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ISOTOPIC EVIDENCE FOR HOLOCENE CLIMATIC CHANGES IN BOSTEN LAKE, SOUTHERN XINJIANG, CHINA

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ABSTRACT: Based on the $\delta^{13}C$ and $\delta^{18}O$ fluctuation of lacustrine carbonate, $CaCO_3$ content and spore-pollen data, a palaeoclimatic history of Bosten Lake during the Holocene has been outlined, several stages of climatic changes are divided, and the following resultes are obtained: (1) Palaeoclimatic changes revealed by carbonate isotope around Bosten Lake are basically identical with that revealed by other geological records in Xinjiang. Environmental changes presented apparent Westlies Style model: during cold period, relative humidity increased, $\delta^{18}O$, $\delta^{13}C$ and $CaCO_3$ appeared low; but in warm periods, the dry regime aggravated. (2) The temperature reflected by $\delta^{18}O$ exist evident features being increase in the late period during the Holocene. Together with the $\delta^{13}C$, pollen and $CaCO_3$ analyses, several cold and warm phases which are of broad regional significance can be identified. The warm peaks occurred at about 11.0 ka B. P., 9.4 ka B. P., 7.5 ka B. P., 5.0 ka B. P., 3.0 ka B. P. and 2.0 ka B. P.; the cold peaks at 11.5 ka B. P., 10.5 ka B. P., 8.8 ka B. P., 5.5 ka B. P., 3.3 ka B. P., 2.2 ka B. P. and 1.5 ka B. P.. (3) Several climatic events with the nature of "abrupt climatic changes" are revealed in the periods of 11.0 ka B. P.–10.5 ka B. P., 9.4 ka B. P.–8.8 ka B. P., 5.5 ka B. P.–5.0 ka B. P. and 2.0 ka B. P.–1.5 ka B. P.. (4) The results show that carbonate isotopic record of lacustrine sediment in arid area is very sensitive to climatic changes, and may be play a very important role in understanding the features and mechanism of palaeoclimatic changes.

KEY WORDS: Bosten Lake, $\delta^{18}O$ of carbonate, $\delta^{13}C$ of carbonate, Holocene, climatic changes

I. INTRODUCTION

Bosten lake (86°40′–87°26′E, 41°56′–42°14′N), a lake of tectonic origin, is the largest inland freshwater Lake in China. It lies in the depression of the southern part of Yanqi Basin. The mean monthly temperature ranges from −9.2℃ in January to 23.6℃ in July, while the mean annual temperature and precipitation are about 6.3℃ and 68.2 mm respectively. The ratio of evaporation to precipitation ranges between 26 and 30. Bosten Lake is very sensitive to regional climatic changes because it supplied mainly by melting water from glaciers and snow in the Tianshan Mountains and tectonics have not significantly modified its hydrology in the late Quaternary. In an attempt to find Holocene lacustrine records, which is available to reconstruct the history of the Holocene climatic evolution in this area, an excavation was carried out in the site about 2 km southwest from Bohu County town, a pit was dug to 3.2 m. In this paper, we aim to use isotopic records of carbonate, spore-pollen data and $CaCO_3$ content to rebuilt the processes and features of climatic changes during the Holocene.

II. SAMPLING AND METHODS

The Holocene lacustrine sediment of Bosten Lake is characterized by green-grey, grey-black clay or silt clay and yellowish silt clay. Peatification layers have developed at 1.2 m, 1.6 m, 2.1 m and 2.8 m. Six samples were taken for ^{14}C dating measurement, the results are shown in Fig. 1. Based on the mean deposit rate, chronologic sequence of this section can be constructed by age-intercalation.

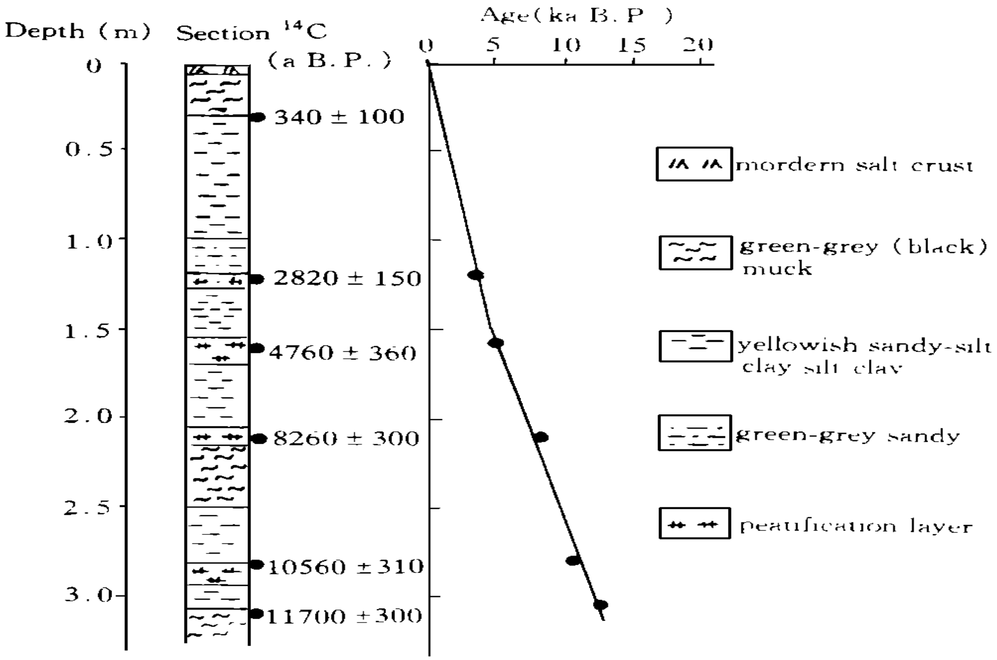

Fig. 1 Sedimentary feature and age-depth relation in the section of Bosten Lake

Samples were collected for isotopic examination at 0.05 m intervals. Isotopic analysis methods presented herein are the same as that proposed by Wu Jinglu (1997). Fraction below 0.002 mm have been seperated by means of gravity-settling. By treatment with 100% H_3PO_4, the isotopic analysis of carbonate was performed on CO_2 prepared from the carbonate. Prior to analysis, samples were heated for 1 hour under vacuum at about 475 ℃ to drive off any organic carbon interference. The $\delta^{18}O$, $\delta^{13}C$ of carbonate are reported in the standard notation relative to the PDB standard.

III. RESULTS AND PALAEOCLIMATE

The isotopic composition of carbonate and the contents of $CaCO_3$, together with the A/C ratio *(Artemisia/Chenopodiaceae)* are presented in Fig. 2. The values of carbonate $\delta^{18}O$ and $\delta^{13}C$ of the Holocene sediment in Bosten Lake vary from − 10.33‰ to 3.75‰ and from − 6.78‰ to 1.67‰ respectively. Former studies (Krishnamurthy *et al.*, 1982; Gasse *et al.*, 1991) have shown that for lacustrine carbonate, in the case that there is a reverse correlation of fluctuation between $\delta^{18}O$ and $\delta^{13}C$, $\delta^{18}O$ is chiefly influenced by tem-perature, increasing tem perature is generally benefit to accumulate heavy oxygen isotope. While on the contrary, if

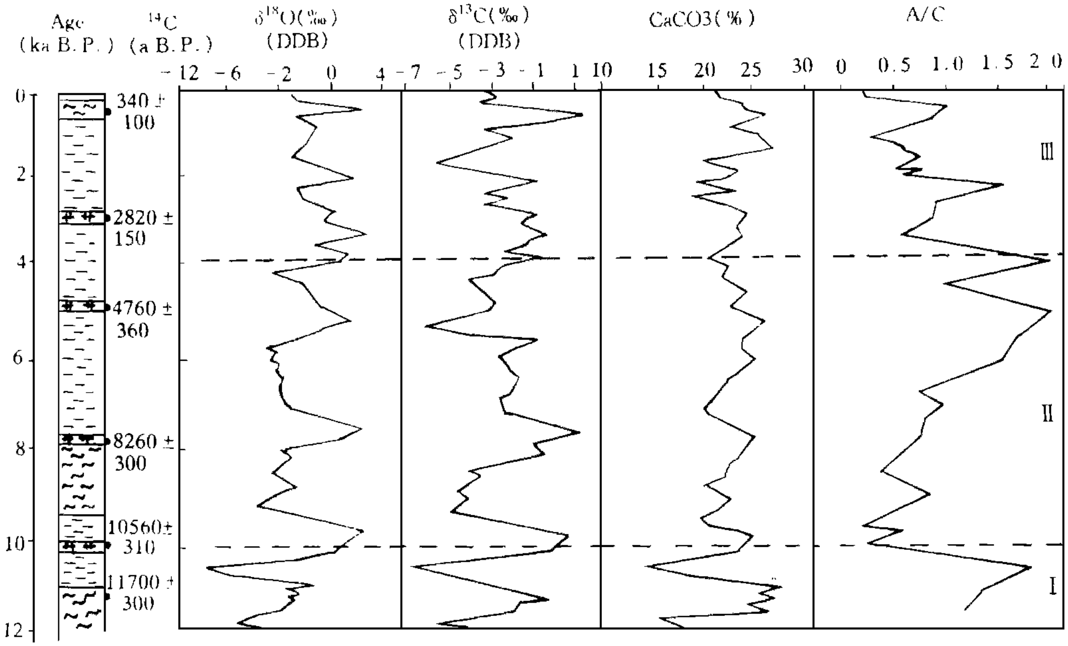

Fig. 2 Various indices of climatic changes during the Holocene recorded by lacustrine sediment of Bosten Lake

there exists a positive correlation, $\delta^{18}O$ is controlled largely by the isotopic content of lake water, which is correlated negatively with atmospheric relative humidity and temperature of carbonate illuviation, but positively with the $\delta^{18}O$ contents of supplying water and the ratios of evaporation to supplying volume (Gasse *et al.*, 1991). Higher $\delta^{18}O$ indicates severer evaporation and salinization, while conversely, lighter $\delta^{18}O$ suggests desalination of lake water (Krishnamurthy *et al.*, 1982). $\delta^{13}C$ of lacustrine carbonate is mainly controlled by the exchange between atmospheric CO_2 and carbonate of lake water, the salinity of lake water, lake productivity and freezing time (Gasse *et al.*, 1991). Intenssive exchange makes ^{13}C accumulating, high lake water salinity and shorter freezing time lead to heavier $\delta^{13}C$. Values of A/C (*Arteermisia/ Chenopodiaceae*) can be used as an indicator of vegetational ecology, the lower A/C value, the drier vegetational ecology (Sun *et al.*, 1994). Solubility of $CaCO_3$ in lacustrine deposit decline with increasing temperature. So, on the basis of these indices, several palaeoclimatic phases can be identified (Fig. 2).

Phase 1 (12.0– 10.0 ka B.P., 3.2– 2.75 m in the section). Spore-pollen composition flora is of the typical characteristic of desert-steppe. Low $\delta^{18}O$ contents indicate short residence time causing low evaporation rate/or a continental effect on a limited amount of atmospheric vapour(Gasse *et al.*, 1991). Between 12.0– 11.5 ka B.P., the synchronous decreases in $\delta^{18}O$, $\delta^{13}C$ and $CaCO_3$ content reflect a shorter residence time with evaporation and exchange with the atmosphere, perhaps owing to a decrease in temperature and leading to an increase in relative humidity of atmosphere. But during 11.5– 11.0 ka B.P., a abrupt shift towards higher $\delta^{18}O$, $\delta^{13}C$ and $CaCO_3$ occurred, indicating a relative warm-dry phase, which maybe correspond to the Allerød interstadial in times. From 11.0– 10. 10.0 ka B.P., a simultaneous sharp change of $\delta^{18}O$, $\delta^{13}C$, $CaCO_3$ and A/C ratio can be observed. The lowest $\delta^{18}O$ values in this section (– 10.33‰) indicates a cooling, and the synchronous decrease in $\delta^{13}C$ may again reflect the presence of longer freezing time during this period. This severe cooling may be thus attributable to the Younger Dryas cooling event, the higher A/C ratio (Fig. 1) indicates the regional expansion of desert-steppe, and an increase in atmospheric relative humidity, implying a change in precipitation-evaporation, is beneficial to the prosperity of the desert-type vegetation.

Phase 2 (10.0– 4.0 ka B.P., 2.75– 1.60 m in section). Climatic evolution during this period was quite complex. The higher $\delta^{18}O$, $\delta^{13}C$ generally represented a relative warm-dry condition. This was at the very beginning of global warming which started at about 10.0 ka B.P. and culminated about 9.4 ka B.P., the highest $\delta^{18}O$ of this section, being identical with a sharp increase in $\delta^{13}C$, $CaCO_3$, and decrease in A/C ratio, reflect a reinforcement of desertification. Afterwards, at about 8.8 ka B.P., climate turned rapidly into cooling, showing an evident nature of "Abrupt Climatic Change". These two dry-warming and humid-cooling peaks are compatible with that revealed in Dunde ice core (Yao *et al.*, 1992) (Fig. 3), the cooling, another brief climatic extreme is recorded by the sharp increase in $\delta^{18}O$, $\delta^{13}C$ and $CaCO_3$ from 7.5 ka B.P. to 7.0 ka B.P., which presents warm-dry regime, and coincides with the "new warm-dry period IV" recorded in the Holocene lacustrine sediment of Balikun Lake in northern Xinjiang (Han *et al.*, 1992). The occurrance of reverse correlation between $\delta^{18}O$ and $\delta^{13}C$ shows that changes of $\delta^{18}O$ is mainly relative to lake water temperature (Wu, 1997). This phenomenon possibly correlate to a relative warm, wet condition, especially during 6.0 ka B.P.– 4.0 ka B.P., higher $\delta^{18}O$ and lower $\delta^{13}C$ maybe correspond to the Megathermal Maximum in the Holocene, indicating an increase in atmospheric humidity and temperature, induced by strengthened Asian summer monsoon (Han *et al.*, 1993; Wen *et al.*, 1992; Li, 1997), which is beneficial to the luxuriance of desert-type vegetation, leading to higher A/C (Fig. 2).

Around 5.5 ka B.P., the peak of $\delta^{13}C$ (– 1.26‰), with low $\delta^{18}O$ (– 4.25‰) repre-

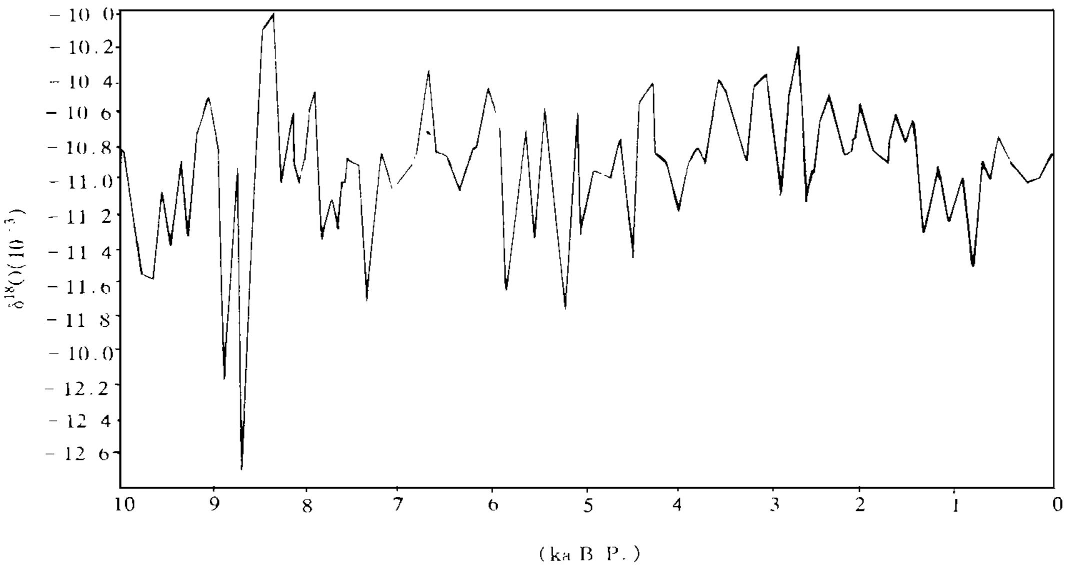

Fig. 3 Holocene fluctuation of $\delta^{18}O$ in Dunde ice core

sents a relative cold, dry regime. This cooling event which is of global significance has also been discovered in Aibi Lake (Li, 1993), Balikun Lake (Han *et al.*, 1993) in northern Xinjiang, and coincides with the second neoglacial epoch in the Northern Hemisphere (Denton *et al.*, 1993). But at about 5.5 ka B.P., the lowest $\delta^{13}C$ in this section (−6.78‰) and a rise in $\delta^{18}O$ and $CaCO_3$ indicate a relative warm-wet condition, which can be compatible with the warm-wet summit occurred at about 5.3 ka B.P. revealed by turf $\delta^{13}C$ record on the Zoigê Plateau (Wang *et al.*, 1993). A reversal of the trends in climate after 5.0 ka B.P. is interpreted as a return to cool-dry condition again, the summit appear at about 4.0 ka B.P.

Phase 3 (4.0–0 ka B.P., 1.6–0 m in section). Starting at 4.0 ka B.P., relatively higher mean $\delta^{18}O$ values than the former stages and the general appearance of high $\delta^{13}C$, decrease in A/C ratio and increase in heavy isotope contents (longer residence time) and $CaCO_3$ suggest aridification, which is agree reasonably with the former understandings deduced from various geologic records (Zhong *et al.*, 1996). Two warm-dry (3.0 ka B.P., 2.0 ka B.P.) and two cold-humid (3.3 ka B.P., 2.2 ka B.P.) pulses can be observed in this period. The warming peak of 3.0 ka B.P. is compatible with the sub-extreme warming event recorded in Dunde ice core (Yao *et al.*, 1992).

After 2.0 ka B.P., sharp decrease in $\delta^{13}C$ and $CaCO_3$ content, especially in $\delta^{13}C$ culminate about 1.5 ka B.P., indicate a short cooling, wet interval, one of a short period of turf development widely recorded in Xinjiang (Zhong *et al.*, 1996). Afterwards, at about 0.3 ka B.P., the highest $\delta^{13}C$ of this section (1.67‰), an increase in $\delta^{18}O$, $CaCO_3$ and decrease in A/C ratio show an intensive increasing aridity. But a synchronous decline in $\delta^{18}O$, $\delta^{13}C$ and $CaCO_3$ after this dry-warming phase shows a little increase in atmospheric humidity.

IV. DISCUSSION

Comparatively speaking, the study on the Holocene climatic changes in the southern Xinjiang is much more lacking because of the difficulties in obtaining a contineous, high-resolution geological record. The Bosten Lake data show that the carbonate isotope composition of inland lacustrine sediment is very sensitive to the regional climatic changes, and plays an important role in reconstructing the history of climatic evolution. Palaeoclimatic changes revealed by carbonate isotope around Bosten Lake are basically identical with that revealed by other geological records in Xinjiang. Environmental changes present apparent Westlies Style model: during cold periods, relative humidity increased, $\delta^{18}O$, $\delta^{13}C$ and $CaCO_3$ appeared low; but in warm periods, the dry regime aggravated. The temperature reflected by $\delta^{18}O$ present evident features being increase in the late period during the Holocene. Together with the $\delta^{13}C$ and $CaCO_3$ fluctuations, several cold and warm phases which are of broad regional significance can be identified. The warm peaks occurred at about 11.0 ka B.P., 9.4 ka B.P., 7.5 ka B.P., 5.0 ka B.P., 3.0 ka B.P. and 2.0 ka B.P.; the cold peaks at 11.5 ka B.P., 10.5 ka B.P., 8.8 ka B.P., 5.5 ka B.P., 3.3 ka B.P., 2.2 ka B.P. and 1.5 ka B.P. During 7.0– 4.0 ka B.P., relative warm-humid conditions may be induced by the strengthened force of summer monsoon, which is the unique warm-humid phase reflected by isotopic record of lacustrine carbonate during the Holocene in Bosten lake. Several climatic phased with the nature of "Abrupt Climatic Changes" are revealed i.e. 11.0– 10.5 ka B.P., 9.4– 8.8 ka B.P., 5.5– 5.0 ka B.P., 2.0– 1.5 ka B.P.. These preliminary results obtained from lacustrine sediment of Bosten Lake add a new and potentially important method to the geologist arsenal for studing climatic changes in the inland arid area in China. Further study on inland climatic changes helps for the enhancement of the accuracy in predication of future climatic trends.

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