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The study on the depositional styles of major ions and the climatic effect of nssSO_4^{2-} in Princess Elizabeth Land, Antarctica

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Abstract Snow samples collected from a 50 m firn core and two snow pits along the route of the 1996/1997 Chinese First Antarctic Inland Traverse Expedition in Princess Elizabeth Land, East Antarctica, have been analyzed for chemical composition and oxygen isotope ratio. Analyzing the relationship between the concentration and flux of major ions and accumulation rate can draw the following conclusions. 1) The concentrations of major ions in the atmosphere in the study region is big enough so that the concentrations of the ions do not vary with snow accumulation rate, that is to say, the concentrations of major chemical species are independent of snow accumulation rate. 2) The results of analyzing the depositional styles of major chemical species suggest that wet deposition dominates the major ions flux. In addition, there is no apparent correlation between nssSO_4^{2-} fluctuations and isotope profile. This would indicate the short-term climatic effect of volcanism is not evident in the region.

Key words ion, dry deposition, wet deposition, volcanic.

1 Introduction

Ice cores from Antarctica provide abundant information on paleoclimate and the history of atmosphere composition (Delmas 1992). Great achievements have been obtained in the knowledge of the paleoenvironment and paleoclimate in recent years (Lorius *et al*. 1985; Jouzel *et al*. 1987; Angelis *et al*. 1987; Barnola *et al*. 1987; Chappellaz *et al*. 1990; Legrand *et al*. 1988; Petit *et al*. 1997). However, it is still difficult to interpret all kinds of parameters quantitatively obtained from analyzing the ice cores, because we do not know exactly the link between the ion concentrations in the atmosphere and the ion concentrations in the ice cores. It means that the depositional process of major ions is still an open question. The ultimate object of studying ice cores is to learn the history and to predict the future environmental change. To explain the ice core records quantitatively and to establish reliable models are necessary to obtain this

object. By studying the relationship between the concentration and flux of major ions and accumulation rate of the samples collected from a 50-meter firn core along the route of the 1996/1997 Chinese First Antarctic Inland Traverse Expedition in Princess Elizabeth Land, East Antarctica, this paper will make a primary research on the above questions.

2 Sampling, analysis and firn core dating

During 1996/1997 Chinese First Antarctic Inland Traverse Expedition from Zhongshan Station to Dome A, two snow pits (2.5 m and 4.5 m) were excavated at LT921 and LGB65, respectively (Fig. 1). In addition, one 50 m firn core was drilled at LGB65 (Here we call firn core because the density at the end of the core is less than the glacial ice density). Samples from snow pits were collected in a span of 3 cm in-situ. Before sampling, one of the snow pit walls was scraped with a pre-cleaned stainless steel shovel. Then vertically continuous snow samples were collected from pit wall and sealed in the polyethylene (PE) sampling bottles that were pre-cleaned by deionized water (18.3 MΩ). All the samples were carried to the cold chamber (−15℃) in Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academic of Sciences (CAS) where the firn core were cut at 3 cm intervals.

The major ions and $\delta^{18}O$ were analyzed in the Laboratory of Ice Core and Cold Regions Environment, Cold and Arid Regions Environmental and Engineering Research Institute, CAS. All snow samples were melted at room temperature in the laboratory, the measurement was done under a super-cleaned (1000-class) environment. Deionized water (> 18.3 MΩ) was used to clean the experiment utensils and make standard solution during the measurement process.

Cations were measured by Dionex300 Ion Chromatograph and anions by Dionex100 Ion Chromatography, $\delta^{18}O$ were analyzed using MAT-252 Gas Mass Spectrograph. The detection limits for cation, anion and $\delta^{18}O$ were 1×10^{-9} g/g, 1×10^{-9} g/g, ± 0.5‰, respectively.

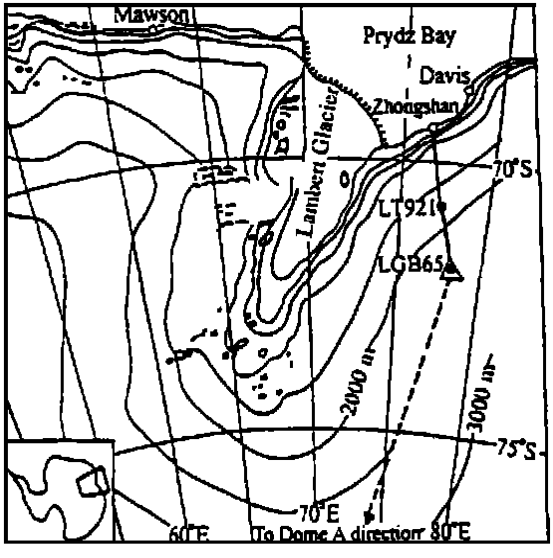

Fig. 1. Map showing the route of the Chinese First Antarctic Inland Traverse during 1996/1997. ●: the location of the two snow pits; △: the location of the firn.

Ice core dating is a basis for ice core research. For this, we especially have studied on the seasonal variations of the major ions in the snow and firn obtained from Princess Elizabeth Land, Atarctica (Li *et al.* 1999). The results show that the variations of sea-salt ions (Cl^- and Na^+) and NO_3^- fairly better represent the seasonal variations. Therefore, the firn core was dated on the basis of the well-preserved $\delta^{18}O$ (smoothed blow 3 m), NO_3^-, Cl^- and Na^+ seasonal cycles which were counted to establish the

depth-age relationship with excellent accuracy (e. g., the 1815 Tambora eruption was dated in the firn core at 1817, as expected). The accumulated errors, attributable to a few ambiguous seasonal cycles, are estimated to be only ± 3 a at the end of the record. The 50-m firn core contains 251 a (1745- 1996 A. D.).

3 The relationship between the chemical concentration and chemical flux of major ions and the snow accumulation rate

Following the above-mentioned dating method, the accumulation rate in the past 251 years can be calculated by using the firn core densities. The chemical flux in this paper refers to chemical concentration multiplying accumulation rate.

From figure 2 it is clear that the concentration series of chemical species are not statistically related to snow accumulation rate. On the contrary, we can see from figure 3 that each flux series are significantly related to snow accumulation rate, the best fit linear regressions of the chemical species in the figure 3 are tested at a significance level $T = 0.001$.

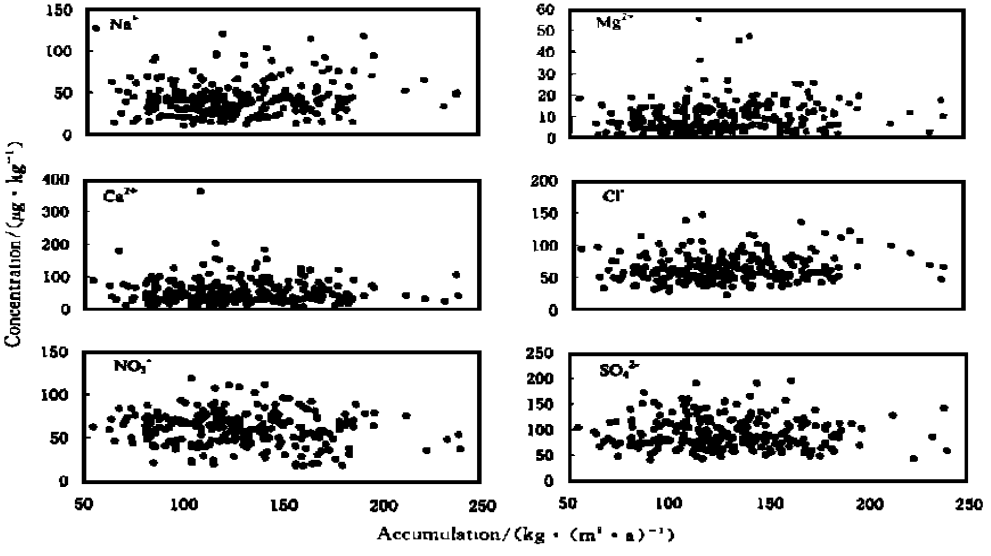

Fig. 2. The relationship between the chemical concentration (Na^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^- and SO_4^{2-}) and the snow accumulation rate in the 50 m firn core.

4 Discussion

Figure 3 shows that the ion concentrations in Princess Elizabeth Land, East Antarctica neither increase along with the accumulation rates increasing, nor decrease along with the accumulation rates decreasing. The change of accumulation rates in this region was very great and ranged between 55 kg/(m^2· a) and 239 kg/(m^2· a). The ion concentrations do not change with the accumulation rates under such conditions. We can draw the conclusion that the dilution effect do not occur in the ion concentrations of this region, and that the accumulation rate does not affect the ion concentration. From figure

3 we can see that the ion concentration in the atmosphere is great enough to keep precipitation absorbing all kinds of ions. Therefore, the ion concentrations in the firn and ice in this region may reflect the precipitation absorbing ability, the transmission path and the depositional style of all kind of ions. This paper will discuss the depositional styles of major ions. As has been known, there are two kinds of depositional style: dry deposition and wet deposition. The intercept in figure 3 suggests the dry deposition contribution (Dai *et al*. 1995). From the best-fit linear regression equation in the figure 3 we can see that the dry deposition contributions of sea-salt ions (Cl^-, Na^+ and Mg^{2+}) are negative, which shows that the wet deposition mainly contributes to the above-mentioned ions deposition. It is not difficult to understand the conclusion from the source of the sea-salt ions. Otherwise, the dry deposition contributions of Ca^{2+}, NO_3^- and SO_4^{2-} are positive, which shows that dry deposition makes up a certain proportion to the above-mentioned ions deposition. If we calculate on the basis of the ion flux, we can get the result that the dry depositions of Ca^{2+}, NO_3^- and SO_4^{2-} contribute to 3%, 15% and 6% of all depositions, respectively. As the position where samples were collected is nearly 300 km from coast, there are some Ca^{2+} and SO_4^{2-} which come from sea, therefore, the dry deposition proportion of Ca^{2+} and SO_4^{2-} is lower than that of NO_3^-. As has been discussed, wet depositions dominate the major ions flux in Princess Elizabeth Land, East Antarctica, moreover, the dry deposition proportion of sea-salt ions is lower than that of non-sea-salt ions.

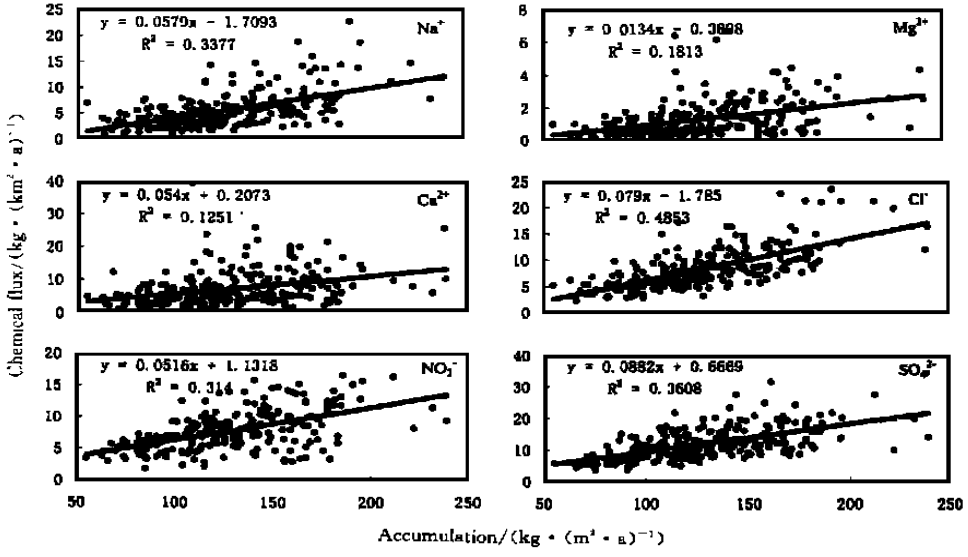

Fig. 3. The relationship between the chemical flux (Na^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^- and SO_4^{2-}) and the snow accumulation rate in the 50 m firn core. The solid line denotes the monistic linear regression curve. The formula in the upper part of left-hand side represents the regression one.

5 The climatic effect of nssSO_4^{2-}

The short-term climatic impact of explosive volcanic eruptions has been documented (Rampino and Self 1982; Robock 1991). For example, following the Pinatubo eruption,

a decrease of 0.2 – 0.7℃ was observed in global tropospheric and near-surface temperatures (McCormick *et al*. 1995; Robock and Mao 1995) with a corresponding increase in stratospheric temperatures (Randel *et al*. 1995). We not only detected the traces (the increased nssSO_4^{2-} concentrations) of the June 1991 Pinatubo eruption in Philippines and the August 1991 Cerro Hudson eruption in Chile in the two snow pits (Zhang *et al*. 1999), but also detected 16 volcanic eruption traces in the 50-m firn core (Zhang *et al*. 2000). Since the short-term climatic impact of explosive volcanic eruptions has been documented, there should be some relations between nssSO_4^{2-} and $\delta^{18}O$. The former shows the volcanic eruption and the latter represents the temperature. For this, the relationships between nssSO_4^{2-} and $\delta^{18}O$ of the two snow pits and 50-m firn core have been studied (Fig. 4).

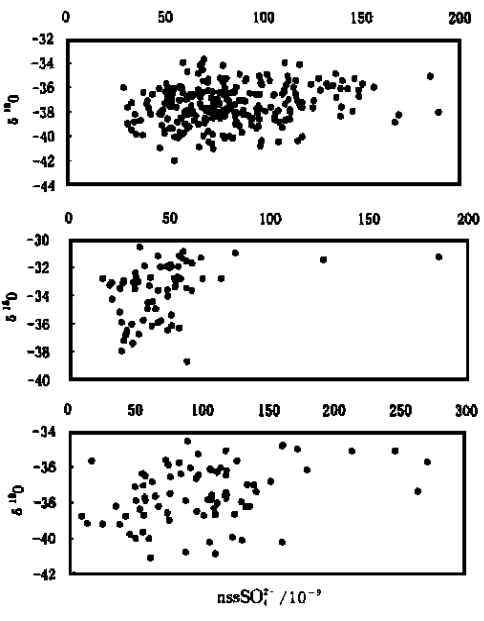

Fig. 4. The relationship between nssSO_4^{2-} concentration and $\delta^{18}O$ in 50 m firn core and two snow pits. Up: 50 m firn core; Middle: LT921 snow pit; Down: LGB65 snow pit.

From figure 4 it is clear that the concentration series of nssSO_4^{2-} are not statistically related to $\delta^{18}O$. That is to say, the climatic effect of volcanism is not evident in the region either on the scale of 10 a or on the scale of 100 a. The reason is due to the small temperature changes (0.2 – 0.7℃) which were caused by volcanic eruptions. Moreover, there are some other factors that can affect the value of $\delta^{18}O$. Therefore, it is not strange that $\delta^{18}O$ can not show the temperature decreasing caused by volcanic eruption.

6 Conclusion

By analyzing the relationship between the concentration and flux of major ions and accumulation rate, we can draw the following conclusions:

(1) The concentrations of major ions in the atmosphere in the study region is great enough so that the concentrations of the ions do not vary with snow accumulation rate, that is to say, the concentrations of major chemical species are independent of snow accumulation rate.

(2) The results of analyzing the depositional styles of major chemical species suggest that wet depositions dominate the major ions flux, the wet deposition proportion of sea-salt ions (Cl^-, Na^+ and Mg^{2+}) is greater than that of Ca^{2+}, NO_3^- and SO_4^{2-}.

In addition, there is no apparent relationship between nssSO_4^{2-} fluctuations and isotope profile. This would indicate the short-term climatic effect of volcanism is not evident in the region.

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