**Characterization of individual insoluble particles in ice core**


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**Introduction**

The main purpose of this study is to identify individual particles contained in an ice core and trace their sources by the combined use of quantitative energy-dispersive electron probe X-ray microanalysis (ED-EPMA), which is also known as low-Z particle EPMA, and attenuated total reflectance FTIR (ATR-FTIR) imaging. It is capable of characterizing different minerals and their isomorphs even on single particle basis. Totally 606 individual insoluble particles from the ice core collected in the East Rongbuk from Mt. Qomolangma (Everest) were classified into 17 particle types based on their morphology, elemental concentrations, and molecular species and/or functional groups of individual particles available from the two analytical techniques.

**Samples**

Sampling site: The East Rongbuk glacier located on the northern slope of Mt. Everest (28°03′ N, 86°58′ E, 6518 m asl)

- Summer, wet monsoon blowing from the Indian ocean generated by the low pressure on the continent
- Winter, dry monsoon blowing from the continent by the high pressure on the continent
- windward sources such as the Thar and Sahara desert, and other arid regions contribute to the aerosols trapped in the Mt. Everest snowfall.

Geographical distributions of volcanoes: The size of dot represents the value of Volcanic Explosivity Index (VEI).

- The two locations represent the two most likely source regions of the volcanic eruptions to Mt. Qomolangma area. (Yu et al., 2019)

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**Results**

**Typical EPMA data and ATR-FTIR spectra of particles**

Representative ATR spectra of 5 individual particles of sample A containing feldspars (Na, K, Ca)AlSi O2 and SiO2 (feral materials) where silica content is less than 20% indicating presence of volcanic basalt.

Representative ATR spectra of 4 individual particles of sample C showing SiO2 polymorphs. No tridymite and coesite were observed.

Representative ATR spectra of 7 individual particles of sample C showing SiO2 polymorphs. No tridymite and coesite were observed.

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**Measurement and analysis**

- **Low-Z particle EPMA using SEM/EDX**
- **SEM-EDX (Scanning Electron Microscopy–Energy Dispersive X-ray Spectrometry)**
  - Individual Particle Analysis:
    - shape and size: secondary / backscattered electron images
    - chemical composition: X-ray spectrum
  - Ultra-thin window EDX for low-Z elements detection (C, N, O, F)
  - Metallic collecting substrates for minimizing charging effects (Ag or Al)
- Jel JSM-6390 SEM
- Oxford Link SATW ultrathin window EDX detector
- The detector resolution: 133 eV for Mn Kα X-rays
- 10 kV accelerating voltage
- 0.5 nA beam current
- Oxford INCA Energy software
  - X-ray spectra and elemental maps
- **ATR-FTIR imaging**
  - Perkin Elmer Spectrum 100 FT-IR spectrometer interfaced to Spectrum Spotlight 460 FT-IR microscope
  - Image pixel size = 1.56 μm
  - Spectral resolution = 8 cm−1
  - Scan per pixel = 32
- **Individual Particle Analysis**
  - location: optical image
  - functional groups, molecular species, and crystal structure: IR spectra

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**Volcanic ashes of Huaynaputina**

- andesites to dacitic pumices (SiO2 wt% from 57-67)
- high K-content (Oliver et al., 1996)

Our study reveals that the possibility of encountering a SiO2 particle to that of a feldspar particle in this sample is 34% and 16%, respectively. The possibility ratio of SiO2/Feldspar particle is 34/16 or 68/32 which might be correlated with the reported wt% of andesite to dacite mineral in bulk volume of Huaynaputina volcanic rock. However, when this bulk mineral is dispersed as single particles due to volcanic activity possibility of encountering SiO2 and feldspar particles may remain similar.

Moreover, this sample encounter a large number of particles majoring in K-containing minerals i.e. K-feldspar, muscovite and biotite. This results is consistent with the before mentioned report saying the enrichment of K-content observed in bulk mineral analysis of Huaynaputina volcanic rock.

**Relative abundance and characteristics of specific samples**

- High K contents
- Na, Ca, Feldspars (plagioclase) / Tix-containing
- Cristobalite, Tridymite, Coesite / K-containing minerals
- Quartz (major), Cristobalite (minor) / Montmorillonite, Kaolinite
- Vitreous glass, Muscovite / Montmorillonite

**ICP-SFMS (Inductively Coupled Plasma-Sector Field Mass Spectrometry)**

- Element 2 (X-cone), Thermo Scientific
- Agilent HP-ICPMS membrane desolvation unit, Elemental Scientific Inc.