EXTRATERRESTRIAL DUST LAYERS IN DOME FUJI ICE CORE, EAST ANTARCTICA.

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Introduction: Recent asteroid breakups due to disruptive collisions in the main belt were proposed by [1,2]. These authors suggested that signs of collisional events may be found by analyzing tracers of extraterrestrial dust in Antarctic deep ice cores. Thus, micrometeorites (MMs) recovered from polar ice cores would shed light on accretion histories of extraterrestrial materials to Earth.

A 3,035.22 m deep ice core was drilled at Dome Fuji Station (77°19'S, 39°42'E), East Dronning Maud Land, Antarctica [3] (Fig. 1). Two visible layers which contain abundant μm-sized particles were found in the ice core at depths of 2,641.07 m and 2,691.05 m.

Fig. 1. Dome Fuji Station is located in East Dronning Maud Land, Antarctica at 3,810 m above sea level. Other deep ice coring sites, Vostok and EPICA Dome C, are also shown.

Experimental: Dust particles were picked out from the ice core using a ceramic knife as well as were collected from meltwater of the ice by filtering after chemical, particle-number count and isotopic analyses. Mineralogical and petrological observations were performed using SEMs. Bulk compositions of dust particles were determined using an EPMA. Noble gas analysis was carried out on each sample by using laser heating method [4]. Oxygen three isotope measurement was conducted for olivines in two samples (2,641_p1 and _p2) using an ion microprobe [5]. For five samples, ^{10}Be was measured by AMS using the techniques in [6].

Mineralogy and petrography: An upper dust layer (2,641 m), which found soon after recovery at Dome Fuji Station, consists of large spherules up to 700 μm in size and some of them have voids due to degassing of volatiles. They show quenching texture of barred olivine and dendritic magnetite embedded in glass. Olivines are zoned with iron-rich rim (Fig. 2a,b). The lower dust layer (2,691 m) proved to be unique. It contains much smaller spherules (≤5 μm), compared with the upper layer, and abundant ~20 μm-sized aggregates which consist of spherules ranging from sub-μm to 5 μm in size (Fig. 2c). Individual spherule shows dendritic texture with olivine and magnetite (Fig. 2d).

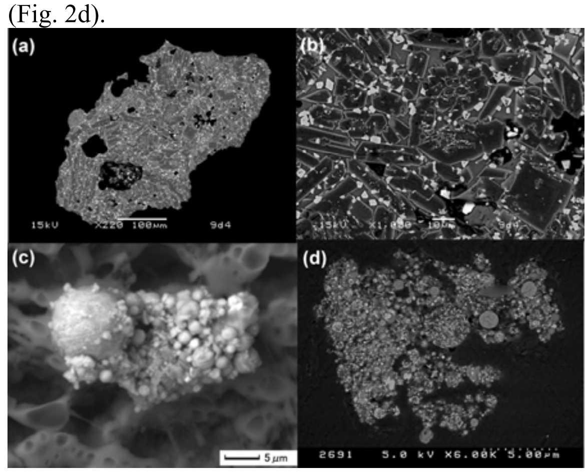

Fig. 2. SEM images of Dome Fuji dust particles. a) and b) BSE images of 2,641_p1, completely melted sample with voids. c) Aggregate of spherules from the lower layer (2,691 m). d) FE-SEM BSE image of aggregates. Several tens of sub-μm-sized spherules are adhered.

Bulk composition: CI-chondrite normalized (Si≡1.0) elemental abundance patterns of dust particles from the upper layer are chondritic, except some volatile elements, such as sodium, potassium and sulfur (Fig. 3a). There is no remarkable refractory/volatile fractionation. Aluminum and calcium depletions observed in 2,641_p2 (Fig. 3a, green square) may be related to a non-representative analysis. Abundance patterns of dust particles from the lower layer are broadly chondritic but somewhat scattered. This is mainly due to small size (1-5 μm) of the spherules we analyzed. Enhancement of potassium abundances and decrease of magnesium abundances are observed in many small particles in the lower layer. Enrichment factors of sulfur in dust particles from the lower layer are up to 0.2 x CI (Fig. 3b), and are different from those of dust particles in the upper layer (≤0.02 x CI, Fig. 3a). These characteristic features may have come from formation of secondary minerals such as jarosite during long-time storage in ice [7].

Oxygen isotope: Oxygen isotope values of olivine in 2,641_p1 and 2,641_p2 were measured relative to SMOW, and range from δ^{18}O=–27‰ to –47‰, falling along the terrestrial fractionation (TF) line (Fig. 4). The fact suggests that the two samples are highly depleted in $\delta^{17}O$ and $\delta^{18}O$ relative to SMOW. The $\delta^{18}O$ values are completely different from those previously reported MMs ($\delta^{18}O$ ranges from –2‰ to +60‰ [5,8–10]), but overlap with the $\delta^{18}O$ values (from –20‰ to -50‰) of unmelted MMs reported by [11].

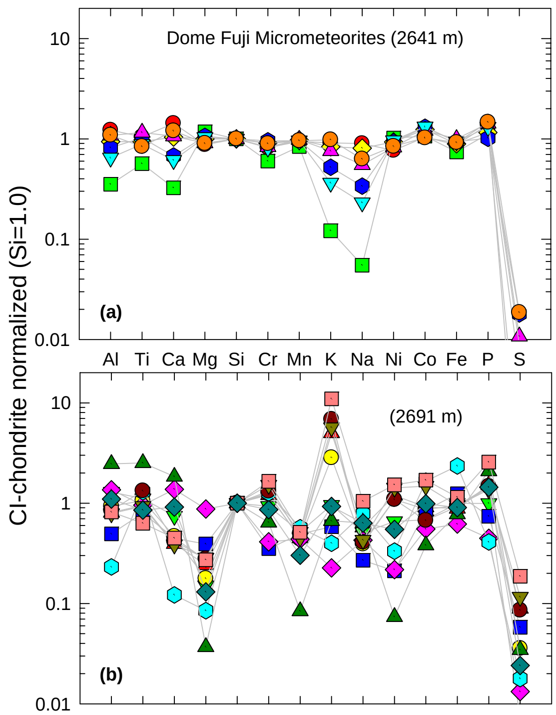

Fig. 3. CI-chondrite normalized (Si≡1.0) abundance patterns of Dome Fuji dust particles. (a) Upper layer, average of twenty-points analysis. (b) Lower layer, single-spot analysis. Elements are arranged, from left to right, in the order of increasing volatility, and lithophile, siderophile and charcophile elements.

Discussion: Morphology, petrographic features and bulk chemistry of dust particles in both layers clearly indicate that they are MMs extraterrestrial in origin. Concentrations of cosmogenic nuclide ^{10}Be in MMs from the upper layer also confirm extraterrestrial origin [12]. Noble gas analysis on three MMs from the upper layer showed that measured amounts of ^{3}He and ^{4}He were very similar to those of analytical blanks. As a result, these MMs did not show any indicative signature of cosmogenic noble gases [12]. The present results are different from those reported by [13]: even if MMs suffered complete melting, they still contained certain amounts of cosmogenic noble gases.

The upper and lower dust layers lie at Marine Isotope Stages 12 and 13, respectively, on an oxygen isotope profile. This indicates that they correlate with MM layers found at depths of 2,788 and 2,833 m, respectively, of the EPICA Dome C ice core [14]. On the other hand, the two MM layers are excellent time markers to calibrate both ice cores' dating that is totally independent from climate data. Dome Fuji Station states about 2,000 km apart from the Dome C coring site (Fig. 1). Thus, the dust layers represent two distinct meteoritic events, which are considered to be global. Dust streams resulting from large impact event(s) at an inner Solar System could have come to Earth, otherwise Earth may have encountered cometary dusts.

Since olivines in 2,641_p1 and 2,641_p2 are not affected by aqueous alteration, we can rule out the possibility of isotope exchange between olivine and surrounding ice with $\delta^{18}O$=–56‰. Oxygen isotopic compositions of upper atmospheric air and CO_2 are much heavier ($\delta^{18}O_{atm}$=+23.5‰, $\delta^{18}O_{CO2}$=~+50‰ [15]), thus the precursor material of two MMs could have possessed isotopically light oxygen.

Characteristic feature of MMs from the lower layer is that aggregates contain several tens of sub-µm-sized spherules. Compared with spherules from ablation debris of meteorite shower [16], the Dome Fuji aggregates are much smaller in size, and do not contain relict grains. Numerical simulation by [17] indicates that entrance velocities of sub-µm-sized particle into Earth's atmosphere exceed 50 km/sec, in order to produce totally melted spherules under negligible mass loss conditions. The estimated velocities are extremely large for those of asteroidal dust particles.

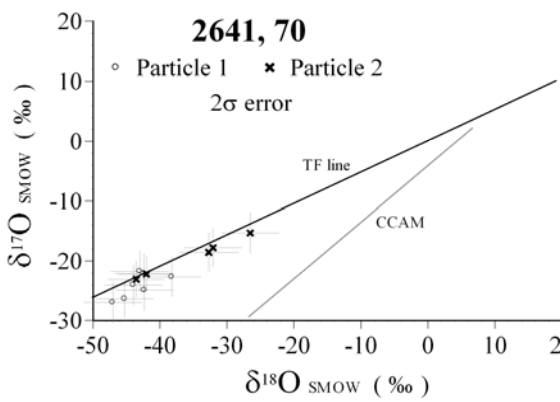

Fig. 4. Oxygen isotopic compositions of olivines in Dome Fuji dust particles (2,641_p1 and 2,641_p2).

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