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APPLICATIONS OF ISOTOPE GEOCHEMISTRY TO RESEARCH ON CHINESE GLACIERS

by

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ABSTRACT

We report trace element, tritium, and hydrochemical analyses for glaciers in mountain regions of western China, based on about 200 samples collected between 1980 and 1983. Conclusions are drawn about the origin of water vapour contributing to precipitation (local or otherwise) and about the contributions to glacier run-off (meltwater or precipitation), based on the tritium measurements.

INTRODUCTION

The glaciers studied are located in mountain areas, at altitudes of over 3000 m, in western China and are listed in Table I. Snow samples were also collected from the Kunlun mountains, Fenghuoshan (K'un-lun mountains, Feng-huo-shan) and the Tanggula mountains, Qinghai-Xizang Plateau (T'ang-ku-la mountains, Ch'ing-hai - Hsi-tsang Plateau).

RESULTS AND DISCUSSION

1. Hydrological characteristics and trace elements

Our results show that the pH of melted snow and ice samples is approximately neutral (Table II) (Vilenskiy and Miklishanskiy 1976, Wang Ping and Liu Zhi 1982, Wang Ping and others 1983); however, a snow sample from Galongla glacier had a pH of 4.25, which is unusually low for the area studied. The degree of mineralization of the samples was also low, samples from "Hars", Gonggashan, and Duoxiongla glaciers generally containing less than 15 mg l^{-1} of dissolved mineral salts. This shows that the snow and ice of Chinese glaciers are generally fresh and extremely soft.

Table III summarizes the measured concentrations of trace elements and heavy metals. Concentrations of Mg, Co, Cr, Sr, Ni, Cu, Zn, V, Pb, Ti, Sn, Hg, Ag and Se were all found to be below the maximum permissible levels for harmful metals in groundwater, as published by the Department of Health in China in 1963. However, the levels of As and Cd were found sometimes to exceed the maximum safe concentrations; for example, the levels of As in samples taken from Dunte flat-topped glacier and Zelonglong glacier were above 50 ppb, and samples from Zelonglong, Galongla, Namula, and Duoxiongla glaciers showed Cd levels in excess of 10 ppb (the National Standard).

2. Impurity enrichment factors

Table IV shows measured enrichment factors for major impurities in Chinese mountain glaciers (Boutron and Lorius 1977, Wang Ping and Luo Hongzhen 1980, Luo Hongzhen 1983, Wang Ping 1983). The order of enrichment of the major ions was found to be:

"Hars" glacier	Na > K > Mg > Ca	or	Mg > K > Na > Ca
Tianshan Mountains	Mg > Ca > Na > K	or	Ca > Mg > Na > K
Dunte flat-topped glacier	Na > Mg > Ca > K	or	Mg > Na > K > Ca
Gonggashan glacier	Mg > Na > Ca > K	or	Na > Mg > Ca > K
Zelonglong glacier	Mg > Ca > Na > K		
Galongla glacier	Na > Mg > K > Ca		
Namula and Duoxiongla glaciers	Mg > Ca > K > Na	or	K > Na > Ca > Mg
Zhongrongbu glacier	Ca > Na > Mg > K		
Yulongshan glacier	Na > Mg > Ca > K		
Kunlun, Fenghuoshan and Tanggula Mts	Mg > Na > K > Ca	or	Na > Ca > Mg > K

This shows that the pathways of water replenishment vary with locality in the mountainous regions of China, and that it is mainly controlled by the high atmospheric oceanic water vapour.

3. Tritium measurements

Tritium measurements can be used to estimate the annual accumulation and mean accumulation ratios (Boutron and Lorius 1977, Wang Ping and others 1984). We found environmental tritium levels in the range from 13 to 196 TU in samples of precipitation from the Altay, Tianshan, Qilian, Gonggashan, Tanggula and Kunlun mountains and from the Nanjiabawa Peak area (Table V). We also determined mean annual accumulation ratios of 618 mm a^{-1} (west Qiongtailan glacier), 645 mm a^{-1} ("Hars" glacier), and 424 mm a^{-1} ("No.1 glacier").

Tritium data can also be used to calculate the percentage of local vapour in the air and precipitation of glacial regions (Wang Ping and others 1984). Based on these results, local contributions were calculated:

Mt Youyi (Altay Mountains)	35%	
"No.1 glacier"	12.0% (1981)	15.8% (1982)
west Qiongtailan glacier	17.6%	
Badaishi glacier	30.5%	
Lenglongling glacier	40.6%	
Gonggashan glacier	13.5%	
Tanggula Mountains	40.0%	
Yulongshan glacier	23.0%	
Nanjibawa glaciers	22.3%	

Finally, we can use tritium measurements to separate the different contributions to the total glacier run-off. Analysis of the tritium content at the source of Qiongtailan River, Mt Tuomer, by Wang Lilun (Wang Li-lun), Su Zhen (Su Chen) and Zhang Wenjing (Chang Wen-ching) in July 1978 shows that glacier meltwater accounts for 34% and precipitation for 66% of the total glacier run-off. Table VI shows results obtained by the present author for "No.1 glacier" at the source of the Urumqi River, Tianshan mountains (Urumchi River, T'ien Shan) at different times during 1983.

*Wade-Giles: Wang P'ing

House Editor's note: in this paper, when a Chinese name is used, the Pinyin form of transliteration is given first, followed by the Wade-Giles form in round brackets (for the convenience of bibliographers who are accustomed to this form).However, Table I lists these forms for glaciers and their geographical locations (including two instances where anglicized forms of Chinese names of glaciers are commonly used, even in China), and the list at the end of the paper includes transliterations for all references in Chinese (authors, titles of articles, periodicals) together with English translations. In these cases, therefore, only the Pinyin form is given in the text.

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TABLE I. LIST OF GLACIERS STUDIED AND THEIR GEOGRAPHICAL LOCATIONS, WITH PINYIN AND WADE-GILES TRANSLITERATIONS

Name of glacier (Pinyin)	Geographical location (Pinyin)	Name of glacier (Wade-Giles)	Geographical location (Wade-Giles)
Ha-la-si ["Hars"]	Mt Youyi, Altay mountains	Ha-la-ssu ["Hars"]	You-yi-feng Altay mountains
Haxileigen	western Tianshan	Ha-hsi-lei-ken	western T'ien Shan
Qiongtailan	Mt Tuomuer, Tianshan	Hsi-ch'iung-t'ai-lan	T'o mu-erh-feng, T'ien Shan
Keqiqiaer	southern slope of Mt Tuomuer	K'e-ch'i-ch'ia-erh	southern slope of T'omu-erh-feng
Yi-hao bing-chuan ["No.1 glacier"]	source of Urumqi river, Tianshan	Yi-hao ping-ch'uan ["No.1 glacier"]	source of Urumchi river, T'ien Shan
Badaishi	Haerlikeshan, Hami	Pa-tai-shih	Ha-erh-li-k'e-shan, Ha-mi
Dunte	Kakitushan, south-west Qilian Shan	Tun-t'e	Kakitu Shan, south-west Ch'i-lien Shan
Lenglongling	eastern Qilian Shan	Lenglung Ling	eastern Ch'i-lien Shan
Gonggashan	Hengduan mountains	Kung-ka-shan	Heng-tuan mountains
Yulongshan	northern Yunnan	Yu-lung-shan	northern Yun-nan
Zelonglong	vicinity of Nanjiabawa Peak, Ximalaya mountains	Tse-lung-lung	vicinity of Nan-chia-pa-wa Peak, Hsi-ma-la-ya mountains
Galongla		Ka-lung-la	
Namula		Na-mu-la	
Duoxiongla		To-hsiung-la	
Rongrongbu	Himalaya mountains	Chung-jung-pu	Hi-ma-la-ya mountains

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TABLE II. THE DEGREE OF MINERALIZATION AND HYDROCHEMICAL TYPE IN SNOW AND ICE SAMPLES

Glacier	Time of collection	Altitude	pH	Type	Degree of mineralization (mg l^{-1})	Hydrochemical type
"Hars" glacier, Mt Youyi, Altay Mountains	July 1980	3200	6.62	snow	15.35	Mg^{2+}, Na^{+}, HCO_3^-, Cl^-
	July 1980	2800	6.16	snow	25.09	Na^{+}, Mg^{2+}, HCO_3^-, Cl^-
	Aug 1980	3300	6.07	snow	23.82	Na^{+}, Mg^{2+}, HCO_3^-, Cl^-
	Aug 1980	2800	6.60	ice	12.59	Na^{+}, Mg^{2+}, HCO_3^-
	Aug 1980	3000	6.52	ice	9.49	Na^{+}, Mg^{2+}, HCO_3^-, Cl^-
	Aug 1980	3200	6.24	ice	9.50	Mg^{2+}, Na^{+}, SO_4^{2-}, Cl^-
Haxileiggen glacier	June 1981	3600	6.80	snow	14.13	Mg^{2+}, Ca^{2+}, SO_4^{2-}, HCO_3^-
Mt Tuomuer (northern)	July 1981	4000	6.70	hail	35.98	Ca^{2+}, Mg^{2+}, SO_4^{2-}
	July 1981	4000	7.90	snow	25.32	Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^-
Mt Tuomuer (southern)	July 1981	3600	6.9	snow	20.95	Ca^{2+}, Mg^{2+}, SO_4^{2-}
	June 1979	5300	-	snow	39.15	Ca^{2+}, Mg^{2+}, HCO_3^-
	June 1979	5300	-	snow	28.29	Ca^{2+}, Mg^{2+}, HCO_3^-
	June 1979	5300	-	snow	14.46	Mg^{2+}, Ca^{2+}, HCO_3^-
No.1 glacier, at the source of Urumqi River	June 1982	3700	6.32	hail	41.14	Ca^{2+}, Mg^{2+}, HCO_3^-
	June 1982	3700	6.34	rain	22.92	Mg^{2+}, Ca^{2+}, HCO_3^-, SO_4^{2-}
	May 1982	4100	6.46	snow	9.25	Mg^{2+}, Ca^{2+}, HCO_3^-, SO_4^{2-}
Badaishi glacier	Aug 1981	3300	6.00	snow	25.59	Mg^{2+}, Ca^{2+}, SO_4^{2-}, HCO_3^-
Gonggashan glacier	Aug 1981	6000	6.12	snow	5.49	Mg^{2+}, Na^{+}, Cl^-, HCO_3^-
	Aug 1981	6000	6.30	ice	9.40	Mg^{2+}, Na^{+}, HCO_3^-, Cl^-
Dunte flattopped glacier, Kakitushan	Aug 1981	5000	7.70	ice	166.98	Ca^{2+}, Mg^{2+}, HCO_3^-
	Aug 1981	5200	6.65	snow	33.82	Na^{+}, Mg^{2+}, HCO_3^-
	Aug 1981	5320	6.70	snow	31.12	Na^{+}, Mg^{2+}, HCO_3^-
	Aug 1981	5300	7.00	snow	33.20	Mg^{2+}, Na^{+}, Cl^-, HCO_3^-
Lenglongling glacier	June 1963	4100	-	snow	32.47	Ca^{2+}, Mg^{2+}, HCO_3^-
	July 1982	4300	6.43	snow	16.62	Ca^{2+}, Mg^{2+}, HCO_3^-
Zelonglong glacier	Sept 1982	3550	6.68	rain	28.78	Mg^{2+}, Ca^{2+}, HCO_3^-
	Sept 1982	3700	5.58	ice	21.70	Mg^{2+}, Na^{+}, HCO_3^-
Galongla glacier	Aug 1982	3640	4.25	snow	21.71	Na^{+}, Mg^{2+}, Cl^-, SO_4^{2-}
	Aug 1982	3700	6.26	ice	39.36	Ca^{2+}, SO_4^{2-}, HCO_3^-
Duoxiongla glacier	Sept 1982	4100	5.50	firn	7.64	Mg^{2+}, HCO_3^-, Cl^-
	Sept 1982	4100	5.47	firn	3.08	Mg^{2+}, Ca^{2+}, HCO_3^-, Cl^-

TABLE III. CONCENTRATION OF TRACE ELEMENTS IN SNOW AND ICE

Glacier	Sampling date	Altitude (m)	Type	ppb															
				Mg	Co	Cr	Sr	Ni	Cu	Zn	V	Pb	As	Cd	Ti	Sn	Hg	Ag	Se
"Hars" glacier, Mt Youyi, Altay Mountains	July 1980	3200	snow		171.7	10.7	2.1	2.4	13.9	10.1	11.8	-	-	0.3					
	July 1980	3000	ice		159.0	8.3	6.5	5.3	11.0	9.1	-	-	-	0.3					
	July 1980	2800	rain		45.0	1.0	4.0	0.6	0.9	-	-	-	-	0.3					
	July 1980	1900	rain		45.0	1.0	1.7	0.6	0.9	-	-	-	-	0.3					
	July 1980	480	river		38.6	-	33.7	-	6.8	-	-	-	16.0	0.3					
	July 1980	1300	river		-	-	47.3	-	-	-	-	-	-	0.3					
Glaciers of Tianshan Mountains	July 1980	4000	snow		0.13	1.5			0.9	11.0				0.9		0.38			
	July 1980	4000	snow		-	-	14.2	-	0.5	3.6	-	-	11.8	0.3	-	1.55			
	Aug 1980	4000	ice		0.13	1.4			0.8	27.0				0.9		0.50			
	Aug 1982	3700	hail	29.4	83.2	17.2	41.1	-	29.8	24.2	12.0	9.7	-	9.3	0.1	6.1	11.7	17.4	16.8
	June 1982	3700	rain	26.0	64.2	11.2	21.6	-	20.7	72.9	10.9	6.4	-	7.7	-	3.0	11.0	15.0	11.9
	May 1982	4200	snow	8.3	76.8	12.0	11.8	-	22.5	80.1	12.1	6.7	-	8.0	0.4	4.4	10.7	16.3	11.4
Dunte flattopped glacier, Kakitushan	Aug 1981	5000	ice		-	-	82.0	-	-	-	0.3	-	-	-	-	-		-	
	Aug 1981	5100	snow		-	1.6	6.5	4.0	11.5	3.8	-	-	46.7	0.9	6.5	-		-	
	Aug 1981	5300	snow		-	-	9.4	-	3.6	3.2	-	-	-	1.2	-	-		-	
	Aug 1981	5200	snow		0.37	-	3.3	77.2	28.0	9.5	9.4	-	92.1	12.8	1.1	4.7		23.1	
Lenglongling glacier	Aug 1982	4300	snow	21.0	90.3	13.0	8.2	-	23.8	43.2	12.6	4.2	-	9.3	0.5	3.0	12.6	17.6	13.6
Gonggashan glacier	Aug 1981	6000	snow		0.04	28.5	0.8	-	20.5	-	5.5	-	-	0.3	-	-		22.6	
	Aug 1981	6000	ice		0.01	6.7	-	-	9.2	-	-	-	-	0.3	-	-		19.6	
Zelonglong glacier	Sept 1982	3700	ice	27.0	97.3	9.7	2.2	9.3	23.3	64.4	11.8	17.6	-	11.0	2.5	5.8	11.8	20.1	18.3
	Sept 1982	3500	ice	16.0	26.3	6.2	0.8	-	17.6	60.2	6.7	9.9	-	7.5	-	4.3	6.6	8.7	15.9
	Sept 1982	3550	rain	21.0	91.1	12.6	13.4	11.6	62.7	33.8	11.3	24.5	32.8	13.0	0.7	9.9	11.7	18.8	25.4
	Sept 1982	2820	river	41.9	107.6	11.6	72.3	9.9	21.7	73.3	12.0	18.1	135.0	11.9	0.8	13.8	12.8	19.9	32.1
	Oct 1982	2850	spring	59.8	166.6	16.7	147.6	25.1	24.0	87.1	15.8	32.7	508.2	19.2	1.5	30.0	16.7	24.6	63.0
Galongla glacier	Aug 1982	3700	ice	19.4	91.7	11.5	3.9	1.5	30.8	71.5	12.1	14.2	-	11.4	0.5	6.5	12.7	19.4	17.9
	Aug 1982	3640	snow	31.3	108.4	14.6	2.3	-	39.1	268.9	15.1	13.2	-	11.9	1.1	6.1	14.6	22.2	19.9
Namula glacier	Oct 1982	4600	ice	12.0	56.3	9.3	1.1	-	20.6	208.0	9.8	8.5	-	8.3	-	3.6	9.6	13.7	11.8
	Oct 1982	4600	snow	24.1	85.5	11.8	2.3	-	23.8	238.6	11.9	11.7	-	11.0	0.5	5.0	12.2	19.3	17.8
	Oct 1982	4130	lake	33.4	88.6	13.3	14.8	-	22.5	59.5	12.7	10.5	-	10.1	2.4	8.6	12.4	17.7	22.5
Duoxiongla glacier	Sept 1982	4100	snow	28.4	81.6	8.8	0.2	4.2	21.4	63.9	9.5	15.9	-	9.7	0.4	4.9	9.9	16.0	16.6
	Sept 1982	4100	snow	35.5	88.0	11.2	0.2	-	21.6	65.2	12.3	14.8	-	12.1	0.2	6.7	12.8	19.3	18.6
Qinghai-Xizang Plateau	July 1980	4800	snow		0.2	10.5	57.7	0.6	6.2	-	10.5		-	0.3	-				
	Aug 1982	4800	snow	22.0	98.2	13.6	2.4	-	22.9	60.3	13.7	12.0	-	10.1	0.9	6.8	13.1	20.6	17.7
	Sept 1982	4700	snow	19.2	92.6	12.6	15.7	-	25.9	106.6	12.8	11.6	-	10.8	0.6	6.1	12.6	19.9	15.8
Yulongshan glacier	July 1982	4500	firn	12.2	37.2	-	-	10.4	27.0	-	2.5	26.9	-	15.5	4.6	9.7	24.4	-	18.3
	Aug 1982	4500	snow	11.6	30.2	-	-	3.4	20.8	-	1.9	16.7	-	9.8	3.5	4.1	18.7	-	5.9

TABLE IV. ELEMENT ENRICHMENT FACTORS IN SNOW AND ICE

Glacier	Sampling time	Altitude (m)	Type of samples	Enrichment factor (EF/Al)				Enrichment order
				Na	Mg	K	Ca	
"Hars" glacier, Mt Youyi, Altay Mountains	Aug 1980	3380	snow	110.2	55.7	86.9	51.5	Na>K>Mg>Ca
	July 1980	3200	snow	15.8	55.7	17.3	11.2	Mg>K>Na>Ca
	July 1980	3200	snow	10.1	41.5	26.8	9.8	Mg>K>Na>Ca
	July 1980	2800	snow	603.6	416.2	515.6	149.5	Na>K>Mg>Ca
	July 1980	3200	ice	25.0	50.5	10.0	11.9	Mg>Na>Ca>K
	Aug 1980	2600	ice	1.0	28.8	10.0	23.8	Mg>Ca>K>Na
Haxileigen glacier	June 1981	3600	snow	5.3	37.4	3.5	25.4	Mg>Ca>Na>K
Quiongtailan glacier, Mt Tuomuer	June 1978	4000	snow	1.6	2.3	0.3	5.1	Ca>Mg>Na>K
	July 1981	3600	snow	2.6	16.6	0.7	33.9	Ca>Mg>Na>K
	July 1981	4000	snow	4.5	23.6	4.2	30.5	Ca>Mg>Na>K
	June 1978	4000	ice	49.8	54.1	13.0	101.3	Ca>Mg>Na>K
No.1 glacier at the source of Urumqi	May 1982	4000	snow	3.9	16.7	2.8	13.4	Mg>Ca>Na>K
	May 1982	4000	snow	8.8	25.6	2.9	17.6	Mg>Ca>Na>K
Badaishi glacier	Aug 1981	3300	snow	23.3	49.4	22.2	30.2	Mg>Ca>Na>K
Dunte flattopped glacier Kakitushan	Aug 1981	5100	snow	15.3	20.2	11.6	6.3	Mg>Na>K>Ca
	Aug 1981	5200	snow	109.2	34.4	30.5	32.4	Na>Mg>Ca>K
	Aug 1981	5320	snow	48.2	43.4	5.7	13.1	Na>Mg>Ca>K
	Aug 1981	5200	snow	158.3	74.2	133.5	55.8	Na>K>Mg>Ca
	Aug 1981	5100	snow	5.0	21.6	1.1	11.1	Mg>Ca>Na>K
	Aug 1981	5000	ice	4.8	17.0	3.9	28.5	Ca>Mg>Na>K
Lenglongling glacier	Aug 1982	4300	snow	5.2	11.0	5.5	18.3	Ca>Mg>K>Na
Gonggashan glacier	Aug 1981	6000	ice	55.4	52.1	17.6	8.1	Na>Mg>K>Ca
	Aug 1981	6000	snow	10.2	41.1	3.6	6.4	Mg>Na>Ca>K
Zelonglong glacier	Sept 1982	3550	rain	10.6	28.8	8.9	11.3	Mg>Ca>Na>K
	Sept 1982	3700	ice	33.6	95.6	32.4	3.2	Mg>Na>K>Ca
	Sept 1982	3500	ice	43.9	58.1	32.9	34.8	Mg>Na>Ca>K
Galongla glacier	Aug 1982	3640	snow	57.4	47.9	26.1	4.7	Na>Mg>K>Ca
	Aug 1982	2700	ice	3.6	9.4	28.7	26.6	K>Ca>Mg>Na
Namula glacier	Oct 1982	4600	snow	73.0	23.6	23.1	6.2	Mg>K>Ca>Na
	Oct 1982	4600	ice	695.2	34.0	297.2	1.1	Mg>Ca>K>Na
Duoxiongla glacier	Sept 1982	4100	firn	9.7	42.4	18.6	24.3	Mg>Ca>K>Na
	Sept 1982	4100	firn	9.0	7.4	18.3	7.5	K>Na>Ca>Mg
Rongbuk glacier	1964		snow	19.3	5.0	4.8	28.3	Ca>Na>Mg>K

TABLE V. TRITIUM CONTENT IN SNOWFALL FOR MOUNTAIN AREAS

Glacier	Time of collection	Altitude (m)	Type of samples	Position		Tritium content (TU)	
				Latitude	Longitude	Content	Mean
"Hars" glacier	Aug 1980	3380	snowfall	49°07'N	87°47'E		102.8*
No.1 glacier at the source of Urumqi River	May-Sept 1980	4100	snowfall	43°06'N	86°49'E		106.7*
	Aug 1983	4100				113	
	Aug 1983	4100				82	100.7
	Aug 1983	4100				76	
	Aug 1983	4100				118	
	Aug 1983	4100				120	
	Aug 1983	4100				95	
Gonggashan glacier	Sept 1982	5180	firn	29°36'N	101°56'E	60	33.0
	Sept 1982	5180				19	
	Sept 1982	5180				47	
	Sept 1982	5180				26	
	Sept 1982	4100	snowfall			13	
Region of Nanjibawa Peak	Oct 1982	4700	snow	29°38'N	95°10'E	34	25.5
	Oct 1982	4700				27	
	Oct 1982	4700				23	
	Oct 1982	4700				31	
	Oct 1982	4500				15	
	Oct 1982	4500				23	
Yulongshan glacier	July 1983	4600	snowfall	27°25'N	100°10'E	11	26.2
	July 1983	4670				44	
	Aug 1982	4770				27	
	Aug 1982	3460	rainfall			21	
	Aug 1982	3460				28	
Lenglongling glacier	Aug 1982	4260	snowfall			196.0	196.0

TABLE VI. THE PERCENTAGE OF GLACIAL MELTWATER IN GLACIER No 1 AT THE SOURCE OF URUMQI RIVER

Months	Tritium content (TU)	Glacial meltwater (TU)	Run-off volume (TU)	Run-off volume (cm^3 s^{-1})	Glacial meltwater (%)	Snowfall (%)
May 1983	79	50	66	0.009	18.9	81.8
June 1983	128	83	114	0.067	31.3	68.7
July 1983	83	50	69	0.400	42.0	58.0
Aug 1983	120	50	106	0.034	20.0	80.0
Mean	113	54	108	0.084	8.48	91.52