EXPOSURE HISTORIES OF MICROMETEORITES FOUND IN A 434 KYR OLD LAYER IN THE DOME FUJI ICE CORE, ANTARCTICA.

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Introduction: Micrometeorites (MMs) in the size range ~0.1-1 mm, originally extracted magnetically from deep-sea sediments [1] have been collected from polar ice [*e.g.,* 2, 3]. Most MMs are delivered from short-period comets or main-belt asteroids. Although MMs are the dominant source of extraterrestrial materials accumulated on Earth and the Antarctic ice sheet is the best site to collect MMs, concentration of MMs in ice is extremely low [*e.g.,* 3]. Furthermore, the temporal variation of MM influx rate was not known except in relation to large impact events [*e.g.,* 4].

Two distinct highly concentrated particles layers were found in the Dome Fuji (Dome-F) (77˚19'S, 39˚42'E) and the EPICA-Dome C (Dome-C) (75˚06'S, 123˚21'E) ice cores, Antarctica [5, 6]. The depths of two layers are 2641.07 m and 2691.05 m for the Dome-F [6] and 2788 m and 2833 m for the Dome-C core [5]. The Dome-C ages of the two layers are 434±6 ka and 481±6 ka respectively based on the EDC3 chronology [5, 7]. Since the ages for the two layers of the Dome-F core are the same as those of the Dome-C core based on phasing of isotope records in the ice cores, the two layers of both cores are the same event [8]. The major elemental compositions of those particles found at both layers in two ice cores suggest that they might be MMs [5, 6]. However, the most unambiguous means of identifying those particles as extraterrestrial materials is the detection of cosmogenic nuclides. The concentrations and the ratios of cosmogenic nuclides provide reliable exposure ages and conditions for those particles.

Sample Description and Experimental Procedures: Five large particles, 2641-a, b, g, n, and o were collected from the Dome-F ice core, Antarctica [8]. These particles were hand picked from the ice core at the depth of 2641 m. All particles were not spherules but contained many bubbly void spaces that indicate partial or total melting during atmospheric entry. Especially, 2641-a and -g contain a large hole at center of the particle (see Fig. 1). Each particle was transferred to a quartz plate and mounted by 7036 Blanchard Wax and a small surface was polished. Quantitative elemental analysis of these polished surfaces was performed by EPMA at NIPR with a 5 µm spot size of diameter beams. After EPMA, each particle was separated from the bond and C-coating with a few drops of acetone and washed with acetone and ethanol in an ultrasonic bath. After weighing, the individual particles were dissolved with a drop of $HF\text{-}HNO_3$ along with Be, Al, Cl, and Mn carriers. After chemical separation and purification, ^{10}Be ($t_{1/2}$=1.36x10^6 yr) was measured by accelerator mass spectrometry (AMS) at PRIME Lab, Purdue University [9]. The ^{26}Al and ^{36}Cl AMS measurements are in progress. Concentrations and isotopic ratios of noble gases (He, Ne, Ar, Kr, and Xe) in 3 small particles, 2641-f, h, and i, from 2641 m layer were analyzed using a laser gas-extraction system at the University of Tokyo [10]. Those particles were selected by morphological features that seem to be less melted or degassed.

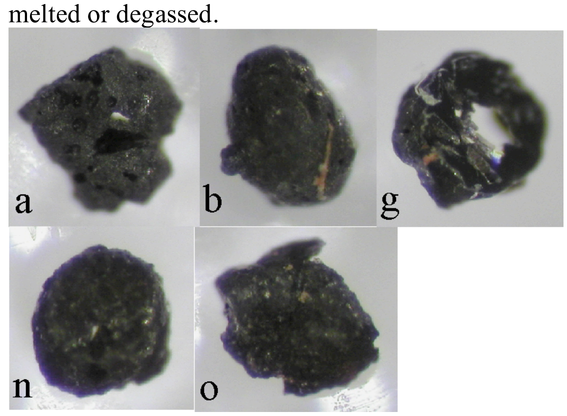

Fig. 1. Pictures of 2641-a, b, g, n, and o particles before dissolution. Each size was shown in Table 1.

Results and Discussion: Apparent density of the particles was ~1 g/cm^3 except 2641-b that was ~3.5. A summary of cosmogenic ^{10}Be concentrations as well as major chemical compositions of 5 Dome-F particles is shown in Table 1. The EPMA results were averaged from 20 spot analyses for each particle. Major elemental abundances of 5 particles relative to that of CI chondrite (normalized to Si) was found to be 0.6-1.5 except some depletion of K, Na, and S [8]. Those patterns are similar to that of MMs and indicate those particles are meteoritic origin. Fe/Mn ratios were 86-95, similar to CI or L chondrites.

All particles contain 2.5-4.2 dpm ^{10}Be/kg except 2641-a, which contains no ^{10}Be distinguishable from the chemistry blank. The ^{10}Be concentrations at the time of fall, 434 ka, are 3.1-5.2 dpm/kg and shown in Table 1. Polar ice contains meteoric (atmospheric) ^{10}Be. Especially, the Dome-F ice core contains very high ^{10}Be due to the low snow accumulation rate. We estimated that the ^{10}Be concentration is ~2x10^{5} atom/g ice at 2641 m MMs layer. The maximum amount of meteoric ^{10}Be contribution from ice during sample handling was estimated to be ≤1x10^{4} atoms. Since ^{10}Be concentration of each particle is 1-3x10^{5} atom (≤1x10^{4} atom for 2641-a), we concluded that the ^{10}Be in particle was produced in space. Complete exclusion of terrestrial ^{10}Be contamination requires the awaited results from ^{26}Al measurements.

On the other hand, noble gas concentrations in 3 particles are indistinguishable from analytical blank (see Table 2), indicating low ^{4}He concentrations (<5x10^{-7} cm^{3} STP/g) in the Dome-F particles. Because ^{4}He concentration is generally in the range of 10^{-5} cm^{3} STP/g in meteorites and is much higher in MMs with solar gases [*e.g.,* 11], the low ^{4}He concentrations indicate degassing from the particles. The concentrations of He and Ne in the 3 Dome-F particles are lower than those of Antarctic glassy spherules, and the atmospheric ^{40}Ar/^{36}Ar ratios are similar to those of the spherules with low Ar concentrations [12]. Noble gas data indicated that the Dome-F MMs had experienced much higher heating temperature than that of previously studied MMs. Moreover, the noble gas features as well as atmospheric ^{40}Ar/^{36}Ar ratio found in the particles are very similar to noble gas behaviors by laboratory heating experiments [13]. The higher heating might have occurred due to a high atmospheric entry velocity or a catastrophic break up in the earth's atmosphere.

The cosmogenic nuclide production rate varies with size and depth of an object in space. Assuming all ^{10}Be were produced in space, the minimum cosmic ray exposure (CRE) age was ~0.5 Myr for ordinary size (< m size) of meteoroid, ~1.1 Myr for a large object (2π exposure), and ~2 Myr for a mm sized object. Previous cosmogenic radionuclide measurements in individual MMs suggested that the majority of MMs were exposed to cosmic rays as small bodies in space for >1 Myr [*e.g.,* 14], consistent with the 4 Dome-F MMs. Although the 5 MMs were collected in the same ice core, similar ^{10}Be concentrations in 4 out of 5 MMs indicate that the pre-atmospheric sizes were smaller than m sized objects and not 10 m or larger objects in space.

The meteoritic materials from two distinct events fell over the distance between Dome-F and Dome-C, at least 2,000 km. Assuming a MM concentration of 1g/m^{2}, a minimum influx was >3 Mton or a >100 m diameter object at the source region.

One model suggested breakup of a main belt asteroid 450 kyr ago with delivery of particles to Earth [15]. However, the ^{10}Be CRE age and a wide range of particle sizes found in discrete layers exclude the possibility that the proposed event was related to the MMs in this work.

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Table 1. Cosmogenic ^{10}Be concentration and major chemical composition of 5 Dome Fuji particles.

	Mass (μg)†	Size (μm)†	^{10}Be (dpm/kg)	^{10}Be* (dpm/kg)	Mg (%)	Al (%)	Si (%)	Ca (%)	Mn (%)	Fe (%)	Ni (%)	O (%)
2641-a	60.3	500x550	0.04±0.19	0.05±0.24	14.7	1.25	16.4	1.44	0.30	25.4	1.58	37.6
2641-b	72.2	280x450	4.16±0.54	5.19±0.67	15.3	1.07	16.1	0.92	0.29	26.2	1.55	37.4
2641-g	58.3	450x500	3.81±0.41	4.76±0.51	13.0	1.41	16.0	1.44	0.29	27.8	1.37	37.4
2641-n	32.7	350x450	3.48±0.49	4.34±0.61	15.0	0.86	16.3	0.84	0.29	26.3	1.61	37.9
2641-o	41.5	400x450	2.49±0.38	3.11±0.48	13.2	1.45	16.4	1.66	0.29	26.1	1.42	38.2

† After polished surface (for cosmogenic radionuclide measurement), *Activity at the time of fall (434 ka).

Table 2. Concentration (cm^{3} STP) and isotopic ratio of light noble gases in 3 Dome Fuji particles.

	Mass (μg)	^{3}He (10^{-16})	^{4}He (10^{-12})	^{20}Ne (10^{-14})	^{21}Ne (10^{-16})	^{22}Ne (10^{-15})	^{40}Ar (10^{-10})	^{38}Ar/^{36}Ar	^{40}Ar/^{36}Ar
2641-f	4.3	2.0	2.6	4.0	1.9	4.2	2.0	0.187±0.006	300.9±2.5
2641-h	4.5	2.7	2.5	6.9	2.6	7.0	1.2	0.197±0.006	286.7±5.1
2641-i	5.8	5.1	3.7	9.6	4.4	10.4	2.5	0.188±0.008	287.8±3.1
Blank		3.1-5.3	2.8-3.3	6.3-8.5	3.8-4.1	7.4-9.1	0.83-0.94	0.185-0.194	280-286