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The difference of atmospheric chemical loadings shown by electrical conductivity of snow and ice between Antarctica, Arctic and Qinghai-Tibetan Plateau

Xiao Cunde (效存德), Qin Dahe (秦大河), Yao Tandong (姚檀栋), Ren Jiawen (任贾文) and Sheng Wenkun (盛文坤)

Laboratory of Ice Core and Cold Regions Environment, Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, Lanzhou 730000, China

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Abstract The relationship of ECM with ice acidity and impurities concentrations are much different between the Qinghai-Tibetan Plateau and the polar regions. On the Qinghai-Tibetan Plateau, ECM is dependent on the mineral ions (i.e., Ca^{2+}, Mg^{2+}, SO_4^{2-}, etc.) mainly derived from crustal sources, thus displays a positive linear correlation between ECM and these ions. While in polar ice sheets, however, ECM of snow and ice is mainly dependent on the acidic roots such as Cl^-, SO_4^{2-} and NO_3^- that mostly come from ocean. Therefore, there is good relationship between ECM and concentration of H^+. However, the relationship between ECM and major ions has complicated geographical differentiation in the whole Arctic. For instance, there no longer exits the same simple relationship in the central Arctic as that in the Greenland Ice Sheet, probably due to the disturbance of Arctic haze. In general, ECM of snow and ice is a potential indicator of atmospheirc envirmment of cold regions.

Key words Arctic, Antarctic Ice Sheet, Qinghai-Tibetan Plateau, ECM, pH, atmospheric environment.

1 Introduction

Electrical conductivity in precipitation reflects the loading of ions in precipitation, thus displays the chemical outline of the precipitation (Liu *et al.* 1995). Electrical conductivity measurement (ECM) of snow and ice reflects the loading of soluble impurities contained in it (Moore *et al.* 1992). Conductivity measurement has been conducted on samples of snow pits and shallow ice cores extracted from Qinghai-Tibetan Plateau and central Arctic. In this paper, the coupling of ECM with different ions in these samples will be discussed, and contrasting of these correlations will be conducted between polar regions and the Qinghai-Tibetan Plateau.

2 Sampling and analyses procedure

China's First North Pole Scientific Expedition (CFNPSE) was carried out during March to May, 1995. Totally 74 samples from10 snow pits were collected along the

expedition route covering 88° - 90°N. The description of the geographic features of sampling sites and sampling process has been noted by Xiao *et al.* (1996, 1998).

In August, 1993, a 4.93 m shallow core was extracted at Dongkemadi Glacier, Tanggula mountain, Qinghai-Tibetan Plateau. The altitude of drill site is 5700 m a. s. l. At the altitude of 5500, 5700, 5900 m a. s. l. along the main stream line on accumulation basin, three snow pits were dug with depth of 102 cm, 106 cm and 90 cm, respectively. Totally 27 samples were collected from the three pits, each of them contained the snowfall of the past whole year.

During May to June of 1997, two snow pits were dug respectively at the altitude of 6500 and 6400 m a. s. l. on Far East Rongbuk Glacier, Everest Region, middle Himalaya. 13 samples were obtained. At the same time, 36 surface samples were collected along the main stream line of the glacier with the altitude ranging between 6140 - 6400 m a. s. l. Therefore, totally 49 samples were collected on Far East Rongbuk Glacier. In order to measure ECM, samples were measured first by DDS-11A conductivity meter, then the values were conversed into ECM at 25℃. Values of pH were measured using pHS-2 acidity meter. Major cations discussed below were analyzed using PE-2380 Atomic Absorption Spectrophotometer (AAS), with the detection limit $<10\times10^{-9}\,g\cdot g^{-1}$, major anions were analyzed using Dionex-300 Ion Chromatograph (IC), with the detection limit $<1\times10^{-9}\,g\cdot g^{-1}$.

3 Results and discussion

3.1 Polar ice sheets

ECM has been conducted on the ice core extracted from Antarctic and Greenland Ice Sheet, good positive linear correlation exits between ECM and H^+ (Legrand *et al.* 1987; Delmas 1986; Moore and Wolff 1994). Historic volcanic events has been distinguished using ECM signals obtained from the ice cores (Hammer 1980). In Antarctic ice core, active linear correlation was found not only between ECM and H^+ but also between H^+ and major anions, such as SO_4^{2-}, NO_3^- and Cl^- (Legrand *et al.* 1987)(Fig. 1). But there is negative correlation between ECM and aluminium silicate, which is mainly crustal in origin. This indicates that the acidic roots, mainly derived from ocean, are responsible for the loading of impurities in Antarctic Ice Sheet. Among three anions, Cl^- and NO_3^- seem to be contributory to ECM more efficiently than SO_4^{2-}. The relationship of ECM with H^+ implies that acidic impurities tend to gather between the boundary of ice crystals, and thus lead to the decreasing of pH values. In Greenland Ice Sheet, primary study of GRIP ice core show that the peaks of ECM are related to three factors: acidity, NH_4^+ and Cl^- (Moore and Wolff 1994). The main controlling factor is acidity, the importance of the other ions remains unknown. In general, the dominant controlling ions to ECM of snow and ice in polar ice sheets is acidic roots, and thus it is determined that the sorrounding ocean is the main source of chemical loadings of atmosphere over the ice sheets, since these roots are mostly derived from ocean.

3.2 Qinghai-Tibetan Plateau

ECM values are fitted with that of H^+ among 47 samples of 4.93 m ice core from

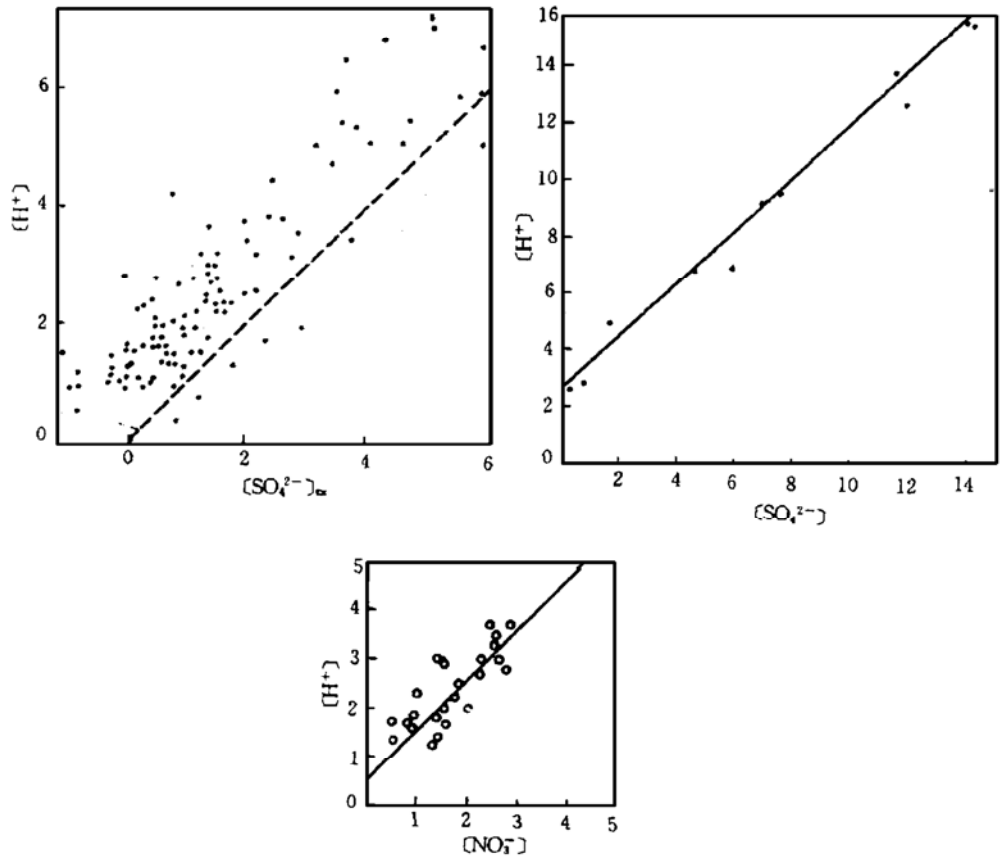

Fig. 1. The correlation of H^+ with SO_4^{2-}, NO_3^- and $nssSO_4^{2-}$ in Antarctic Ice Sheet (Legrand *et al.* 1987).

Mt. Tanggula area. It comes to be a good negative exponent function (Fig. 2a). In addition, the same fitting is done for the samples collected in three snow pits at the same glacier, three negative exponent functions are also established (Fig. 2c). Previous study on ice core from Guliya Ice Cap, northwest of the plateau, also established the same type of relationship between ECM and H^+ (Li *et al.* 1995). However, for the samples collected from Far East Rongbuk Glacier, Everest Region, ECM and H^+ show a negative power function, which has higher correlation coefficiency than exponent function (Fig. 2b). Whatever the relations between ECM and H^+ have been established over the Qinghai-Tibetan Plateau, they are similiar over north and the south of the plateau while opposite to the situation of polar regions. That is to say, unlike polar regions, acidity H^+ is not the dominant controlling factor of ECM over Qinghai-Tibetan Plateau.

Although H^+ is not the contributor of ECM over the plateau, other soluble ions are important to ECM (Fig. 3). For instance, it is closely related to most soluble ions, such as Ca^{2+}, Mg^{2+} and Na^+, in Dongkemadi shallow core, ECM which are mostly derived from alkaline minerals. It is well known that soluble ions are located between boundary of ice crystals. These ions not only determine pH value of snow and ice, but also the ability of conductivity (ECM) when they become electrical ions in solution. Statistics indicates that pH value of unpolluted precipitation is around 5.6 (Shen *et al.* 1995). The precipitation may be impacted by alkaline ions when the value is higher than 5.6, while it may be influenced by acidic ions when lower than 5.6. It is evident that the cations

dominately impact ECM of snow and ice over the plateau. Local dust, mainly of alkaline aerosol, is responsible for the major flux of aerosol deposited into the glacier. What should be noted is that, among the relationships of ECM with Ca^{2+}, Mg^{2+}, Na^{+} and SO_4^{2-}, the highest coefficient is between ECM and Ca^{2+}, and the lowest is between ECM and SO_4^{2-}. We considered that, over Qinghai-Tibetan Plateau, Ca^{2+} in ice cores can show short term atmospheric dust transportation events better than the other ions. To the contrary, Mg^{2+} is insensitive to the temporary atmospheric events, but remains to be relatively stable and can record long term history of climatic change, mainly of change in continental humidity and wind speed.

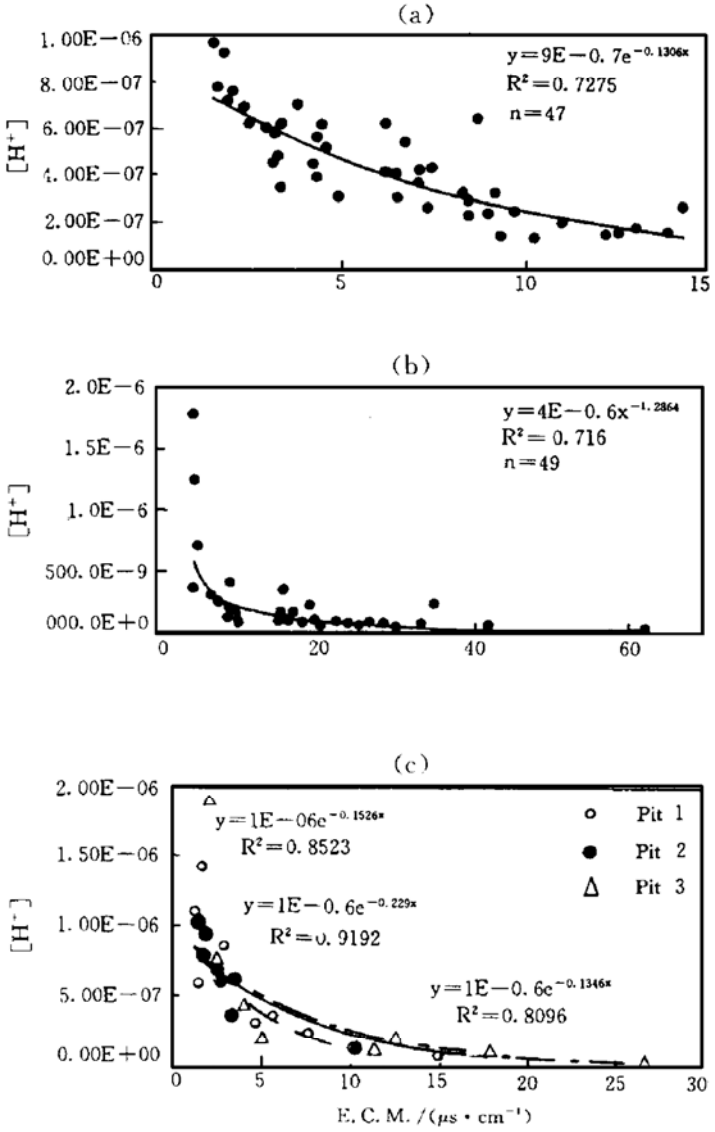

Fig. 2. The correlation of ECM and H^{+} in snow and ice on the Qinghai-Tibetan Plateau.

3.3 Central Arctic

ECM measurement was coupled with H^{+} for the samples collected by CFNPSE (Fig. 4a), and there was little correlation between them. This implies that, unlike polar ice sheets and Qinghai-Tibetan Plateau, ECM over the central Arctic no longer reflects

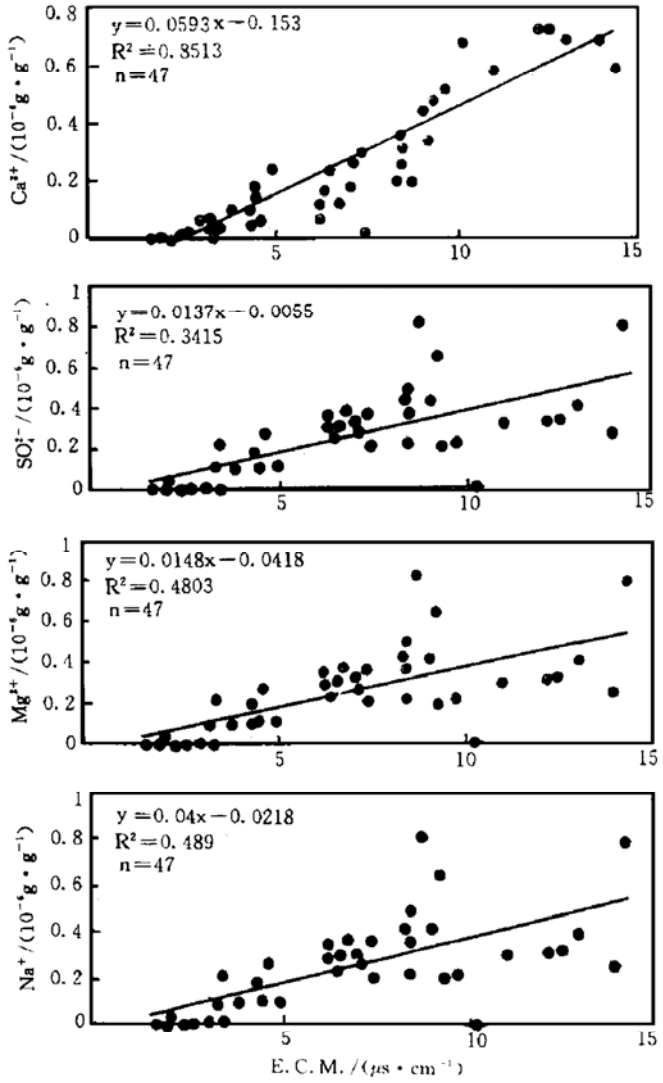

Fig. 3. The correlation of ECM and major ions in snow and ice on the Qinghai-Tibetan Plateau.

only marine or continental environment. There possibly exits the third factor or multiple factors that impacts ECM formation in central Arctic. For instance, SO_4^{2-} and H^+ in Arctic haze are coupled and show a close correlation between them (Fig. 4b). Therefore, pollutants are the most probable factor that disturb ECM of snow and ice over central Arctic.

In the whole Arctic, ECM reflects the geographical differentiation of atmospheric chemical loadings. For instance, the relationship of ECM with H^+ in precipitation of Greenland and Canadian Arctic is as same as that of Antarctic Ice Sheet. The atmospheric chemical loadings generally reflect the fact that the major chemical loadings over the ice sheets are derived from surrounding oceans. The study of lead in precipitation of central Arctic and Canadian Arctic (Xiao *et al.* 1998) shows that central Arctic and other Arctic regions are largely impacted by pollution, while in Greenland and Canadian Arctic the pollution is weak. Therefore, the differentiation of the atmospheric situation is well documented by the relationships of ECM and H^+ in snow and ice.

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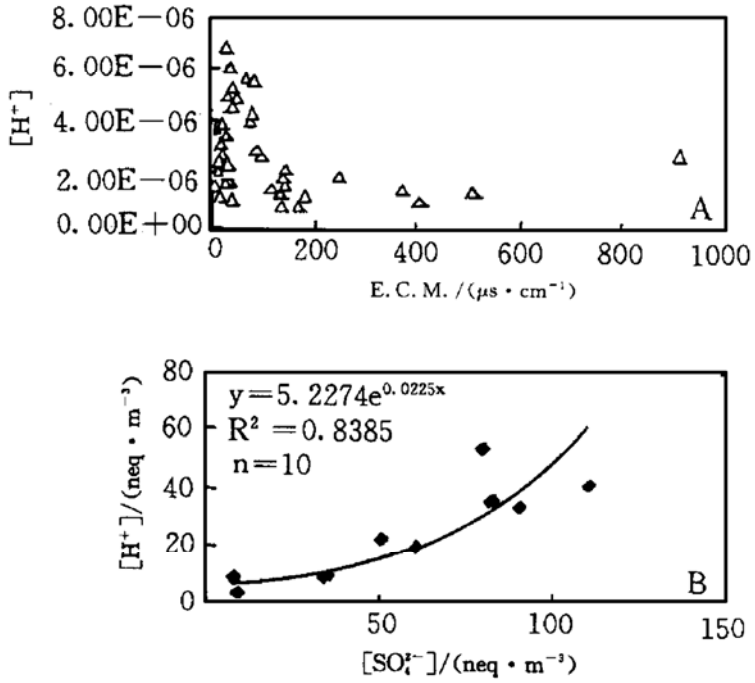

Fig. 4. (a) The correlation of ECM and H^+ in snow at Central Arctic Ocean; (b) The correlation of SO_4^{2-} and H^+ in Arctic haze (After Lazrus and Ferek 1984).

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