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Two extraterrestrial dust horizons found in the Dome Fuji ice core, East Antarctica

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ABSTRACT

Two silicate-rich dust layers were found in the Dome Fuji ice core in East Antarctica, at Marine Isotope Stages 12 and 13. Morphologies, textures, and chemical compositions of constituent particles reveal that they are high-temperature melting products and are of extraterrestrial origin. Because similar layers were found ~2000 km east of Dome Fuji, at EPICA (European Project for Ice Coring in Antarctica)-Dome C, particles must have rained down over a wide area 434 and 481 ka. The strewn fields occurred over an area of at least 3×10^6 km^2. Chemical compositions of constituent phases and oxygen isotopic composition of olivines suggest that the upper dust layer was produced by a high-temperature interaction between silicate-rich melt and water vapor due to an impact explosion or an aerial burst of a chondritic meteoroid on the inland East Antarctic ice sheet. An estimated total mass of the impactor, on the basis of particle flux and distribution area, is at least 3×10^9 kg. A possible parent material of the lower dust layer is a fragment of friable primitive asteroid or comet. A hypervelocity impact of asteroidal/cometary material on the upper atmosphere and an explosion might have produced aggregates of sub-μm to μm-sized spherules. Total mass of the parent material of the lower layer must exceed 1×10^9 kg. The two extraterrestrial horizons, each a few millimeters in thickness, represent regional or global meteoritic events not identified previously in the Southern Hemisphere.

1. Introduction

The Earth has continually accreted extraterrestrial materials which mainly originate from asteroids and comets, accumulating at a rate of $3\pm1\times10^7$ kg per year (Love and Brownlee, 1993; Engrand and Maurette, 1998). Reconstructing the influx of extraterrestrial materials to Earth is an important issue for understanding the nature of accreted materials to Earth, the flux of extraterrestrial materials at the Earth's surface, and possible terrestrial climate change (e.g. Alvarez et al., 1980). Remnants of higher fluxes of interplanetary dust particles, impact plumes, airbursts, cometary showers, and the ablation products of such phenomena can be identified by high contents of iridium as well as high ^{3}He in particles from marine sediments (e.g. Alvarez et al., 1980; Schmitz et al., 1997; Farley et al., 2006). Although specific asteroidal breakups are proposed for a few meteoritic materials found in sediments (Schmitz et al., 1997; Farley et al., 2006; Bottke et al., 2007), debris layers from many events probably have been buried due to continuous accumulation of terrestrial materials and have eventually disappeared over geological timescales by diagenesis.

Polar ice cores have several advantages for examining extraterrestrial fallout. First, stratigraphic ages of ice are defined from profiles of deuterium and oxygen isotopes. Second, the slow rate of ice flow from the interior of Antarctica allows almost continuous time stratigraphic records through the ice, without large hiatus. Finally, the ice-coring sites are well isolated from terrestrial eolian- and volcanic-dusts, making them possible reservoirs of μm-sized extraterrestrial materials (Gabrielli et al., 2004; Winckler and Fischer, 2006). High-resolution analysis of extraterrestrial dust records back to 800 ka is now achievable using Antarctic ice cores (Jouzel et al., 2007; Motoyama et al., 2007).

Recently, two extraterrestrial dust layers were reported in the EPICA-Dome C ice core (L1 and L2 layers lie at depths of 2788 and 2833 m, respectively; Narcisi et al., 2007). In the Dome Fuji ice core two

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extraterrestrial dust layers were also found independently (Misawa et al., 2008). Since the two ice-coring sites are ~2000 km apart, it is important to compare the dust layers between Dome Fuji and Dome C. Here, we present initial analytical results of Dome Fuji dust particles and discuss the implications of this finding for regional/global extraterrestrial fallout events and possible origins of these materials.

2. Sampling and analytical techniques

A 3035.22 m deep ice core was drilled at the Dome Fuji station (77°19′S, 39°42′E; Fig. 1), East Dronning Maud Land, Antarctica (Motoyama et al., 2007). During the course of initial description of ice core at the station, more than forty dusty layers were identified. Although later studies have shown that almost all the visible layers consist of tephra and/or continental dusts, the two dust layers described here were independently recognized as peculiar.

At a depth of 2641.70 m, an upper dust-layer (hereafter DF2641, Fig. 2a) dips ~15° from horizontal and contains large particles up to ~1 mm in size. At a depth of 2691.05 m, a lower dust-layer (hereafter DF2691, Fig. 2b) dips ~40° from horizontal and consists of abundant silicate-rich spherules sub-μm to several-μm size as well as aggregates of micro-spherules. The inclination angle of the borehole is 6° (Motoyama et al., 2007).

Dome Fuji ice cores were cut into three parts; A, B, and C. C cuts, with a cross-section area of 1200 mm^2, were used for routine analyses, namely deuterium profiles, oxygen isotopes, particle count, and chemistry (Motoyama et al., 2007). Particles studied in this work were picked from the C cut using a ceramic knife and were also separated from meltwater of the ice using a polycarbonate membrane filter with pore size of 0.4 μm. They were embedded in Petropoxy 154 resin or in 7036 Blanchard Wax, and polished using diamond paste. For particle-size-number and size-volume distribution measurement in the DF2641 layer, we used a subsample (20 mm × 40 mm × 419 mm), which covers depths of 2641.50 to 2641.92 m (i.e. 219 mm below and 200 mm above the DF2641 layer), taken from the B cut with a section area of 800 mm^2, and using a ceramic knife we scraped off rectangular prisms of ice in increments of 6–8 mm thickness. This work was done in a low-temperature clean room at the Institute of Low Temperature Science, Hokkaido University. Sixty-three samples such obtained were packed in dust-free polyethylene bags and were kept frozen.

Polished surfaces of the samples were analyzed using a JEOL JXA-8200 electron probe microanalyzer (EPMA) at the National Institute of Polar Research (NIPR). The acceleration voltage was 15 kV and the specimen current was 10 nA. A defocused beam-spot of 5 μm was used to avoid volatile loss. For large samples from the DF2641 layer, twenty random analyses were averaged. Single-spot analysis was performed for the particles from the DF2691 layer. Detailed images of the DF2691 aggregates were taken with a JEOL JSM-5600LV scanning electron microscope (SEM) at the Ibaraki University. The samples were put on a Teflon sheet and the SEM was operated in a low-vacuum mode with chamber pressure of 25 Pa and the accelerating voltage of 15 kV. Back-scattered electron (BSE) images of particles from the DF2691 were taken with a Hitachi S-4500 field emission gun scanning electron microscope (FE-SEM) at the University of Tokyo. The accelerating voltage was 5 kV and the specimen current was 15 nA. Because sizes of constituent phases were small, we obtained only qualitative data on olivine, pyroxene, magnetite, and glass in the DF2691 particles using the FE-SEM equipped with an energy dispersive spectrometer.

The oxygen isotopic measurement of olivine in DF2641 particles was performed on polished sections with gold coating by using a secondary ion mass spectrometer, a model CAMECA IMS-6f at the

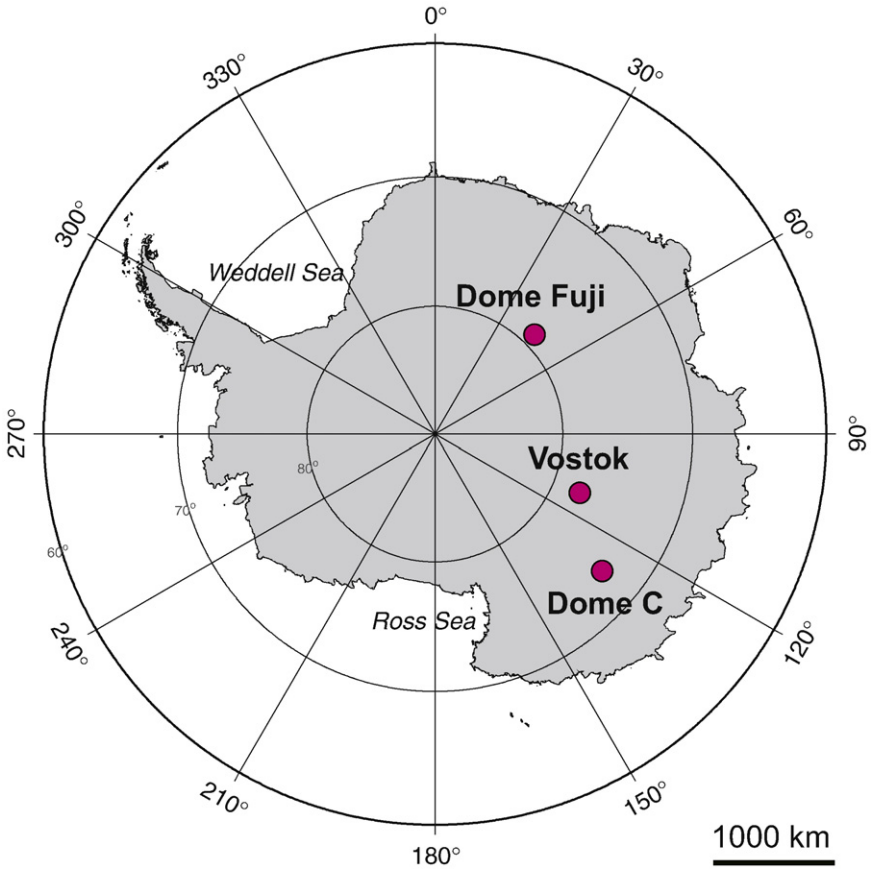

Fig. 1. Map of drilling sites of deep ice core in Antarctica. The Dome Fuji station is located in the eastern part of Dronning Maud Land (77°19′S, 39°42′E), Antarctica at 3810 m above sea level. The Vostok (78°28′S, 106°48′E) and EPICA-Dome C (75°06′S, 123°23′E) stations are 1480 and 2038 km, respectively, from the Dome Fuji station.