第5卷第3期 冰 川 冻 土 Vol. 5 No. 3
1983年 9 月 JOURNAL OF GLACIOLOGY AND CRYOPEDOLOGY Sept. 1983

Oxygen Isotope Characteristics of Glaciers in the Eastern Tian Shan

Okitsugu Watanabe*, Wu Xiaoling**, Koichi Ikegami* and Yutaka Ageta***

(*Water Research Institute, Nagoya University Nagoya 464, Japan; ** Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica, Lanzhou China; *** Faculty of Education, Yamaguchi University, Yamaguchi 753, Japan)

Abstract

For the study of glacier nourishment and the hydrological characteristics in inland Asia, measurements of oxygen isotope composition were carried out on samples of precipitation and glacial water collected during the period from the middle of July to the middle of August in 1981. $\delta^{18}O$ values of each half day precipitation at Tian Shan Meteorological Station (43°06′N, 86°50′E; 3539m) and the base camp (3640m) in the Mt. Bogda region during the observed period had a weighted average of -10～-11‰ with a range between -1‰ and -16‰. The daily mean $\delta^{18}O$ value of precipitation decreased with a decrease in daily mean air temperature. $\delta^{18}O$ values of glacier ice and snow were less than those of summer precipitation. The difference of $\delta^{18}O$ values between the precipitation and the glacial water is attributed to the dependence of the oxygen isotope composition on the air temperature.

I. Introduction

Stable isotope studies in glaciology and hydrology have been done in various regions in the world for the last twenty years, and various glaciological problems, such as the process of precipitation, accumulation rate and runoff characteristics, have been studied. The Tian Shan is one of the most inland glacierized areas in the world. Therefore, the stable isotope composition of precipitation in this area is interesting from the point of view of the geographical situation. However, such information has not yet been obtained from inland Asia.

For the study of the glacier nourishment and the hydrological characteristics of this glacierized area, measurements of oxygen isotope composition were carried out on the samples of precipitation and glacial water collected during the summer season in 1981 by the China-Japan Cooperative Glaciological Expedition. In this paper, results of oxygen isotope composition of the samples of precipitation and glacial water are presented and their characteristics are discussed.

II. Method

Precipitation samples were collected at the Tian Shan Meteorological Station (43°06′N, 86°50′E; 3539m a.s.l.) at the headwaters of the Urumqi River during the period from July 9 to August 17, and Mt. Bogda Base Camp (3640m a.s.l.) from July 24 to August 13. The Mt. Bogda Base Camp is located 140km east-northeast from the Tian Shan Meteorological Station. Samples of snow and ice from the glaciers were collected on Glaciers No. 1 and No. 3 (the inventory numbers) at the headwaters of the Urumqi River and the neighbouring 2 glaciers on the northwest slope of the Mt. Bogda massif. Since these 2 glaciers in the Mt. Bogda region have the inventory numbers D-4 and D-5 in the drainage of the Sigong River, they are called 'Glacier D-4' and 'Glacier D-5' in this paper.

Measurements of oxygen isotope composition were performed by analyzing the isotope ratio of CO_2 equilibrated with a sample water using MAT 250 triple collector mass spectrometer. Results of measurements are expressed by a relative difference called the δ-value in permil (‰) defined as

$$\delta^{18}O = [(R_{SA} - R_{SMOW})/R_{SMOW}] \times 1000$$

where R_{SA} represents the isotope ratio ($^{18}O/^{16}O$) of a sample and R_{SMOW} is the corresponding ratio of the Standard Mean Ocean Water. The analytical error of these measurements is ±0.1‰.

Ⅲ. Results

Ⅲ-1. Oxygen isotope composition of precipitation

Oxygen isotope composition of precipitation at Tian Shan Meteorological Station and Mt. Bogda Base Camp is shown in Fig. 1. Each Value indicates a half day mean of $\delta^{18}O$

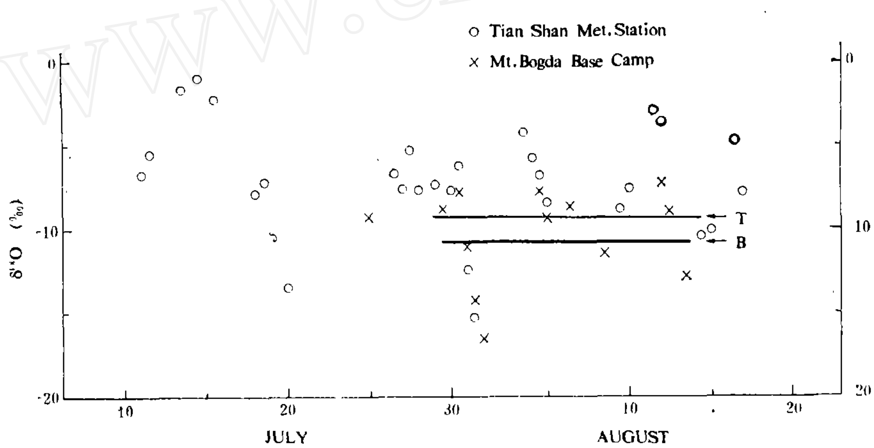

Fig. 1. $\delta^{18}O$ value of precipitation in the eastern Tian Shan in 1981. Each value indicates a half day mean $\delta^{18}O$. Horizontal lines show the mean weighted according to amount of precipitation during the period from July 29 to August 13 (T: Tian Shan Meteorological Station-3539m a.s.l., B: Mt. Bogda Base Camp 3610m a.s.l.).

divided by daytime precipitation (8h-20h) and nighttime precipitation (20h-next 8h). The variation of $\delta^{18}O$ value of precipitation collected at Mt. Bogda Base Camp showed a similar tendency to that observed at Tian Shan Meteorological Station during the same period, as seen in Fig. 1. And the weighted mean of $\delta^{18}O$ considering the amount of precipitation were also similar at both sites. On the other hand, the relation between the daily values of $\delta^{18}O$ and daily precipitation on the same days was checked, but they did not show a relation.

At both the Tian Shan Meteorological Station and Mt. Bogda Base Camp, $\delta^{18}O$ of precipitation had the smallest value on July 31 during the observation period. As analyzed by Ageta et al (1983) from the upper weather charts, a strong cold trough from the polar region was seen over this area and air temperature at Mt. Bogda Base Camp showed a sharp drop on the same day. The relation between the daily mean $\delta^{18}O$ value of precipitation and daily mean air temperature at Mt. Bogda Base Camp is shown in Fig. 2.

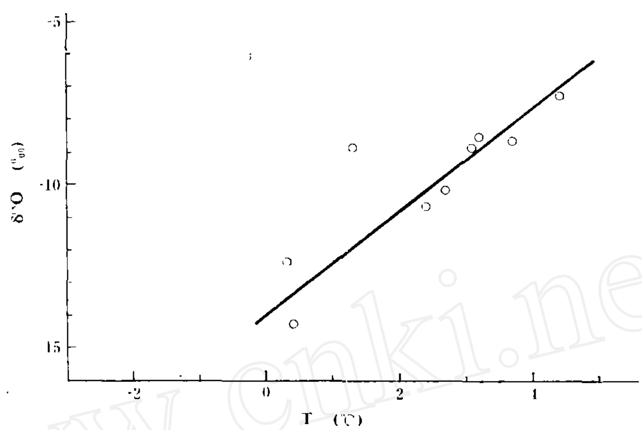

Fig. 2. Relation between daily mean $\delta^{18}O$ of precipitation and daily mean air temperature at Mt. Bogda Base Camp.

It is well known that the $\delta^{18}O$ value of precipitation is correlated with air temperature. Such a relation has been established from monthly mean values in many papers (for example, Siegenthaler et al. 1970). It can be said even from the daily values in Fig. 2 that air temperature is one of the controlling factors of the $\delta^{18}O$ value of precipitation in this region.

Comparing the relationship between $\delta^{18}O$ and temperature in Tian Shan shown in Fig. 2 with that based on a worldwide data compiled by Yurtsever (1975), it is closer to the relation obtained from marine and coastal stations than from continental ones. This is contrary regarding the geographical situation of Tian Shan. Characteristics of hydrological cycle in this region may cause the different tendency of $\delta^{18}O$ - temperature relationship comparing with the other regions.

III 2. Oxygen isotope composition of glacial water

A number of ice and snow samples were collected for the measurements of the oxygen isotope composition. The decrease of $\delta^{18}O$ value with increase in altitude has often been recorded in the various regions (for example, Sharp et al, 1960). The relation between $\delta^{18}O$ values and altitudes of the sampling sites in this region are shown in Figs. 3 and 4.

In Fig 3a for Glacier D-4, results of new snow collected on August 5 show nearly the same value against altitude, although the altitude effect mentioned above can be seen in the results of new snow collected on August 1. These samples are precipitation on the previous days when relatively heavy snow fell. Ageta et al (1983)

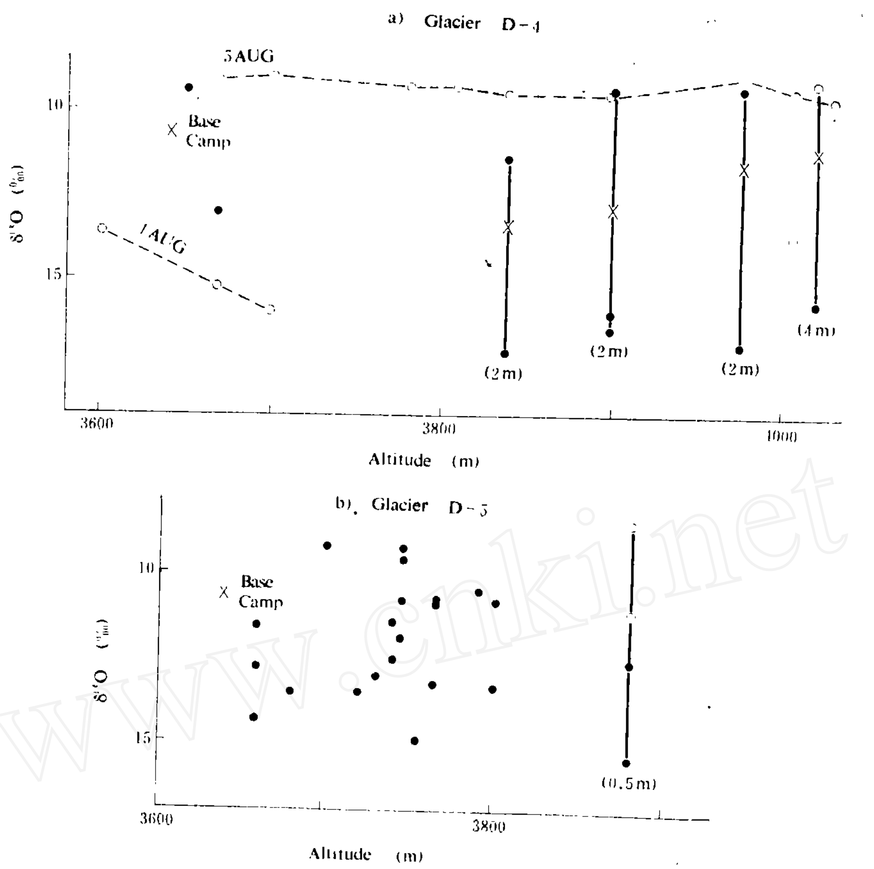

Fig. 3. $\delta^{18}O$ value of snow (open circle) and ice (solid circle) of Glaciers D-4 and D-5, and the precipitation at the base camp in Mt. Bogda region as a function of altitude. dashed line: the same day collection of the new snow which fell on the previous day. solid line: range of the results of a pit or boring cores from the surface to the depth in a parenthesis at a point. Cross mark represents the mean value.

concluded from the analysis mentioned in section 3.1 that precipitation was caused by a large scale cold trough on July 31, and by a local heat thunderstorm on August 4. Therefore, it can be said that the isotopic altitude effect is influenced by the meteorological cause of precipitation. However, more information is necessary for this discussion, especially in the case of inland precipitation.

Ⅳ. Discussion

In this section, $\delta^{18}O$ values of glacier ice and snow will be compared with those of summer precipitation in the Mt. Bogda region. As seen in Fig. 3, $\delta^{18}O$ values of ice and snow on Glacier D-4 and D-5, excluding the new snow collected on August 5, are less than the weighted mean of $\delta^{18}O$ value of precipitation at Base Camp. Since the $\delta^{18}O$ value of precipitation depends on air temperature as mentioned in section 3.1, two reasons can be thought of for the smaller values of the samples from the glaciers.

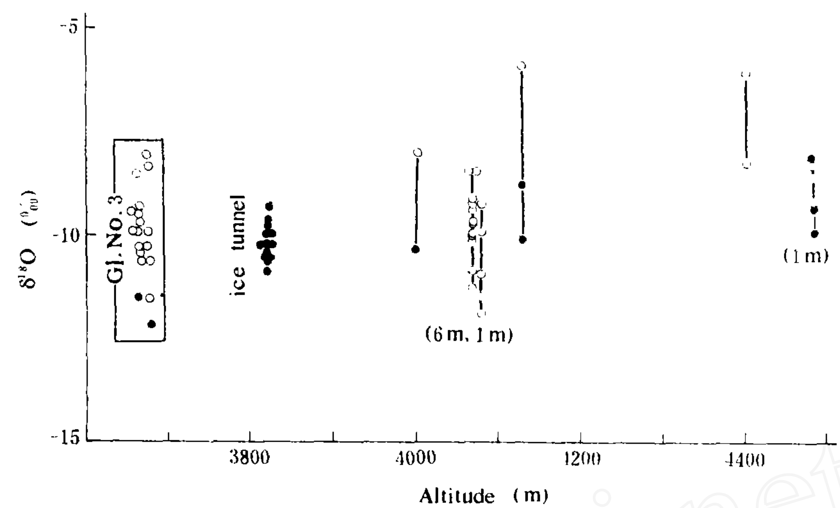

Fig. 4. δ¹⁸O value of snow (open circle) and ice (solid circle) of Glacier No. 1 and No. 3 (in a square) at the headwaters of the Urumqi River as a function of altitude. solid line: same as Fig. 3.

First, the δ¹⁸O value of snowfall which contributes to the accumulation of the glaciers is less than that of rainfall, because the probability of snowfall increases at lower air temperature (Ageta et al. 1983). Second, precipitation samples at Base Camp were obtained in the warmest season in the year, while the samples of the glaciers contain snow which fell not only in summer but also the colder season when δ¹⁸O values were less. However, the change of the δ¹⁸O value after the deposition of snow on the glaciers must be considered as discussed by Watanabe et al (1983a, b) for these glaciers.

Ⅴ. Conclusion

The oxygen isotope composition of precipitation in Mt. Bogda region and the headwaters of Urumqi River in the summer season was -10～-11‰ on the average and scattered in the range between -1‰ and -16‰. Air temperature is one of the facters controlling the δ¹⁸O value of precipitation. Therefore, the δ¹⁸O values of snowfall are less than those of rainfall. This is one of the reasons why δ¹⁸O values of glacier ice and snow were less than the mean δ¹⁸O value of precipitation in the summer season. Since these characteristics of the δ¹⁸O of glacier ice and snow are thought to be usefull in understanding the hydrological conditions in this area, further studies by the isotope method are necessary.

Appendix: Oxygen isotope samples lists

1. The headwaters of the Urumqi River

1—1. Precipitation at Tian Shan Meteorological Station (3,539m a.s.l.)

Period	δ¹⁸O (‰)	Period	δ¹⁸O (‰)
July 9, evening	-8.9	Jul. 30/8ʰ～30/20ʰ	-6.2

Period	δ¹⁸O (‰)	Period	δ¹⁸O (‰)
Jul. 10/20^h ~ 11/8^h	-6.7	30/20 ~ 31/8	-12.4
11/8 ~ 11/20	5.5	31/8 ~ 31/20	-15.3
13/8 ~ 13/20	1.7	Aug. 3/8 ~ 3/20	-4.2
14/8 ~ 14/20	1.0	3/20 ~ 4/8	-5.8
15/8 ~ 15/20	2.2	4/8 ~ 4/20	6.8
17/20 ~ 18/8	-7.8	4/20 ~ 5/8	8.4
18/8 ~ 18/20	7.2	9/8 ~ 9/20	-8.8
18/20 ~ 19/8	-10.5	9/20 ~ 10/8	7.6
19/20 ~ 20/8	13.5	11/8 ~ 11/20	3.0
26/8 ~ 26/20	6.7	11/20 ~ 12/8	-3.6
26/20 ~ 27/8	7.6	14/8 ~ 14/20	-10.4
27/8 ~ 27/20	5.3	14/20 ~ 15/8	10.0
27/20 ~ 28/8	-7.6	16/8 ~ 16/20	-4.7
28/20 ~ 29/8	7.3	16/20 ~ 17/8	7.7
29/20 ~ 30/8	7.8		

1—2. Glacier No. 1

a) Ice of the ice tunnel (3,820m a.s.l.)

distance from the entrance (m)	date	δ¹⁸O(‰)	distance from the entrance (m)	date	δ¹⁸O(‰)
	July 9	-10.6	9	August 16	9.6
3	August 16	-10.5	10	〃	-10.4
4	〃	-9.3	11	〃	-9.9
5	July 17	-10.7	12	〃	-10.2
5	August 16	-9.8	5m from the end	July 17	-10.0
6	〃	-10.5	4m 〃	〃	-10.9
7	〃	-10.2	end of the tunnel	〃	-10.2
dirt layer → 8	〃	-10.5			

b) West branch

altitude (m)	position	level from the surface (cm)	material	date	δ¹⁸O (‰)
4,075	H—3	105cm above summer surface in 1979	snow	July 13	-9.2
		90cm 〃	〃	〃	-10.9
		65cm 〃	〃	〃	-11.4
		40cm 〃	〃	〃	11.8
		20cm 〃	〃	〃	-9.8
		5cm below summer surface in 1979	ice	〃	-11.2

altitude (m)	position	level from the surface (cm)	material	date	$\delta^{18}O$ (‰)
4,075	H—3	25	snow	″	-9.9
		40	″	″	9.2
		50	″	″	-10.1
		60	″	″	9.4
		75	ice	″	10.0
		90	snow	″	-10.8
		100	″	″	-9.6
		120	″	″	-9.1
		140	icy	″	-9.7
		155	″	″	-8.4
		180	ice	″	-8.4
		189	″	July 17	-8.8
		204	″	″	8.7
		219	snow		-8.8
		234	″	″	-8.5
		259	″		-8.2
		299	″	″	-9.5
		319	ice	″	-10.4
		329	″	″	-10.5
		359	″	″	-9.5
		379	″	″	-10.4
		394	″	″	-11.5
		419	snow	July 17	-9.2
		459	″	″	-8.2
		484	ice	″	-9.2
		504	″	″	-9.5
		524	″	″	-10.1
		539	snow	″	-9.6
		574	ice	″	-10.4
		579	snow	″	-9.7

c) East branch

altitude (m)	position	level from the surface (cm)	material	date	$\delta^{18}O$ (‰)
4,480	Tianger II (near the summit)	0—9	snow	August 16	-9.2
		9—25	″	″	-8.6
		25—33	″	″	-8.3
		43	ice	″	-9.9
		65	″	″	-9.3
		83	″	″	-8.1
4,400	Tianger II (below the summit)	snow-firn patch dirty layer	snow	August 16	-6.0
			″	″	-8.2
4,130			snow	August 16	-5.9
			super-imposed ice	″	-10.1
			glacier ice	″	-8.8
4,000			snow	August 16	-8.0
			glacier ice	″	-10.3

1—3. Glacier No. 3

altitude (m)	position	level from the surface (cm)	material	date	$\delta^{18}O$ (‰)
3,650 ~ 3,700	pit No. 1	16	ice	July 14	9.9
		31	〃	〃	9.3
		38	〃	〃	9.7
		52	〃	〃	9.9
	pit No. 2	5	ice	July 11	11.5
		23	〃	〃	10.3
		28	〃	〃	9.9
		42	〃	〃	10.3
	around No. 2		running water	July 14	9.8
	pit No. 3	15	ice	July 14	9.4
		29	〃	〃	10.4
		33	〃	〃	-9.3
		38	〃	〃	9.7
	pit No. 4	20	ice	July 14	-10.6
		45	〃	〃	-8.5
		65	〃	〃	-9.5
		75	〃	〃	-10.4
	St. D		snow cover	August 15	11.5
				〃	12.1
	St. D·B		glacier ice	〃	-8.3
	St. B			〃	-8.1
	St. E			〃	-10.6
3,650	lake		lake water	July 12	-9.9

1—4. Others

altitude (m)	position		material	date	$\delta^{18}O$ (‰)
	Glacier No. 6	terminal moraine	dead ice	July 11	10.2
			lake water	〃	9.6
			river water	〃	-9.9
	Glacier No. 1		river water	July 9	10.1
			river water	July 7	-10.4
			〃	〃	-10.6

2. Mt. Bogda region

2—1. Precipitation at Mt. Bogda Base Camp (3,640m a.s.l.)

Period		$\delta^{18}O$ (‰)	Period		$\delta^{18}O$ (‰)
Jul.	$24/20^h$ ~ $25/8^h$	-9.2	Aug.	$4/22^h$ ~ $4/23^h$	9.4
	28/18 ~ 30/13	-10.0		4/23 ~ 4/24	-9.5
	(Gl. D5 St. D)				
	29/8 ~ 29/14	8.9		4/24 ~ 5/8	-7.4
	30/8 ~ 30/20	7.9		4/20 ~ 5/4	-8.8
	30/20 ~ 31/8	-11.0		6/8 ~ 6/20	-8.6
	31/8 ~ 31/11	-12.6		6/18:30 ~ 6/18:50	-9.0
	31/11 ~ 31/14	-14.0		~ 6/20	-8.7
	31/14 ~ 31/17	-14.9		8/8 ~ 8/20	-10.7
	31/17 ~ 31/20	15.4		8/10 ~ 8/11	10.5
	31/20 ~ 1/8	-16.5		11/20 ~ 12/8	7.2
Aug.	4/8 ~ 4/20	-7.7		12/8 ~ 12/20	-8.9
	4/20 ~ 5/8	-9.3		13/8 ~ 13/20	12.4
	4/20 ~ 4/22	-8.7			

2—2. Glacier D-4

altitude (m)	position	level from the surface (cm)	material	date	$\delta^{18}O$(‰)
3,600	terminus		new snow	August 1	13.6
3,668	St. No. 2		″	″	15.2
3,700	St. No. 3		″	″	15.9
4,006	St. No. 9		″	″	13.7
3,628	St. No. 1		new snow	August 5	9.8
3,668	St. No. 2			″	9.1
3,700	St. No. 3		″	″	9.0
3,781	St. No. 1		″	″	9.3
3,807	St. No. 5		″	″	9.3
3,838	St. No. 6		″	″	9.5
3,899	St. No. 7		″	″	9.5
3,976	St. No. 8		″	″	9.0
1,006	St. No. 9		″	″	9.1
1,030	St. No. 10		″	″	9.6
3,838	St. No. 6	0 —15	ice	August 5	-11.5
		15—28	″	″	-11.8
		28—61	″	″	-13.8
		131—144	″	″	-17.1
		156—175	″	″	-12.5
3,899	St. No. 7	10	ice	August 5	-12.2
		22	″	″	-9.3
		35	″	″	-11.3
		45	″	″	15.2
		65	″	″	-16.4
		75	″	″	-13.8
		85	″	″	15.6
		100	″	″	13.2
		110	″	″	-12.8
		125	″	″	-10.2
		145	″	″	-13.5
		160	″	″	-13.2
		180	″	″	-11.9
		195	″	″	-12.6
3,976	St. No. 8	25	ice	August 5	-9.7
		40	″	″	10.7
		50	″	″	-12.7
		65	″	″	-16.9
		80	″	″	-11.7
		95	″	″	-12.3
		130	″	″	-11.2
		135	″	″	-10.6
		145	″	″	-9.3
		160	″	″	-11.7
		180	″	″	11.0
4,020	St. No 9 —10	5	snow	August 1	15.7
		20	″	″	-11.1
		35	″	″	11.6
		45	″	″	-11.7
		65	ice	″	14.4
		70—75	snow	″	-13.6
		90—95	ice	″	10.9
		105—110	snow	″	-10.2
		123—129	″	″	-10.3
		140—144	″	″	-9.9
		155—160	″	″	-10.1
		180—190	″	″	9.4
		210—214	″	″	-11.6
		215—220	ice	″	11.8
		220—225	″	″	11.0
		270—275	snow	″	-12.3

4,020	St. No. 9-10	275—280 285—290 290—300 305—310 310—315 330—335 350—355 360—368 370—375 385—390	〃 〃 〃 〃 〃 〃 〃 〃 〃 〃	〃 〃 〃 〃 〃 〃 〃 〃 〃 〃	12.9 -12.9 12.1 -11.1 -10.2 -9.1 9.2 9.7 9.9 -10.5
3,668	St. No. 2		glacier ice	August 1	13.0
3,899	St. No. 7		〃	〃	-16.0
4,200			snow 〃 glacier ice	August 5 〃 〃	 8.2 -2.9
	middle part		debris bearing ice	August 6	-12.0 -13.0 -11.1 10.9 -12.1 -11.7
	St. No. 1-2		glacier ice	August 6	-12.5
3,600	lake		lake water	August 1	-10.2

2—3. Glacier D 5

altitude (m)	position	level from the surface (cm)	material	date	$\delta^{18}O$(‰)
	Terminal area 〃	St. T1 St. T2	glacier ice 〃	August 4 〃	14.3 -11.4
3,663	〃	St. T4	〃	〃	11.6
3,670	〃	St. T7	〃	〃	12.8
3,652	〃	St. A		〃	12.5
3,675	St. No. 2 3		dead ice	August 7	14.9
3,677	St. No. 3		stagnant ice	August 3	13.5
3,702	St. No. 1		〃	〃	-9.2
3,765	St. No. 6 St. No. 7 St. No. 9	median moraine	〃 glacier ice debris bearing ice	August 7 〃 August 3	-13.2 -10.7 9.6 -10.8
3,681	St. No 10	No. 1	dirt layer	August 3	10.9
3,722	St C		blue band bubble ice	〃 〃	-11.9 9.3
3,730	Strain Grid		glacier ice	August 4 August 7	13.5 -9.3
3,790	St. 21 St. E			August 4	-10.5
3,890	St. F				-10.8 -13.3
3,890	St. F	5cm from the surface 10cm 〃 27cm 〃 14cm 〃	snow	August 7	-12.5 15.4 -11.1 -8.5

3,790			glacier ice	August 4	-11.8 -12.0 -14.4 9.1 -10.3 10.3
			melt water	August 10	-13.5
	lake		lake water		-11.7
	river		river water		-10.7

2—4. Others

altitude (m)	position	level from the surface (cm)	material	date	$\delta^{18}O$(‰)
4,180	Bogda Ⅲ (by Japanese Tian Shan-kai Expedition, 1981)	along the climbing route on the north ridge	snow	August	-16.6
4,450					-8.1
4,600					-8.8
4,850					-9.8
4,900					-6.8
4,950					7.3
5,120					7.2
5,213	the summit				9.6
1,940	Tianchi Sigong River		lake water	July 21	-10.9
			river water	July 23	-11.5
1,720	Forest Station		precipitation	August 13	-10.1
				August 14	10.2

Acknowledgement

We would like to thank Mr. Sha Zhiyuan of the Tian Shan Meteorological Station for his kind collection of the precipitation samples at the station.

References

[1] Ageta, Y., Qiu, J. and Yasunari, T (1983): Relations between meteorological conditions and mass balance of a glacier on the north slope of Mt. Bogda (in this issue)

[2] Sharp, R. P., Epstein, S. and Vidziunas, I. W. (1960): Oxygen-isotope ratio in the Blue Glacier, Olympic Mountains, Washington, U. S. A.. *J. Geophys. Res.*, 65, 1043--1059.

[3] Siegenthaler, U., Oeschger, H. and Tongiorgi, E. (1970): Tritium and oxygen 18 in natural water samples from Switzerland. Isotope Hydrology, Proceeding of a symposium Vienna, International Atomic Energy Agency, Vienna, 373—385.

[4] Watanabe, O., Ageta, Y. and Ren, J. (1983a): Characteristics of firn stratigraphy in a glacier in the Sigong River headwaters, Mt. Bogda region, eastern Tian Shan (in this issue).

[5] Watanabe, O., Ageta, Y. and Iwata, S. (1983b): some aspects of the glacier structure and moraine characteristics of Glacier No. 3 in the Urumqi River headwaters (in this issue).

[6] Yurtsever, Y. (1975): Worldwide survey of stable isotopes in precipitation. Rep. Sect. Isotope Hydrol. November 1975, IAEA, 40pp.

天山东部冰川的氧同位素特征

渡边兴亚* 武筱舲** 池上宏一* 上田 丰***

(*日本名古屋大学水圈科学研究所；**中国科学院兰州冰川冻土研究所；***日本山口大学教育学部)

摘 要

为研究冰川的补给及亚洲大陆腹部的水文特点，进行了在1981年7月中旬到8月中旬采集的降雨及冰川水样品的氧同位素成分测定。在考察期间，天山气象站（北纬43°06′，东经86°50′，海拔3539米）及博格达峰地区大本营（3640米）每半日降雨同位素($\delta^{18}O$)的平均值为-10‰～-11‰，变化幅度-1‰到-16‰，日降雨的$\delta^{18}O$平均值随日平均气温的降低而减小。冰川水与雪的$\delta^{18}O$值低于夏季降水的$\delta^{18}O$值。降水与冰川水$\delta^{18}O$值的差异是由于氧同位素的成分与气温有关。