediments in the XT Section is affected by distribution and characteristics of the source rocks, and climatic condition. The mountain ranges around Qaidam Basin are mainly composed of igneous and metamorphic rocks (Xu et al., 2006) which provide large amounts of silicates for the basin. The high content of the albite in the coarse sediments of the XT Section may be produced by suitable climatic condition having relatively more precipitation in the catchment of the Xitaijinair region. Meanwhile, more precipitation would strengthen the activity of the river transportation, so the coarse sediments were carried to the Xitaijinair Lake Basin. In sum, the mineral compositions of the sediments in the XT Section are probably related to past climatic conditions, and the albite is an especially sensitive and indicative mineral for past climate change.

Generally, for closed lakes on the QTP, exogenous carbonate delivery to the lake is relative weak during cold periods (Li and Kang, 2007). Interestingly, the coarse sediments in the XT Section contain more dolomite than the fine ones (Fig. 5). This feature may indicate that more dolomite enters the Xitaijinair Salt Lake during relative warm periods.

3 CONCLUSIONS

(1) AMS ^{14}C ages (33–40 cal ka BP) are younger than OSL ages (57.9, 69.1 ka) of sediments in the XT Section. The ^{14}C ages are probably underestimates.

(2) OSL and ^{14}C ages in the XT Section indicate that the surface of the Xitaijinair region has been eroded.

(3) The sediments of XT Section are composed of silicates (quartz, muscovite, clinochlore and albite), carbonates (calcite, dolomite, and ankertie), halite and gypsum.

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