WESTERN PACIFIC EARTH SCIENCES
Vol.2, No.1, P.67-82, 7 Figs., 4 Tabs., February, 2002

STABLE ISOTOPIC VARIATIONS IN OXYGEN AND HYDROGEN OF WATERS IN LAKE BOSTEN REGION, SOUTHERN XINJIANG, WESTERN CHINA

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ABSTRACT

Water samples taken from Bosten Lake and several rivers/channels that flow into or out of the Lake during the summers of 1999 and 2000 were analyzed for their various characteristics, including pH, conductivity, total dissolved solid (TDS), C-14 age as well as oxygen and hydrogen isotopic ratios. The high C-14 activity of water samples suggests that the carbon in lake water is modern and the water circulation is fast. High conductivity and TDS of lake water samples (1000 - 3000 $\mu S. cm^{-1}$) compared to river waters (130 - 300$\mu S. cm^{-1}$) is indicative of the presence of soluble mineral species (e.g., sulfate and chloride), a sign of mineralization of the lake water. The $\delta^{18}O$ values range from -2.5‰ to -10.5‰ whereas δD from -26‰ to -59‰. Compared to the river water samples, lake water shows obvious enrichment of heavier isotopes in both oxygen and hydrogen, suggesting significant evaporation effect despite the fact that the lake water samples were taken during flooding periods of 1999 and 2000. On the $\delta^{18}O$-δD plot the surface water data form a linear array with the best-fit line of $\delta D = 3.7\delta^{18}O - 20$ ($r = 0.91$). The intersection between this line and the Global Meteoric Water Line of Craig is approximately at $\delta^{18}O = -7‰$ and $\delta D = -46‰$, indicative of the average $\delta^{18}O$ and δD values of the precipitation of the middle section of the Tien Shan Range and the Yan Qi Basin. The water source is mainly from the precipitation of warm seasons (April - October).

Key words: oxygen isotope, hydrogen isotope, hydrology, Lake Bosten, Xinjiang

INTRODUCTION

By compiling and examining the isotope data of rain and snow sampled by the network of the International Atomic Energy Agency (IAEA), in his classical paper Dansgarrd (1964) demonstrated the usefulness of ^{18}O and ^{2}H (deuterium) as proxy data for temperature and precipitation. In principle the heavier water, $^{1}H_2{}^{18}O$ and $^{1}H^{2}H^{16}O$, are less diffusive than the "normal" water $^{1}H_2{}^{16}O$, and thus undergo fractionation during any phase transition of water. The liquid or solid phase is therefore enriched in heavier isotopes than the vapor phase. The degree of enrichment in precipitated water is governed mainly by temperature effect and amount effect (Dansgarrd, 1964). Once precipitated, the isotopic composition of water is further modified as a result of evaporation or mixing of waters of different compositions (Swart *et al.*, 1989). Stable isotopes of oxygen and hydrogen have become very useful tracers to study hydrological cycles in recent years.

Lake Bosten (博斯騰湖), situated in an arid intermontane basin in the southern Xinjiang, was investigated during 1999 and 2000 as part of the APEC (Asian Paleo-Environmental Change) Project on the paleoclimates of Xinjiang. To better understand the hydrological background of the region, the authors conducted an isotopic study of various surface water samples taken from the lake area. The present paper documents and discusses the significance of oxygen and hydrogen isotope data of surface waters collected from the region. Because the two sedimentary cores the APEC Project took during Year 2000 are located in the southwestern part of Lake Bosten, this study pays special attention to the western part of the Lake.

LAKE BOSTEN

Lake Bosten was once the largest fresh-water lake in China, but now the lake is slightly brackish (Xu *et al.*, 1995, p. 100). The Bosten Lake lies in the northeastern rim of the Tarim Basin (塔里木盆地) in the southern Xinjiang (Fig. 1). The Tarim Basin itself is a large endorheic depression limited by the high mountain ranges of the Tian Shan (天山) to the north and the Kunlun Shan(崑崙山) to the south. The regional climate is mainly controlled by the westerlies with little influence of the Asian monsoon and Siberian air masses (Watts, 1969).

The Lake drains a catchment area of ~56,000 km2, covering basically the southern slope of the middle section of Tian Shan and a few basins immediately south to the mountain range, including You-Er-Du-Si Basin (尤爾都斯盆地) and Yan-Qi Basin (焉耆盆地)(Zhang *et al.*, 1995, p. 326). The average altitudes of the mountains in the middle section of Tian Shan Range are between 3000 - 3500 m. There are more than a dozen major rivers flowing towards southeastern and southern directions in these piedmont basin plains. The waters flow or seep eventually, either in the form of surface water or ground water, into Lake Bosten if not evaporated.

Lake Bosten is located at 41°56' ~ 42°14'N, 86° 40' ~ 87°26'E. The E-W length of the Lake is about 65 km while the S-N width is 15 km, with a total area of 985 - 1070 km^2 (Xu *et al.*, 1995, p. 101; Zhang *et al.*, 1995, p. 330). The extent of the lake varies year by year, as a function of lake level. The lake level itself, in turn, fluctuates in response to (1) changes in meltwater discharge from mountain glaciers, and (2) variations in local precipitation and evaporation balance. It was reported that the lake level had dropped by more than 3 meters from the highest recorded level of 1048.75 m in 1958 to 1044.2 m asl (above sea level) in 1986 (Xu *et al.*, 1995, p. 113; Tu *et al.*, 1995, p.339, Figure 9-2-2; Zhang *et al.*, 1995, p. 330). The deepest part of the Lake is 16 m in depth while the average depth is 8.8 m (Zhang *et al.*, 1995, p. 330). The total volume is 50.164 x 10^8m3 in 1986 (Xu *et al.*, 1995, p. 113).

Among the various rivers that contribute to the Lake, the largest four in descending order are: Kai Du River (開都河)(3.362 x 10^9 m^3/year), Huang Shui Gou (黃水溝)(0.257 x 10^9 m^3), Qing Shui River (清水河)(0.106 x 10^9 m^3) and Wu-La-Si-Te River (烏拉司特河)(0. 0086 x 10^9 m^3) (Zhang *et al.*, 1995, p. 327). These four rivers contributed about 96% of waters into the Lake (Zhang *et al.*, 1995, p.327). The largest river, Kai Du River, dominated the input by contributing 83% of the total input amount from surface water and groundwater (calculated based upon data provided in Table 10-2-4, p. 340, Zhang *et al.*, 1995). The dominance of Kai Du River can be also exemplified by the record of the average monthly flow rates of the major rivers that contributed to the Lake during 1973 - 1975 shown in Figure 2 (Xinjiang Hydrological Team, 1977, p. 11, Figures 1-7.). The water flux is concentrated during the summer months, namely, May to September. The water source of Kai Du River is mainly composed of precipitation and thawed water from glaciers.

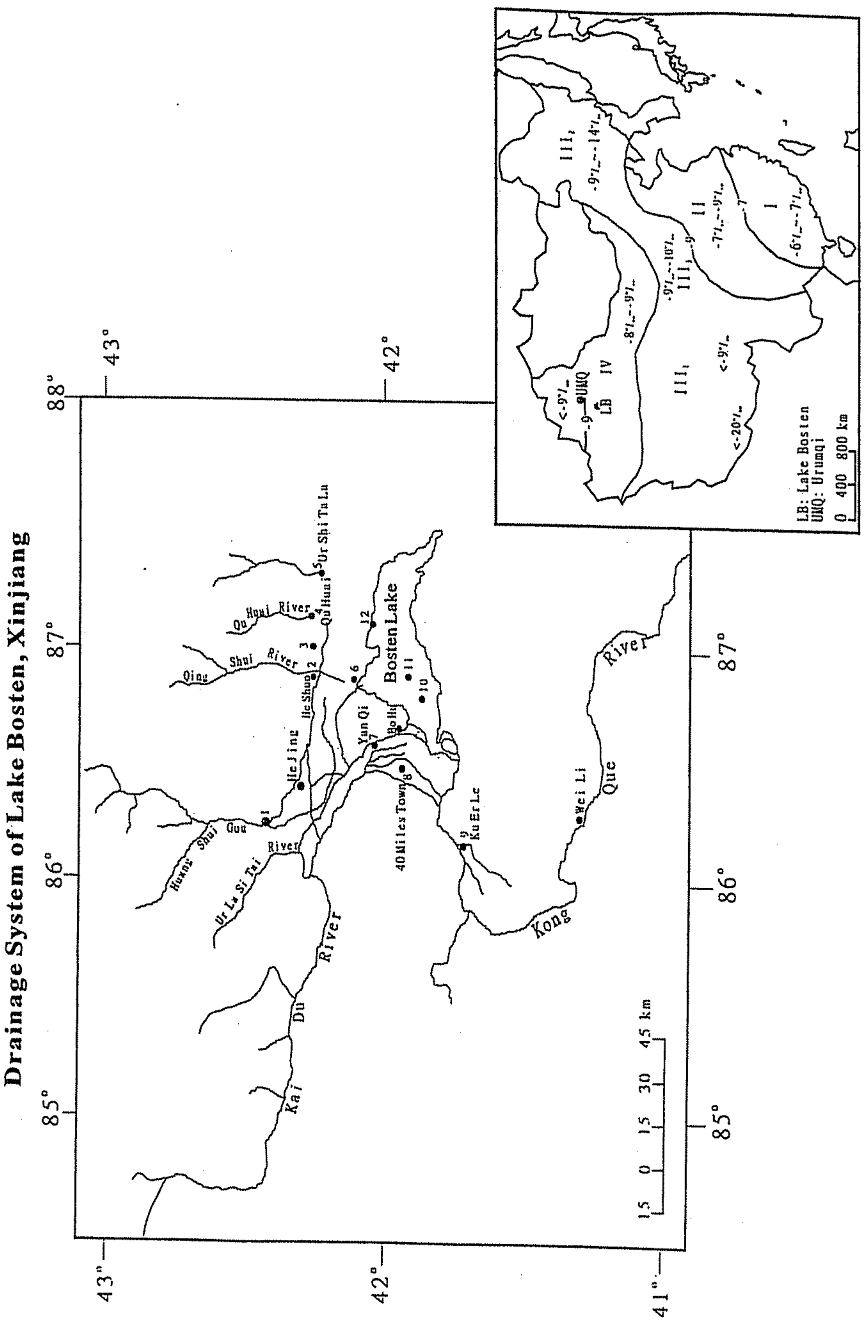

Figure 1. Location map of sampling locations in Lake Bosten, Xinjiang. The large map shows the detailed location of sampling locations in the Lake Bosten drainage system. A total of 12 localities were sampled. The small map shows the locations of Lake Bosten and Urmuqi in China and the four regions delineated based upon oxygen isotopic characteristics of meteoric waters by Wei (1997). The Region VI is under the westerly regime.

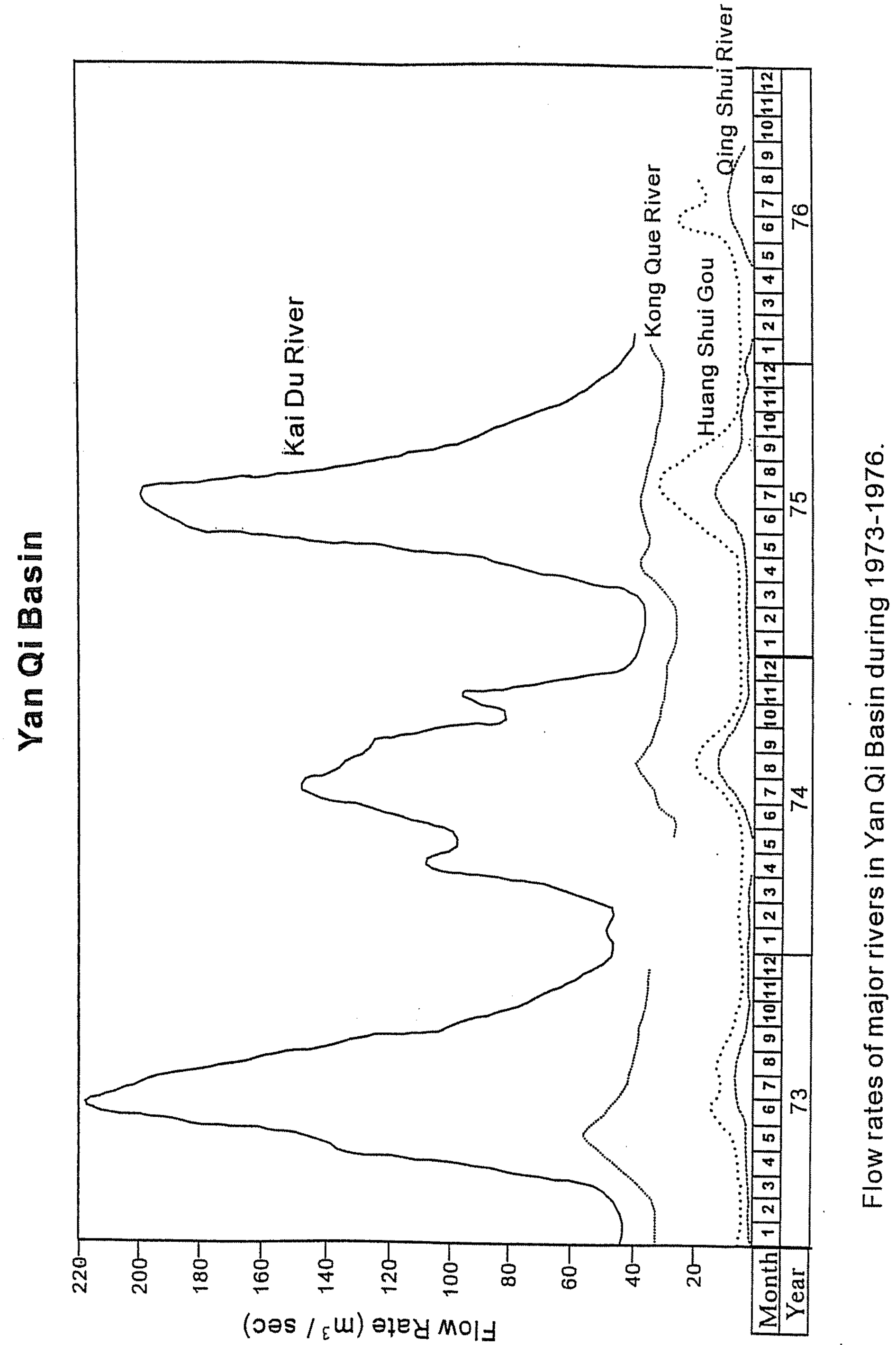

Figure 2. Monthly average flow rates of four major rivers in Yan Qi Basin of the drainage system of Lake Bosten during 1973 - 1976 (modified after Xinjiang Hydrological Team, 1977, p. 11, Figures 1-7).

The only outlet of Lake Bosten is Kong Que River (孔雀河). Kong Que River originates in the "Small Lake Area" （小湖區） of the Lake, which is the swampy area to the west of the main water body of the Lake. The river flows firstly westward and then turns to the east, vanishing eventually in the desert south of the Lake Bosten (Fig. 1). The flow rate of Kong Que River has been artificially controlled through irrigation system ever since early 1980's at an average rate of 1.2 x 10^9 m^3/year (Zhang *et al.*, 1995, p.327). The average evaporation rate of the Lake was estimated to be 1.0 x 10^9 m^3/year. The residence time of the lake water was 1, 731 days (Zhang *et al.*, 1995, p.330).

The local annual precipitation recorded at local meteorological station in 1988 is 141 mm/ year, while the evaporation rate is very high: 2039 mm/year (Zhang *et al.*, 1995, p. 328). It is obvious that the Lake is under strong evaporation. As a result, Lake Bosten itself has been under different degrees of mineralization as a function of evaporation intensities of the different parts of the lake. The average degree of minearalization measured in 1990 was 1.64g/L (Xu *et al.*, 1995, p.106). Since the major inputs and outlets of the Lake are all concentrated in the southwestern corner of the Lake (Fig. 1), the southwestern part of the Lake has the freshest water, showing the lowest degree of mineralization in the range of 0.356~0.560 g/L (Xu *et al.*, 1995, p. 101). The salinity is in general defined by the mixing line of the input water of Kai Du River and the outlet water of Kong Qui River. The salinity of Kai Du River is quite stable at 0. 26 g/L, whereas the salinity of outlet waters flowing into the Kong Que River varies between 0.5 and 1.1 g/L (Zhang *et al.*, 1995, Table 10-2-4, p. 340). In descending order, the dominant ions are Na^+, Mg^{2+} Ca^{2+}, SO_4^{2-}, Cl^- and HCO_3^- (Xu *et al.*, 1995). The pH values of lake-water varied between 8.24 and 9.01 during 1987-1989 (Tu *et al.*, 1995, p. 338). Based upon the measured concentrations of these ions and degree of saturation of common evaporites, it has been calculated that four kinds of authigenic minerals can be formed in the Lake: aragonite ($CaCO_3$), calcite ($CaCO_3$), dolomite ($MgCO_3$), magnesite ($MgSO_4$) and huminite (Zhang *et al.*, 1995, p.361).

Water mixing is mainly driven by wind during unfrozen seasons. In general, the southerly wind prevails during morning and evening while the northerly blows during afternoon. The monthly average wind speeds vary between 1.3 m/s and 6.1 m/s, with the maximum during April and May (Zhang *et al.*, 1995, p.328, 332), and the southwesterly prevails most of the time (Zhang *et al.*, 1995, p.328).

The local meteorological station situated in the southwestern corner of the Lake recorded an annual ground mean temperature of 8.3°C in 1988. The coldest month was January with an average temperature of -9.2°C while the hottest month was July with a mean temperature of 23.6°C (Zhang *et al*, 1995, p. 328). The temperatures of lake water vary between 0°C and 20°C in the southwestern part whereas the summer temperature of surface water can reach as high as 26°C in the center of the Lake (Zhang *et al.*, 1995, p.351). The surface of the lake becomes frozen in December and re-opens in middle of March. The average frozen duration per year is about three months (93 days, Zhang *et al.*, 1995, p. 351). The average thickness of surface ice is about 0.6 m (Zhang *et al.*, 1995, p. 330, 332). With the penetration depths of sunlight being between 0.37 and 3.95 m (1.72 m in average) (Zhang *et al.*, 1995, p.351), the surface water of the Lake supports a diverse community of phytoplankton and zooplankton dominated by diatom (Zhang *et al.*, 1995, p. 344-345). Oxygen concentration varies between 6. 0 and 9.6 mg/L, with an average of 7.3 mg/L. The surface water is more enriched in dissolved oxygen than the deep water (e.g., 5.8 mg/L at 0.5 m water depth versus 4.3 mg/L at 11m; Zhang *et al.*, 1995, p.351). The oxygen concentration decreases to its minimum before the thawing of the frozen surface ice in March (Zhang *et al.*, 1995, p.351).

PREVIOUS STUDIES

Based upon the oxygen isotope characteristics of precipitation, the Mainland China can be subdivided into four regions (Fig. 1) (Wei, 1997). Among them the northwest part of China (Region IV in Figure 1, covering Xinjiang) is the area under the westerly regime and free of monsoon influence. The $\delta^{18}O$ of precipitated water is controlled dominantly by temperature effect (Wei, 1997). The 13 meteoritic water samples collected during 1980 in Urmuqi (烏魯木齊) yielded an average $\delta^{18}O$ = -8.6‰ and δD = -62‰. The variation in $\delta^{18}O$ shows a significant relationship with ground temperature: $\delta^{18}O$ = -0.5‰/1°C (Wei, 1997, p.563). For the southern part of Xinjiang, a systematic investigation of oxygen and hydrogen isotopic ratios of waters near the Lop Nur (羅布泊) was reported by Lin *et al.* (1987) on 19 water samples collected during 1981 and 1983. Seven samples were obtained from the lower reach of the Kong Que River. Due to a strong evaporation gradient in the area, the isotopic ratios show a wide range: $\delta^{18}O$ = -7.7 ~ 20.5‰ and δD = -64 ~ 72‰. The linear equation derived from the 19 data points is $\delta D = 4.35\delta^{18}O - 20.7$ (r = 0.97) (Wei, 1997, p.563). The intersection of this line with the global meteoric water line of Craig (1961) is at $\delta^{18}O$ = -8.4‰, δD = -57.3‰, indicative of the average water isotopic composition of precipitation in the eastern area of the southern Xinjiang (Wei, 1997, p.563). The values suggest a slight enrichment of heavy isotopes in the water compared to waters in the Urmuqi area.

To have a more updated understanding of the isotopic characteristics of precipitation of the Xinjiang area, we have examined the data collected at the Urmuqi (Wulumuqi) Station (43°46'48"N, 87°37'12"E, alt. 918 m) from 1986-1998 by the Global Network for Isotopes in Precipitation (GNIP) project administrated by the Isotope Hydrology Information System (ISOHIS) (http://isohis.iaea.org/). The data indicate that the monthly precipitation varied between 0 and 126 mm/month and is usually high during the summer months (April - October) (Tab. 1, Fig. 3). The atmospheric temperatures are higher than zero from April to October and below the freezing point from November to March. Isotopic variation shows strong temperature effect that winter precipitation is strongly depleted in both oxygen and hydrogen isotopes and vice versa for the summer precipitation (Tab. 1, Fig. 3). The weighted average values for the rain (warm and wet seasons) are $\delta^{18}O$ = -8.5‰, δD = -57‰; and for the snow (cold and dry season) are $\delta^{18}O$ = -15.4‰, δD = -112‰. The weighted averages over all the data are: $\delta^{18}O$ = -10.1‰, δD = -70‰ (Tab. 1). These values also are representative of the Xinjiang area.

Linear regression analyses of δD vs. $\delta^{18}O$ show strong linearity in both rain (April to October) and snow (November to March) data. The linear trends of rain ($\delta D = 6.7\delta^{18}O - 0.4$, r = 0.97) and snow ($\delta D = 7.3\delta^{18}O + 1.0$, r = 0.99) are similar with each other (Fig. 4). The pooled data shows a regression line defined by $\delta D = 7.2\delta^{18}O + 2.0$ (r = 0.99), which deviates slightly from the Global Meteoric Water Line (GMWL) of Craig: $\delta D = 8\delta^{18}O + 10$, most notably in the intercept value. The intercept in the equation has been termed "deuterium excess", which relates to the kinetic effect in evaporation of water vapor generated from ocean or continent (Dansgaard, 1964). The small difference in deuterium excess between the summer and winter seasons in Urmuqi precipitation suggests that the vapor sources do not change much seasonally, and thus not affected by the Asian monsoons (Kondon and Shimada, 1997). The result is in good agreement with Wei (1997).

Table 1. Statistics of precipitation during 1986-1998 at the Urmuqi (Wulumuqi) Station (43°46'48"N, 87°37'12"E, alt. 918m), Xinjiang, Global Network for Isotopes in Precipitation (GNIP) of the International Atomic Energy Agency (IAEA).

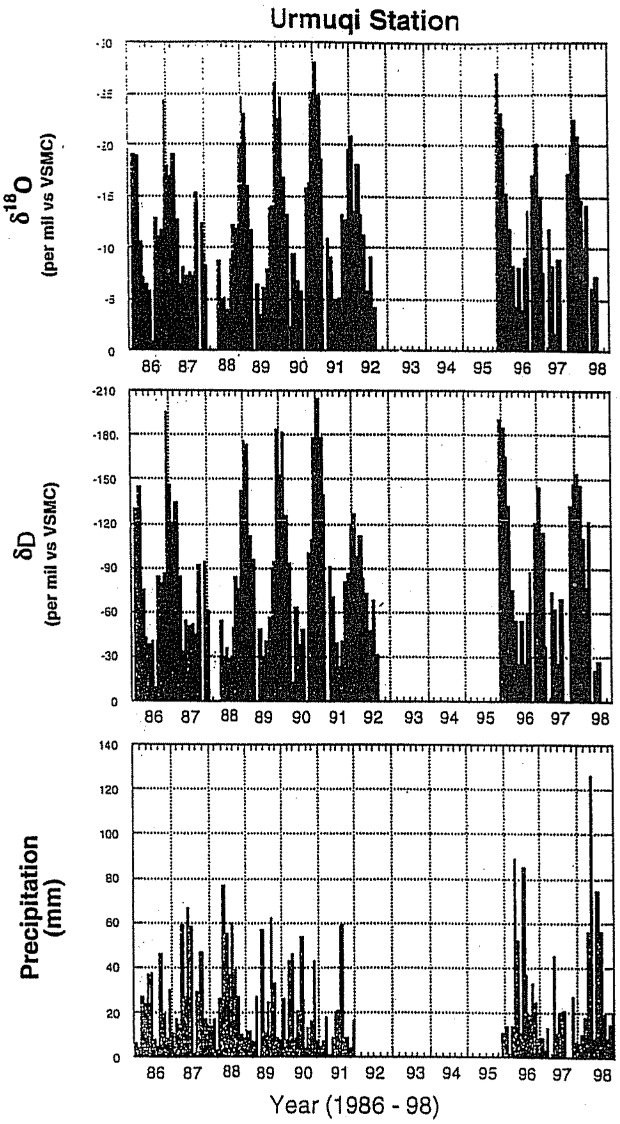

Figure 3. $\delta^{18}O$, δD in precipitation and monthly precipitation during 1986 - 1998 at Urmuqi Station of the Global Network for Isotopes in Precipitation (GNIP), International Atomic Energy Agency. Note that there are no data available for Year 1993-1995. The data were downloaded from the web site of the GNIP- ISOHIS (http://isohis.iaea.org/).

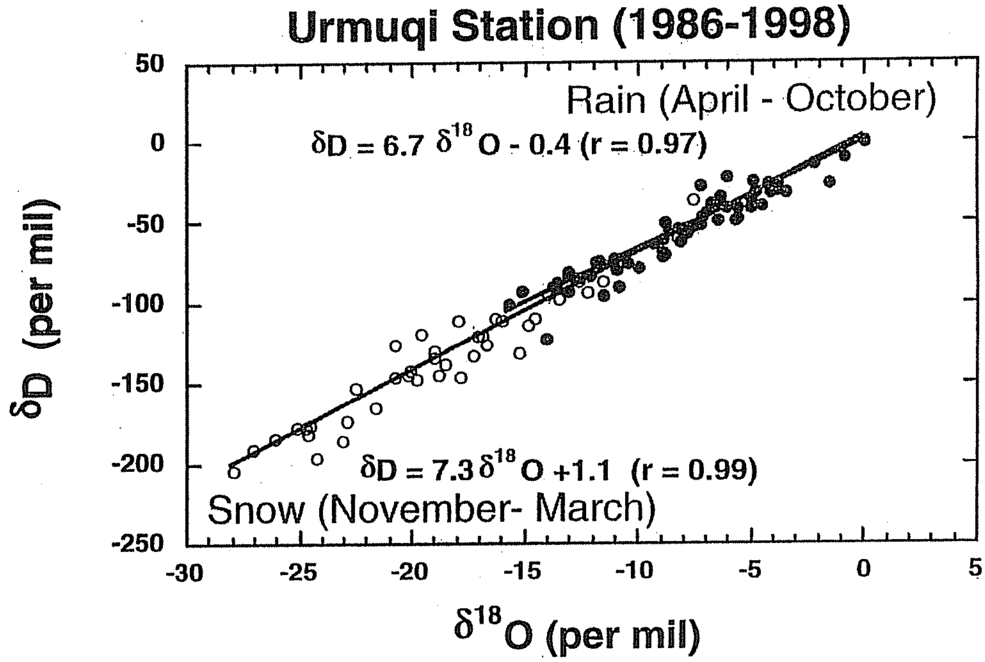

Figure 4. δD vs. $\delta^{18}O$ for precipitation samples collected during 1986 - 1998 at Urmuqi Station. Solid dots represent values collected during warm months of April - October when atmospheric temperatures are higher than 0°C. Open dots represent data of cold and dry months of November to March. The data are available at the web site of the GNIP- ISOHIS (http://isohis.iaea.org/).

MATERIALS AND METHODS

Water samples of 100 ml were collected from 12 locations covering the drainage systems of Lake Bosten Lake in Yang Qi Basin (Fig. 1) during the summers of 1999 and 2000. In addition, several water samples were collected from Tian-Chi (Heaven Pond, 天池) and Kan-Er Well （坎兒井） (sub-ground channels near Pu-Tao Gou (Grape Valley ，葡萄溝)) for reference purpose. Upon collection, several parameters including conductivity, temperature, pH and TDS (Tab. 2), were measured on site.

The water samples were then sterilized by adding a few drops of $HgCl_2$ agent, and then stored in leak-proof glass bottles for transporting back to Taiwan for further analyses.

$BaCO_3$ was precipitated from 10 liters of water collected at Silver Beach of Lake Bosten and Kong Que River near the lake outlet during 1999 summer. The $BaCO_3$ precipitate was dated using scintillator counter of NTU C-14 Dating System housed in Department of Geosciences, National Taiwan University. The C-14 ages and related parameters are reported in Table 2.

We adopted the Epstein-Mayeda (1953) method to measure the $\delta^{18}O$ value of water. The $\delta^{18}O$ value was measured on CO_2 that had been isotopically equilibrated with the water sample at 30°C for 2 hours. An aliquot of CO_2 was taken, dried by freezing out of H_2O in a cold trap, and sealed in a tube. The CO_2 gases collected were analyzed on a triple-collector mass spectrometer (SIRA 10). Hydrogen gas was prepared from 4μl of sample by reduction of zinc (Coleman *et al.*, 1982). The hydrogen isotopic compositions were measured on a MM602D mass spectrometer in Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan. All isotopic data are reported as deviations in per mill relative to the Vienna Standard Mean Ocean Water (VSMOW). Calibration was based upon analyses of SMOW, SLAP (Standard Light Antarctic Precipitation), and our laboratory standards under identical conditions. The analytical precisions expressed as 1σ for the laboratory standards are 0.10‰ for $\delta^{18}O$ and 1.5‰ for δD, respectively (Wang *et al.*, 1996).

Table 2. Characteristics of water samples from Lake Bosten region.

Sample ID	Locality (# on map)	Water Type	Date	Temp. (°C)	pH	Conductivity (μS.cm⁻¹)	TDS (mg/l)
HSG	Huang Shui Gou (1)	river	1999.8.27	17.0	8.1	421	213
QSR-1	Qing Shui River (2)	river	1999.8.28	13.1	8.1	353	177
QH-1	Qu Hui (4)	channel	1999.8.28	13.0	8.0	290	180
USTL-1	Ur Shi Ta La (5)	channel	1999.8.28	16.0	8.2	398	273
BTF-1	Baoertu Farm (6)	well water	1999.8.27	15.5	8.9	256	139
YQ-1	Yan Qi (7)	Kai Du River	1999.8.27	22.3	7.9	358	176
40M-1	40 Miles Town (8)	Small Lake	1999.8.27	27.0	8.7	2660	1421
KQR	Kong Que River (9)	outlet river	1999.8.27	22.0	7.2	1176	62
SV	Silver Beach (12)	lake water	1999.8.26	25.6	8.2	2150	1043

RESULTS

Water samples collected from small rivers and channels tend to have lower temperature and lower conductivity (Tab.2). It is believed that these waters are seepage of shallow groundwater drained in the coarse and loose fluvial sediments in the piedmont. On the other hand the waters from Kai Du River (YQ-1 taken from Yan Qi Hydrological Station), Small Lake Area (40M-1) and the Lake (Silver Beach) show higher temperature, reflecting long exposure of these surface waters to sunlight. The lake water samples are also characterized by higher content of dissolved substance and higher conductivity, indicative of stronger evaporation effect.

Water samples taken from the outlet river of the lake, Kong Que River, show very high percentage of modern carbon (Tab. 3), suggesting that the water circulation is fast in the lake system, at least in the southwestern corner of the Lake and adjacent Small Lake Area. On the other hand, water sample taken from the northern shore of the lake at Silver Beach yields a C-14 age of 420 years (Tab. 3), indicating certain degree of aging of water at this site, or minor contribution of dead carbon from old lacustrine deposits on the north shore.

The hydrogen and oxygen isotope ratios of water samples are listed in Table 4. Figure 5 plots the δD vs. $\delta^{18}O$ values. The water samples were categorized into two groups: (1) the north source including those from rivers/channels draining from the north of the Lake, and (2) the Kai Du River and the Lake, including samples taken from Kai Du River tributaries, the Lake and Kong Que River. The north source shows a limited range both in δD vs. $\delta^{18}O$ (upper panel of Figure 5). The majority of the data points appear to form a linear trend while four points deviate from the trend. Three out of the four samples were collected during August of 2000 when a major flood hit the Basin. The magnitude was reported to be unprecedented by local newspapers. The isotopic values ($\delta^{18}O$ = -7.2 - 8.2‰, δD = -52 - 57‰) of these four deviating water samples (1999 Baoertu Farm, 2000 Ta Ha Chi, Qu Huai and Ur Shi Ta La, Fig. 5), however, resemble to the averages isotopic values of summer rain precipitation ($\delta^{18}O$ = -8. 5‰, δD = -57‰). We infer that these water samples are directly from summer precipitation and had subjected to very little mixing/evaporation. On the other hand, the water samples collected from Kai Du River, the Lake and Kong Que River show a wider range of isotopic ratio, and display a linear trend (lower panel in Figure 5).

Pooling all data together as shown in Fig. 6, the linear trend remains. The linear trend defined by water samples collected during Year 2000 differs slightly from that of Year 1999. The Year 1999 line is defined by $\delta D = 3.1\delta^{18}O - 23.4$ (r = 0.95) while the Year 2000 line is $\delta D = 4.5\delta^{18}O - 15.8$ (r =0.90) (Fig. 6). The Year 2000 line is steeper than the Year 1999 line, indicative of less effect of evaporation taking place in shallow groundwater. Their intersections with the Global Meteoric Water Line of Craig (1961) are $\delta^{18}O1999$ = -6.8‰, δD1999 = -45‰; and $\delta^{18}O2000$ = -7.2‰, δD2000 = -48‰, respectively. The values are close enough to suggest that the waters of these two years originated from the same kind of vapor source. In average, the ratios of the vapor source are approximately: $\delta^{18}O$ = -7‰, δD = -46‰, very close to the weighted average values of summer precipitation of Urmuqi ($\delta^{18}O$ = -8.5‰, δD = -57‰, Tab. 1).

We pooled the two years' data together and derived a linear regression line of $\delta D = 3.7\delta^{18}O - 20.3$ (r = 0.89) (Fig. 7). The intersection of the line to the Global Meteoric Water Line of Craig is at $\delta^{18}O$ = -7.0‰, δD = -46‰. The values are very close to the weighted averages in rain precipitation in the Urmuqi area ($\delta^{18}O$ = -8.5‰, δD = -57‰), suggesting that most of the waters collected during 1999 and 2000 were mainly from summer precipitation. The low slope value (s = 3.7) of the regression line in respect to the theoretical value (s = 8) of evaporation under equilibrium (Dansgarrd, 1964), and the empirical value (s = 7.2) of the Urmuqi precipitation suggests that the evaporation in the Bösten Lake area is somewhere between Releigh condition and kinetic condition.

Table 3. Carbon-14 dates and related parameters of water samples taken from Lake Bosten area.

^{14}C Lab ID	Locality	Water Type	Date	$\delta^{13}C$ vs PDB	^{14}C Age*	$\Delta^{14}C$	Percent Modern**
NTU-3219	Kong Que River	river water	1999.8.27	-8.1‰	modern	38.0‰	104.4 ± 1.3%
NTU-3215	Kong Que River	river water	1999.8.27	-8.3‰	modern	18.7‰	102.5 ± 1.2%
NTU-3214	Silver Beach	Lake Bosten	1999.8.26	-2.7‰	420 ± 80 yrs	-57.1‰	94.8 ± 0.9%

* Reported age is the conventional radiocarbon age before present (BP).

** Percent modern means absolute per cent modern relative to the NBS I oxalic acid standard, corrected for decay since 1950.

Table 4. $\delta^{18}O$ and δD (‰) of water samples.

Sample ID	Locality (# on map)	Water Type	Date	$\delta^{18}O$ (‰)	δD (‰)
Lake Bosten Area					
HSG	Huang Shui Gou (1)	river	1999.8	-9.48	-51.5
QSR-1	Qing Shui River (2)	river	1999.8	-8.53	-50.0
QSR-2	Qing Shui River (2)	river	2000.6	-8.49	-49.1
QSR-3	Qing Shui River (2)	river	2000.8	-7.73	-47.0
THC	Ta Har Qi (3)	channel	2000.8	-7.90	-52.6
QH-1	Qu Huai (4)	channel	1999.8	-8.64	-49.5
QH-2	Qu Huai (4)	channel	2000.8	-8.17	-56.2
USTL-1	Ur Shi Ta La (5)	channel	1999.8	-8.12	-45.8
USTL-2	Ur Shi Ta La (5)	channel	2000.6	-8.14	-48.7
USTL-3	Ur Shi Ta La (5)	channel	2000.8	-7.29	-53.2
BTF-1	Baoertu Farm (6)	well water	1999.8	-8.99	-50.1
BTF-2	Baoeurtu Farm (6)	well water	2000.6	-8.18	-54.7
YQ-1	Yan Qi (7)	Kai Du River	1999.8	-9.55	-56.9
YQ-2	Yan Qi (7)	Kai Du River	2000.6	-10.13	-58.8
YQ-3	Yan Qi (7)	Kai Du River	2000.8	-8.43	-53.8
40M-1	40 Miles Town (8)	Small Lake	1999.8	-5.20	-37.9
40M-2	40 Miles Town (8)	Small Lake	2000.8	-6.25	-49.2
KQ	Kong Que River (9)	outlet river	1999.8	-7.25	-49.2
LB-1	Lake Bosten (10)*	lake water	2000.8	-4.33	-37.2
LB-2	Lake Bosten (11)**	lake water	2000.8	-3.65	-26.1
SV	Silver Beach (12)	lake water	1999.8	-2.57	-32.1
Miscellaneous					
TC-1	Tian Chi (Heaven Lake)	lake water	1999.8	-10.54	-54.9
TC-2	Tian Chi (Heaven Lake)	lake water	2000.6	-10.77	-81.2
KRW	Kan Er Well (Grape Valley)	groundwater	2000.8	-10.06	-70.3
UMQ	Urmuqi (Wei 1997)	rain	1980	-8.58	-62.2
UMQ-G	Urmuqi River (Cui 1988)***	ground water	------	-11.0	-74.6
LN	Lop Nur (Lin et al 1987)	inferred meteoric	1981-83	-8.40	-57.3

* LB1: 41° 54.16'N, 86° 45.71'E, same as the coring site of BLX-C.

** LB2: 41°58.25'N, 86° 50.426'E.

*** According to Wei (1997).

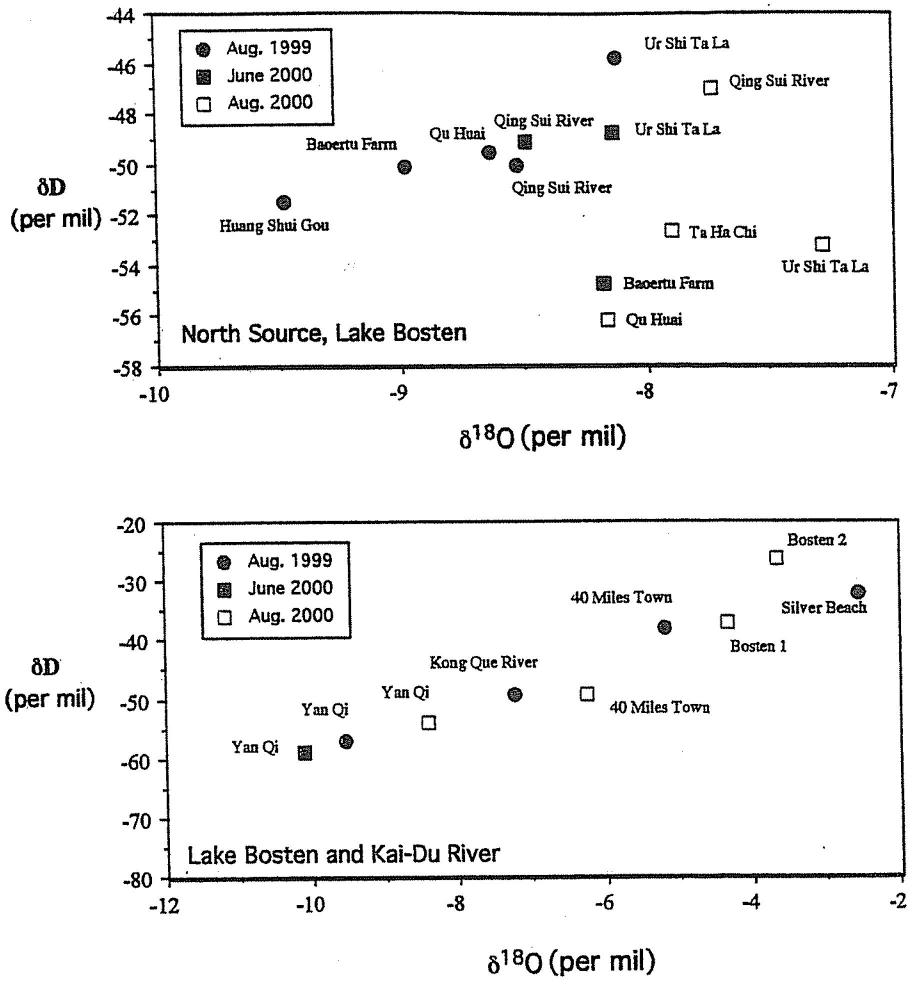

Figure 5. δD vs. $\delta^{18}O$ for water samples collected from the Lake Bosten drainage system. The upper panel shows the values of northern source that drains into the Lake. The lower panel depicts the analytic results of water samples collected from Lake Bosten, the Kai Du River tributary and Kong Que River.

For comparison, the analytical results (listed in Table 4) of water samples taken from other locations (e.g., Tian Chei and Kan Er Well) in Xinjiang are shown in Figure 7. Also shown are data points and regression line adopted from previous studies in Xinjiang (Lin *et al.*, 1987; Wei, 1997). The regression line of Lake Bosten region is basically parallel to that of the Lop Nur area, suggesting a very similar evaporation mechanism. In comparison to the average ratio values of the precipitation at Urmuqi ($\delta^{18}O$ = -10.4‰ and δD = -70‰, this study) the Lake Bosten values ($\delta^{18}O$ = -7‰, δD = -46‰) suggest that the source waters of the Lake are relatively enriched in both oxygen and hydrogen. The enrichment can be attributed to the higher temperature above the southern flank of the Tien Shan Range where the waters came from.

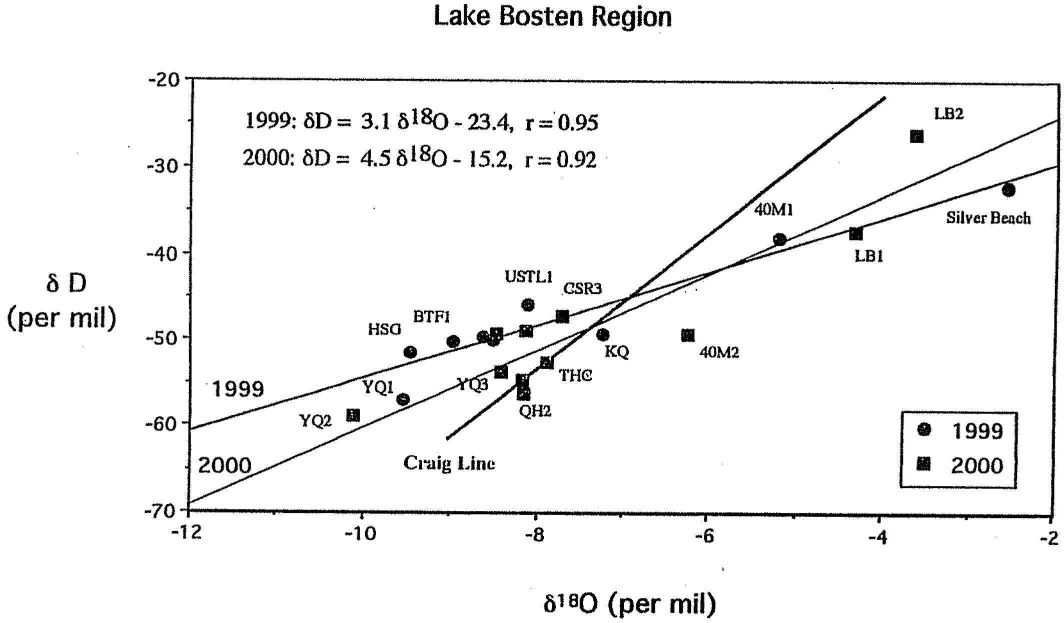

Figure 6. δD vs. $\delta^{18}O$ for water samples of Years 1999 and 2000 from the Lake Bosten drainage system compared with the Global Meteoric Water Line of Craig (1961). Evaporation lines for Year 1999 and Year 2000 are estimated separately.

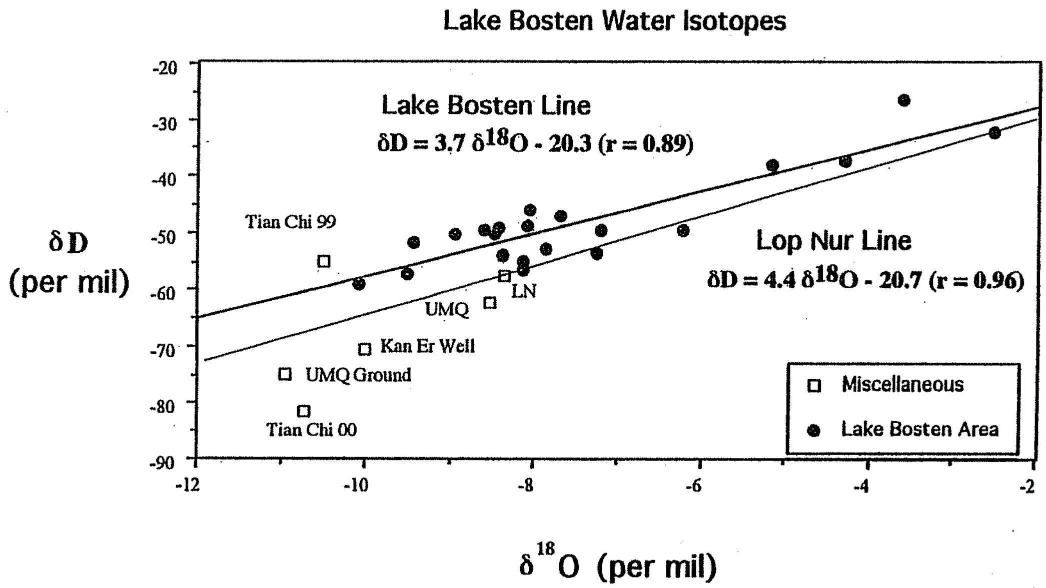

Figure 7. δD vs. $\delta^{18}O$ for water samples of Lake Bosten region and regional evaporation line compared with the line derived from Lop Nur area (Lin *et al.*, 1987). Also shown are analytic results of water samples collected from Tien Chi and Kan Er Well during 1999 and 2000 as well as values for Urmuqi and Nop Nur compiled from literature.

SUMMARY

1. Geochemical parameters of water samples collected from Lake Bosten area of the Southern Xinjiang during the summers of 1999 and 2000 were measured. Compared to river/channel waters, the lake water is characterized by high content of dissolved substance and high conductivity, indicative of mineralization and strong evaporation effect.

2. Water samples of the outlet river (Kong Que River) of Lake Bosten show very high percentage of fresh carbon with a modern C-14 age, suggesting that the circulation of waters in the southwest part of the Lake is efficient and fast. On the other hand, the water sample taken from the northern shore of the Lake yielded a C-14 age of 420 year old. This slightly older age indicates certain degree of aging of the water, or a small contribution of dead carbon from rocks/deposits through weathering process.

3. Waters of northern drainage source show small variation in their $\delta^{18}O$ and δD values whereas the water samples taken from the Lake, and various tributaries of the major input river, the Kai Du River, show a big variation. The $\delta^{18}O$ and δD values of water samples of northern source collected during the flooding period in August, 2000 deviate from the general linear trend defined by other samples in showing more negative δD and positive $\delta^{18}O$. The isotopic signature of these water samples is characteristic of summer precipitation, suggesting that these samples are directly from the summer rain.

4. The regression line in δD versus $\delta^{18}O$ distribution of Year 2000 is steeper than that of 1999, indicative of less effect of evaporation during the record-setting flooding event of Year 2000.

5. Despite the different slopes shown by the Year 1999 and 2000 regression lines, the intersections of these lines to the Global Meteoric Water Line (Craig line) are close enough to suggest that the precipitations of these two years were dominantly from the warm seasons (April - October) characterized by $\delta^{18}O = -7‰$ and $\delta D = -46‰$. In comparison to Urmuqi's summer precipitation ($\delta^{18}O = -8‰$ and $\delta D = -57‰$), the vapor source of precipitation in the middle Tien Shan Range and Yan Qi Basin is more enriched in heavy oxygen and hydrogen isotopes, attributed conceivably to higher condensation temperatures in the air above the southern flank of the Tien Shan Range.

6. The regression line of the $\delta^{18}O$ - δD distribution of waters in the Lake Bosten area is parallel to that of the Lop Nur area south to the Lake. Both lines show lower slope value (s = 3.7) relative to the theoretical value (s = 8) of evaporation under equilibrium, and the empirical value (s = 7.2) of the Urmuqi precipitation. We suggest that the evaporation processes in the Lake Bosten area are somewhat between Raleigh and kinetic conditions.

ACKNOWLEDGMENTS

The study is a contribution to the Asian Paleo-Environmental Change (APEC) Project supported by Academia Sinica (Taipei), and by Chinese Academy of Geological Sciences (Beijing) through a research cooperation contract between the two institutes. We are grateful for Mr. Kuan-Yu Chen and Dr. Tsung-Kewi Liu for lending us measurement facilities used in the field and conducting C-14 dating, respectively. The precipitation data at the Urmuqi (Wulumuqi) Station from 1986-1998 were collected and analyzed by the Institute of Hydrology & Engineering Geology, Shiajiazhung, Hebei, China. The data were downloaded from the website of the Global Network for Isotopes in Precipitation (GNIP) managed by the Isotope Hydrology Information System (ISOHIS) (http://isohis.iaea.org/). Three anonymous reviewers are thanked for their thoughtful reviews and suggestions.

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