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The 4700 aB.P. volcanic signal detected in Vostok BH8 ice core, Antarctica

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Abstract **The detailed electrical conductivity measurement (ECM), trace chemical compositions and microparticles concentration analysis are performed for BH8 ice core from the depth of 126.0m to 130.0m at Vostok Station. At depth 128.7m, a volcanic signal 4726 a B.P. is detected. The volcanic sulphate flux is 95.8 kg·km^{-2}, sulphate peak concentration 1352.8 ng·g^{-1}, duration time about 10.1 years, comparable with some well-known volcanic events. The results indicate that it seems to be a relatively large scale, long lasting volcanic signal with farther volcanic origin.**

Keywords: volcanic eruption, ice core record, Vostok, Antarctica.

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Volcanic ash originating from the same volcanic eruption, after atmosphere transport and deposition, can form an isochronous time marker in different sediments such as ocean, lake, glacier and loess in a wide area. The volcanic tephra marker horizon is a very useful tool for the dating and correlation of different stratigraphical sequences[1].

Because of possible diffusion process of postdeposition for some chemical compositions in snow and ice or even the loss of some unknown stratigraphic sequences and so on, it is generally very difficult to date an ice core with high resolution and get past climate and environment change information, only using traditional dating techniques. Since the pioneering work of Hammer[2,3], the glaciologists have conducted a lot of researches related to volcanic signals in ice cores and established series of volcanism chronology with different time scales[4—7], to control the dating efficiently and quickly through the scattered distribution of dated ash layers in ice cores.

Many glaciologists have successfully used predetermined volcanic signature as absolute time markers for ice core stratigraphy dating. Legrand and Delmas[8] revealed four major volcanic events of past 220 years from the ice cores in several Antarctic locations. Delmas et al.[6] detected 23 major volcanic eruptions from a 1000-year ice core (length 115 m) in South Pole. Cole-Dai et al.[7] have recently released 4100 years volcanic records from a 200 m ice core at Plateau Remote(84°S, 43°E).

In this paper, we present a specific volcanic record about 4726 a B.P. from Vostok (78°28′S, 106°50′E, 3488 m a.s.l., mean temperature −55℃) BH8 ice core.

1 Samples and analysis

At Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE-CNRS), Grenoble, the measurements for Vostok BH8 ice core from 126.0 m to 130.0 m are performed.

In cold room (temperature about −15℃), with traditional operation procedure[3,8], ECM (electrical conductivity measurements) are firstly made. At the interval of 126.0—130.0 m, around the depth of 128.7 m, a prominent ECM peak emerged (Fig. 1, B).

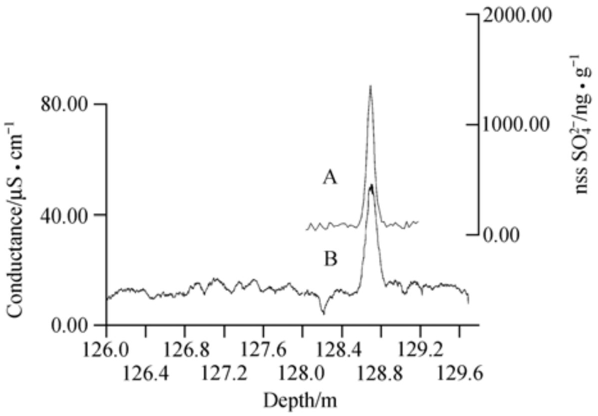

Fig. 1. Depth profiles of non-sea-salt sulphate concentrations (A) and ECM in BH8 ice core (B) at 126.0—130.0 m depth.

The sections of BH8 ice core from the 128.0—129.2m depth interval are sub-sampled specifically for microparticle and chemical compositions analysis. After the outer part of each section is removed using a clean stainless knife in a cold room, each 0.02m ice sample (about one sample per year, Vostok mean snow accumulation rate 2.2 g·cm^{-2}·a^{-1}) is melted in clean room (level 100, room temperature) and partitioned for chemical and microparticle measurements. The total of 50 samples are refrozen and sealed in pre-cleaned Coulter Acuvette vials and kept in a clean freezer until analysis.

The chemical compositions are analysed by ion chromatography: Dionex 4000i for anions (SO_4^{2-}, Cl^-, NO_3^-, MSA) and Dionex 4500i for cations (K^+, Na^+, Ca^{2+}, Mg^{2+}). The accuracy of the determined concentrations is about 5%. The normal analytical procedure is adopted[9,10].

Microparticle counting is determined by Coulter Multisizer II with a 50 μm orifice, and particle distribution in 256 channels from 0.68 to 20.95 μm in diameter[11]. The background value of ultrapure water blank shows 400—700 particles per mL.

2 Results and discussion

2.1 Ice core dating

BH8 ice core was drilled in 1996 austral summer, 300 m distant from core 5G[12]. Based on the principle that the same stratigraphy layer in the same area is isochronous, the dating of the analysed section of BH8 ice core is performed according to the Vostok glaciological timescale GT4(Glaciological Timescale)[13], which is adapted from the Extended Glaciological Timescale (EGT) of Jouzel et al.[14]. It should be specially noted that deuterium contents of Vostok ice core are measured at the interval of 1m ice increments[13,14]. Under the assumption of uniform snow accumulation rate on every 1m long ice core in central Antarctica, the dating of the ice core is performed through extrapolation. The ECM peak at depth 128.7m corresponds to 4726 a B.P. The accuracy of the dating is about 3 %.

2.2 Basic results

Based on the total ions balance equation[15] and different contributions of the ions from sea-salt and non-sea-salt (nss), we get total cations concentration, total anions concentration, H^+ content and nss sulphate concentration. As shown in Fig. 1, nss sulphate peak (1352.8 ng·g^{-1}) emerges in the same position as that of ECM. Of the chemical compositions (Fig. 2), nitrate accounts for only 8.5% of the total anions equivalent concentration, sulphate covers 73%—99%, the mean ratio up to 84% (Fig. 2, B). The nss sulphate accounts for 93.6%—99.7% of the total sulphate concentration (mean ratio 96.8%, Fig. 2, A). At the peak, nss sulphate reaches the highest ratio value (99.7%). The total anions concentration is of the same order of magnitude as that of H^+ content (Fig. 2, C, D). The great match shows that the anions in ice are primarily neutralized by H^+. The acidity is dominated by sulphuric acid[16]. The comparison between Fig.1 and Fig.2 indicates that higher conductivity values may reflect greater acid deposition[17,18].

The microparticles results (Fig. 3) show that at the nss sulphate peak, microparticles number and concentration also reach the highest values (1.12×10^5 mL^{-1}, 486 ng·g^{-1} respectively). The mean microparticle diameter is 2.1 μm, with the largest only up to 3.8 μm. The above fact seems to indicate that most aerosols deposited on ice sheet after long-range transport with air mass.

2.3 Volcanism identification

Explosive volcanic eruptions eject large amounts of

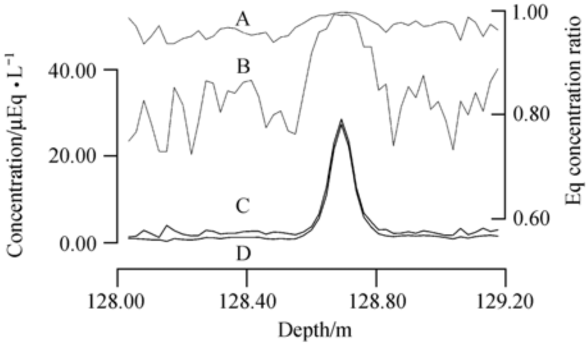

Fig. 2. Depth profiles of equivalent concentration ratio of nss sulphate to the total sulphate (A), equivalent concentration ratio of the total sulphate to the total anions (B), total anions concentration (C) and H^+ concentration (D) in BH8 ice core at 128.0—129.2 m depth.

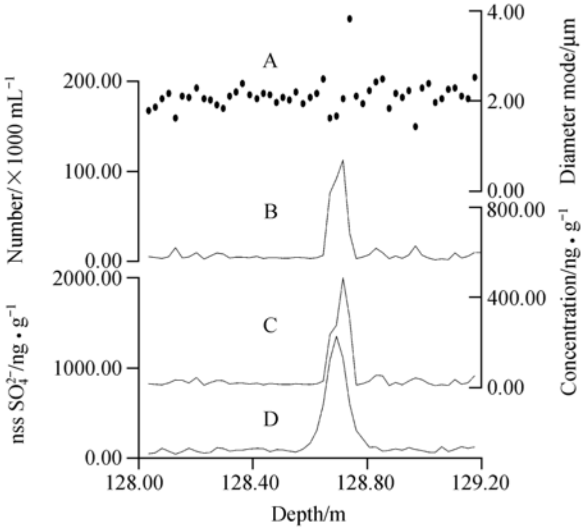

Fig. 3. Depth profiles of particles diameter mode (A), particle numbers (B), particle concentration (C) and nss sulphate (D) in BH8 ice core at 128.0—129.2m depth.

dust and gases (mainly SO_2) into the atmosphere. Over a period of time (a few days or weeks), SO_2 is slowly converted into sulphuric acid aerosol. Through atmospheric circulation and long-range transport, volcanic aerosols and dust are eventually washed out of the atmosphere by precipitation, depositing on ice sheet in the form of ash layers or acid layer[8,19]. Generally, there are two types of measurements performed to construct past volcanic records in ice core: (1) volcanic acidity determined by continuous ECM or DEP (Dielectric Profiling) on ice[12,20], and (2) sulphate or sulphuric acid concentrations in discrete melted samples[6,7].

As shown above, at the depth of 128.7 m in BH8 ice core, the ECM, nss sulphate and microparticle concentrations show the highest peak values, indicating that it seems there exists a prominent volcanic signal. The good relationship between these parameters reveals that large quantities of small-sized dust are also deposited when high concentration of sulphuric aerosols is input to ice sheet. Different from other previously reported volcanic events such as that in Dome F[21] and Collins ice cap[22], no visible volcanic ash layers or cloud bands are found from the sections of BH8 ice core at the depth 128.0—129.0 m. The microparticles diameter mode (Fig. 3) supports the inference that the volcanic aerosols are deposited after long-range transport with air mass[23,24]. The volcanic eruption location seems to be relatively far from Vostok area.

2.4 Volcanic sulphate flux

In order to estimate volcanism scale, volcanic sulphate flux is calculated. The sulphate in ice core mainly comes from marine biogenic sulphur emissions (dimethysulfide, i.e. DMS)[25], sea-salt sulphate, crustal source and input of volcanic activity, etc. In central Antarctica, far from sea, the contribution of sea-salt sulphate to background sulphate is quite negligible[19]. During the period of non-volcanic activity, nss sulphate consists of marine biogenic emission sulphate and crustal sulphate, forming the background of non-volcanic sulphate. The typical background sulphate concentrations may be approximated using mean nss-sulphate concentrations for an extended period free of significant volcanic input[26]. A background sulphate concentration of 86.9 $ng\cdot g^{-1}$ and standard deviation(δ) of 21.9 $ng\cdot g^{-1}$ are got by averaging nss-sulphate concentration, excluding the samples (from BH8-115 to BH8-125) with high nss-sulphate concentration close to the peak. The background sulphate concentration plus double standard deviation (130.6 $ng\cdot g^{-1}$) is used to distinguish the volcanic peak from the background. As shown in Fig. 4, the dash straight line represents average non-volcanic sulphate and the solid line represents the upper limit of non-volcanic sulphate ($\overline{X}+2\delta$). S and E stand for the starting and ending points of volcanic eruption, respectively.

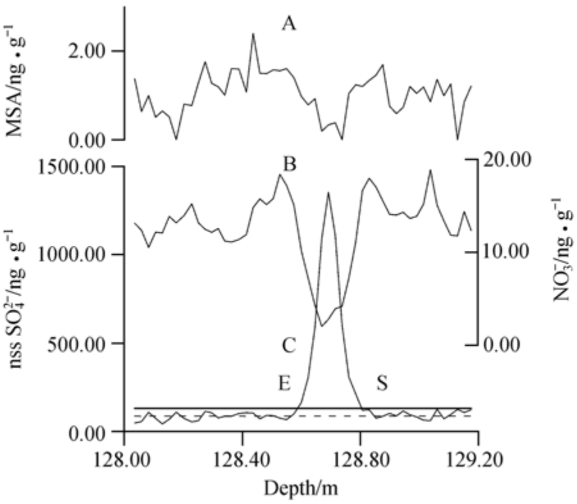

Fig. 4. Depth profiles of MSA (A), nitrate (B) and nss sulphate (C) in BH8 at 128.0—129.2 m depth. The dash straight line (bottom) represents average non-volcanic sulphate ($\overline{X}$), and the solid line (upper), the upper limit of non-volcanic sulphate ($\overline{X}+2\delta$). S and E stand for the starting and ending points of inputs of volcanic sulphate, respectively.

By multiplying the net volcanic sulphate concentration (nss-sulphate concentration minus background value) by the sample length representing time in water equivalent, using the similar calculation method[6,26,27], we get volcanic sulphate flux of 95.8 $kg\cdot km^{-2}$.

2.5 Volcanism scale and comparison with other volcanic events

Volcanic sulphate flux is usually used to estimate volcanism scale. Compared with the volcanic events in Plateau Remote (PR), Antarctica[7], the detected volcanic sulphate flux in BH8 ice core is nearly four times larger than that of Tambora /1815(22.39 $kg\cdot km^{-2}$), being just less than that of Kuwae/1454 (133.37 $kg\cdot km^{-2}$), with its peak sulphate concentration (1352.8 $ng\cdot g^{-1}$) close to that of Kuwae/1454 (1380.4 $ng\cdot g^{-1}$) detected in Plateau Remote ice core. Based on the volcanic scale categories released by Cole-Dai et al.[7], the discussed volcanic signal belongs to large scale volcanic eruption (volcanic sulphate flux $\geq$20 $kg\cdot km^{-2}$).

As shown in Fig. 4, the input of volcanic sulphate (from point S to E) lasts about 10.1 years, comparable with Kuwae/1454 (PR12, duration 7.2 years), Kuwae/1277 (PR15, duration 9.0 years) and Taupo/–719 (PR39, duration 9.8 years) in Plateau Remote ice core, east Antarctica[7]. The evident longer duration time maybe is explained as longer atmospheric residence time of volcanic aerosols, the mixture of surface snow layers containing volcanic ash with neighbouring snow samples, or the two samples length (especial at the boundary of the volcanic and non-volcanic input, close to the points S and E respectively) partially covering non-volcanic input portion.

2.6 MSA, nitrate and volcanic acidity

Surrounding the nss sulphate peak (Fig. 4), MSA and nitrate concentration show significant inverse change. Nitrate concentration drops from 18.0 $ng\cdot g^{-1}$ (128.83 m) and 18.39 $ng\cdot g^{-1}$ (128.53 m) to 2.0 $ng\cdot g^{-1}$ (128.67 m). MSA concentration decreases from 1.7 $ng\cdot g^{-1}$ (128.88 m) and 2.4 $ng\cdot g^{-1}$ (128.44 m) to 0.2 $ng\cdot g^{-1}$ (128.67 m, near detection limit). Similar nitrate concentration change caused by volcanic eruption is previously reported in South Pole snow layers[5], explained as probable atmospheric process change (such as weakened conversion between NO_x and HNO_3) during the volcanic eruptions. Recent studies suppose that such phenomenon maybe results from re-migration after snow deposition rather than an atmospheric effect[28]. The acid volatile gaseous compounds such as nitrate and MSA tend to migrate to the surface and partially redeposit after deposition, characterized by high concentration in superficial snow layers. At the site with lower accumulation rate (< 6 $g\cdot cm^{-2}\cdot a^{-1}$), the migration of the acid compounds is more readily and well marked[28,29]. Our data show that the overall mean concentrations of MSA and nitrate (1.1 and 12.5 $ng\cdot g^{-1}$, respectively) is not modified much in spite of the trough and peak. This fact supports the inference that high concentration volcanic sulphuric acid maybe expels volatile acids such as nitrate and MSA to adjacent, less acidic layers and redeposition. In deeper firn layers, the redeposition process probably dominates the migration rather than reemission to free atmosphere.

3 Conclusions

The sections of BH8 ice core (126.0—130.0 m) at Vostok are chosen for detailed analysis on ECM, trace chemical compositions and microparticles concentration. At the depth of 128.7 m, a prominent volcanic signal dated 4726 a B.P. is detected. The presented volcanic signature seems to be a relatively large scale (volcanic sulphate flux 95.8 $kg\cdot km^{-2}$, peak sulphate concentration 1352.8 $ng\cdot g^{-1}$) and long-lasting (duration 10.1 years) volcanic event with remote eruption source (possible with regional significance). It is comparable with some previously reported well-known volcanic events such as Tambora, Kuwae.

The above detected 4700 a B.P. volcanic signal will probably make contribution to supplementing or extending the volcanism chronology from ice cores.

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