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Change of isotopic and ionic profiles at two successive snow pits on the No. 1 Glacier at the head of Ürümqi River, Northwest China

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Abstract

Two snow pits were successively sampled at the same spot on the No.1 Glacier at the head of Urumqi River, Tian Shan, China, on June 4 and 17, 1996, respectively. Through comparison of the $\delta^{18}O$ and ionic profiles of the two snow pits, we suggest that changes of stratigraphic $\delta^{18}O$ variations as water percolated through the snowpack are less significant than those of ionic concentrations. Therefore, it is necessary to distinguish how much the snow chemical records can reflect the original climatic and environmental conditions during precipitation before we can use the ice core records for paleoclimate reconstruction with high confidence.

1. Introduction

Over the past few years, there has been a growing interest for extracting paleoclimatic information from isotopic and ionic profiles measured in high latitude ice cores. Such valuable ice core records, however, usually experienced occasional to moderate melt, which limits the application of ice core for paleoclimatic reconstruction. Several ice cores recently drilled from the Qinghai-Tibetan Plateau necessitate a better understanding of the effect of summer snow melt on the isotopic and ionic profiles in the snow and firn layers (Thompson *et al.*, 1989, 1997).

Recent work suggests that the $\delta^{18}O$ values of precipitation samples collected on the northern Qinghai-Tibetan Plateau during the period of 1991-1994 are positively correlated to contemporaneous surface air temperature, with slopes of linear fit ranging from 0.29 to 0.67 ‰/°C (Zhang *et al.*, 1995). However, 30-yr records of annually averaged $\delta^{18}O$ from three different ice coring sites in this region are not correlated significantly with the contemporaneous air temperature records from their corresponding closest meteorological stations, 150 to 200 km away from the coring sites (Yao *et al.*, 1996). Similar result was also achieved with regard to the precipitation and ice core samples collected at the head of Ürümqi River (Hou *et al.*, 1999a).

Melting causes leaching of ions in the snowpack. This post-depositional effect homogenizes the snow chemistry, thereby reducing the seasonal variations often used to detect annual layering and to date the core. Furthermore, some ions, such as SO_4^{2-}, are preferentially leached from the snow. Thus the ion ratios perpetually preserved in ice cores can not reflect their original fraction during precipitation.

On June 4 and 17, 1996, a 3 m snow pit and another 2.3 m snow pit were successively sampled at the same spot (4230 m above sea level) at the West Branch of the No. 1 Glacier at the head of Ürümqi River (shown as "SP" in Fig. 1). For convenience, we name the 3 m and 2.3 m snow pits as Snow pit "A" and Snow pit "B", respectively. Here we compare the $\delta^{18}O$ and ionic profiles of the two snow pits to identify the effect of the post-depositional processes on the snow chemical records.

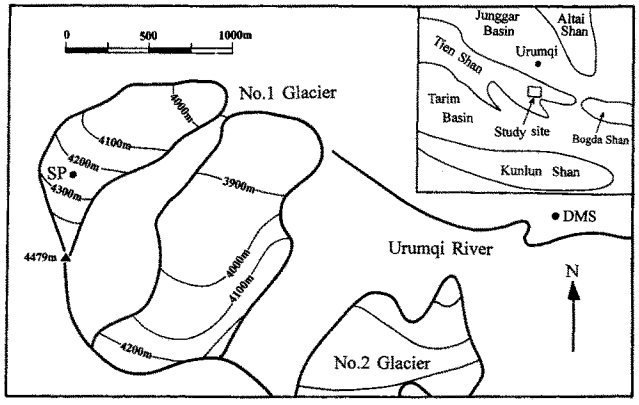

Fig. 1. A map of the head of Ürümqi River, Tian Shan, China, showing the sampling spot. SP: the snow pit sampling site; DMS: the Daxigou Meteorological Station. Inset map shows the location of Tian Shan in relation to geographic feature of northwestern China.

2. Methodology

Both of the snow pits were sampled at exact 10 cm intervals. Sampling was made by personnel wearing disposable polyethylene gloves to minimize contamination. After sampling the snow pit was partially refilled, and sampling on successive days involved digging it out and re-facing the sampling surface by at least 1m. The same strata were re-sampled on each occasion after allowing for accumulation or ablation. Snow samples were transferred into pre-cleaned polyethylene bags with plastic scoops, then transferred into a pre-cleaned polyethylene container after melting.

Bottled samples were returned frozen to the Laboratory of Ice Core and Cold Regions Environment in Lanzhou, and kept in a cold room at −20°C until measurement was performed in a Class 100 Clean Room. The $\delta^{18}O$ was determined by a Finnigan MAT-252 Spectrometer (precision 0.05 ‰, and

the anions by a Dionex DX-100 ion chromatography using IonPac AS4A-SC column system and an isocratic carbonate/bicarbonate eluent. Precision is estimated better than 5% with a detection limit of 5 ngg^{-1} (Huang *et al.*, 1998).

3. Results

The $\delta^{18}O$, Cl^-, NO_3^- and SO_4^{2-} profiles of the two snow pits are shown in Fig. 2. Several features are apparent: (a) The $\delta^{18}O$ profiles of the snow pits are very similar, especially for the $\delta^{18}O$ troughs as indicated by the dashed lines of ② and ⑤. (b) The Cl^- and SO_4^{2-} peaks of Snow pit "A" as indicated by the dashed lines of ① and ② almost disappear in their corresponding positions in Snow pit "B". (c) The ion peaks as indicated by the dashed lines of ③ and ④ remain relatively stable in Snow pit "A" and Snow pit "B". (d) All the Cl^-, NO_3^- and SO_4^{2-} peaks of Snow pit "A" as indicated by the dashed lines of ⑤ moved 0.1-0.2 m downwards compared with their corresponding ion peaks in Snow pit "B", and the Cl^-, NO_3^- and SO_4^{2-} peak concentrations increased significantly from 0.48μgg^{-1} to 0.74μgg^{-1}, from 0.23μgg^{-1} to 0.46μgg^{-1}, and from 0.58μgg^{-1} to 1.24μgg^{-1}, respectively. (e) No apparent ion peaks existed in the position of Snow pit "A" as indicated by the dashed lines of ⑥, whereas high ion peaks appeared in the corresponding position of Snow pit "B", especially for Cl^- and SO_4^{2-} as their corresponding maxima of the whole Snow pit "B". Here the Cl^-, NO_3^- and SO_4^{2-} peak concentrations increased from 0.43μgg^{-1} to 1.11μgg^{-1}, from 0.03μgg^{-1} to 0.44μgg^{-1}, and from 0.45μgg^{-1} to 1.77μgg^{-1}, respectively.

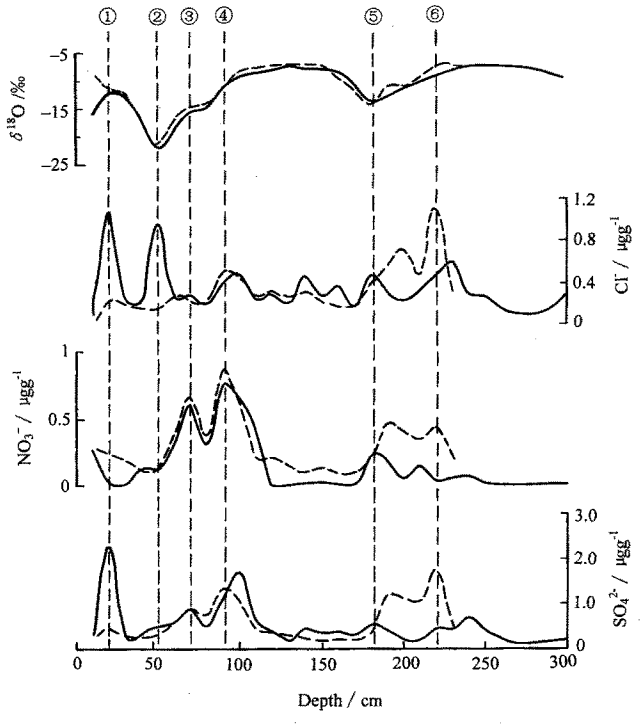

Fig. 2. The $\delta^{18}O$, Cl^-, NO_3^- and SO_4^{2-} profiles of Snow pit "A" (June 4 : solid line) and Snow pit "B" (June 17 : dashed line). The straight dashed lines of ①-⑥ indicate the comparative features of the two snow pits.

4. Discussion and conclusions

The snow pits were located in the typical firn zone. Though the upper snow layers were relatively wet, no liquid snowmelt was detected in the field. However, ice lenses and thin ice layers tended to develop at stratum boundaries within the snowpack. Moreover, loose coarse firn still existed below 3 m in depth as observed in the field. In fact, at our snow pit sampling site, Wang *et al.* (1986) found firn layer even at 26 m in depth by borehole observation.

Compared to the ion profiles, the $\delta^{18}O$ profiles of the two snow pits remained quite stable (Fig. 2). A summary of the characteristic $\delta^{18}O$ and anion (SO_4^{2-}, NO_3^-, and Cl^-) values of the snow pits is presented in Table 1. For better comparison, we separate the upper 2.3 m portion of the Snow pit "A" as snow pit "A1", whose corresponding characteristic values are also given in Table 1. Clearly, no significant change is observed for the mean, minimum and maximum $\delta^{18}O$ values in the snow pits. In fact, Raben and Theakstone (1998) also observed that the isotopic composition of the snowpack remained relatively unchanged at the Glacier Austre Okstindbreen, Norway, as the first meltwater percolated from top of the snowpack, which eluviated most of the ions to a greater depth. However, the $\delta^{18}O$ stability in the snowpack is still quite frangible, and the original $\delta^{18}O$ profiles might be destroyed by heavy snowmelt (Raben and Theakstone, 1998; Hou *et al.*, 1999a), consequently the isotopic oscillations are rapidly reduced in the presence of percolating meltwater (Arnason, 1969; Buason, 1972).

Only a little change is observed for the Cl^- mean concentrations of the snow pits, but the NO_3^- and, to a less degree, SO_4^{2-} concentrations increased considerably (Table 1). Previous research indicates that NO_3^- can be acquired from anthropogenic emissions, biomass burning, and soil emissions resulting from the use of nitrogen fertilizers (Sun *et al.*, 1998), and it is co-deposited with terrestrial dusts by dry processes (Hou *et al.*, 1999b). These processes may also contribute to the increase, moreover, the following chemical reactions in presence of meltwater may have also played an important role: $4FeS_2$ (pyrite)$+15O_2+8H_2O=2Fe_2O_3+8SO_4^{2-}+16H+$ (Williams *et al.*, 1995); or $4FeS_2$ (pyrite)$+16CaCO_3+15O_2+14H_2O=16Ca^{2+}+16HCO_3^-+8SO_4^{2-}+4Fe(OH)_3$ (Hasnain and Thayyen, 1999). Nevertheless, the main reason for the modification of the ion profiles is still the eluviation process, which leaches most of the ions from the uppermost part of the snowpack. The concentrated meltwater moves downwards, then refreezes on the underlying ice layers, which act as physical obstacles against meltwater percolation. The temperature within the

Table 1. Characteristic $\delta^{18}O$ and anion values of the snow pits

	Mean and standard deviation			Value range		
	Snow pit "A"	Snow pit "A1"	Snow pit "B"	Snow pit "A"	Snow pit "A1"	Snow pit "B"
$\delta^{18}O$(‰)	−11.01±3.83	−11.91±3.93	−11.15±3.82	−22.12~−7.23	−22.12~−7.37	−21.27~−7.18
SO_4^{2-}($\mu g/g$)	0.52±0.48	0.59±0.51	0.62±0.45	0.10~2.30	0.19~2.30	0.18~1.77
NO_3^-($\mu g/g$)	0.15±0.21	0.19±0.23	0.30±0.20	0~0.75	0~0.75	0.08~0.85
Cl^-($\mu g/g$)	0.33±0.22	0.37±0.24	0.35±0.23	0.09~1.08	0.10~1.08	0.06~1.11

Table 2. The correlation coefficients among the anions

	SO_4^{2-}			Cl^-		
	Snow pit "A"	Snow pit "A1"	Snow pit "B"	Snow pit "A"	Snow pit "A1"	Snow pit "B"
NO_3^-	0.48	0.42	0.81*	0.05	−0.09	0.45
Cl^-	0.67*	0.63*	0.84*			

* significant at the p=0.001 confidence level.

snowpack is usually below zero, which provides the necessary condition for freezing. Though Tranter (1991) indicated that SO_4^{2-} and NO_3^- might be preferentially eluviated than Cl^-, this preferentially eluviation is not apparent since all the three ions behaved in a similar way. Moreover, the eluviation process is not only related with the special properties of each ion, it is also restricted by air and snow temperature, snow stratigraphy, accumulation and ablation processes (Hou *et al.*, 1996).

There is evidence that the $\delta^{18}O$ peaks correspond with the high ion concentrations in the Dasuopu ice core of Xixiabangma, Himalayas, which provides the basis for ice core dating (Huang *et al.*, 1998). Though such correspondence is also observed for the ice core from the Far East Rongbuk Glacier, Mt. Qomolangma (Everest), a certain phasic discrepancy generally existed between the $\delta^{18}O$ and the ion peaks (Hou *et al.*, 2000). Yao *et al.* (1990) also noticed the phasic discrepancy between the $\delta^{18}O$ and the dust concentration (or electric conductivity) peaks of the Dunde ice core on the northern Tibetan Plateau, and attributed the discrepancy to "high $\delta^{18}O$ values occurring in the winter precipitation, while high dust content occurring mainly in the spring and summer seasons". However, subsequent research indicates that the $\delta^{18}O$ composition of precipitation falling at this site reflects seasonal variations in near-surface air temperatures, i.e. high $\delta^{18}O$ values should occur in the summer (Yao *et al.*, 1996). Therefore, similar phase might be expected for the $\delta^{18}O$ and the dust concentration (or electric conductivity) peaks of the Dunde ice core. As to our current understanding, such phasic discrepancy should be primarily caused by the post-depositional processes, in other words, the original positions of the $\delta^{18}O$ and ion (or dust) peaks change to different degrees due to their varied stability against melt percolation, as shown by the peaks remarked by the ⑤ dashed line in Fig. 2.

The correlation coefficients among the anions of the two snow pits are shown in Table 2. The correlation of the anions of Snow pit "B" is more significant than that of Snow pit "A". Therefore, the ice core records and the relationship among them is not only affected by the climatic and environmental conditions during precipitation, but also affected by the post-depositional processes. Before we use the ice cores, especially those drilled from less than ideal environments, for paleoclimate reconstruction with much confidence, it is necessary to distinguish how much the records can reflect the climatic and environmental conditions, and which records is just the modified results of the post-depositional processes.

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