EXPOSURE HISTORIES OF 10 MICROGRAM INDIVIDUAL ANTARCTIC MICROMETEORITES: RADIONUCLIDE MEASUREMENTS, CHEMICAL, AND MORPHOLOGICAL ANALYSES. K. Nishiizumi[1], T. Nakamura[2], M. W. Caffee[3] and T. Yada[4], [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA (kuni@ssl.berkeley.edu), [2]Department of Earth and Planetary Sciences, Kyushu University, Fukuoka 812-8581, Japan (tomoki@geo.kyushu-u.ac.jp), [3]Department of Physics, Purdue University, West Lafayette, IN 47907 (mcaffee@purdue.edu), [4]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Kanagawa 229-8510, Japan (yada@planeta.sci.isas.jaxa.jp).

Introduction: Micrometeorites (MMs) are the dominant source of extraterrestrial materials accreting onto Earth. By mass, meteorites are only a small fraction of the MM flux. Most MMs are delivered from short-period comets or main-belt asteroids. Although micrometeoroids (or cosmic dust) exist in the interplanetary medium, the origin and orbital histories of MMs are not well known.

Cosmogenic radionuclide measurements in individual MM suggested that majority of MMs were exposed to cosmic rays as small bodies in space for >1 Myr [*e.g.* 1]. While noble gas measurements in individual MM typically require only ~μg, radionuclide measurements require ~100 μg, severely restricting the samples that can be studied. To expand the applicability of radionuclide measurements to a greater number of samples we have developed techniques for the analysis of cosmogenic radionuclides to samples weighing ≤10 μg. We have applied these techniques to a suite of Antarctic micrometeorites (AMMs). To maximize the scientific yield of our measurements we have also performed chemical, mineralogical, and morphological analyses. In many respects these techniques are similar to those that will be used for future sample return missions.

Sample Description and Experimental Procedures: Twelve large AMMs were selected from the National Institute of Polar Research (NIPR) collection. All AMMs were collected from Tottuki Point, near Syowa Station in 1998-99 [2, 3].

After SEM characterization, individual AMMs were analyzed by synchrotron X-ray diffraction (SXRD). Each particle was mounted on a 5 μm diameter thin glass fiber. Each particle was secured to the fiber by a small amount of acetone-soluble bond. The sample assembly was placed in a Gandolfi camera for exposure to synchrotron X-rays with a wavelength of 2.161 ± 0.001 Å for up to 30 minutes, producing a powder X-ray diffraction pattern [4]. The analysis was performed at the beam line 3A of the Photon Factory Institute of Material Science, High Energy Accelerator Research Organization.

Each sample was then embedded in resin and a small surface was polished. Quantitative elemental analysis was performed by EPMA; 20 spot analyses were performed on the polished surface of each AMM. The spot size was 20 μm in diameter.

After EPMA, each AMM was separated from the resin and C-coating with a few drops of acetone and washed with deionized water and ethanol in an ultrasonic bath. After weighing, individual AMMs were dissolved with a drop of HNO_3 and a few drops of HF along with Be, Al, Cl, and Mn carriers. After chemical separation and purification, ^{10}Be ($t_{1/2}$=1.5x10^6 yr), ^{26}Al (7.05x10^5 yr), and ^{36}Cl (3.0x10^5 yr) were measured by accelerator mass spectrometry (AMS) at PRIME lab, Purdue University [5].

Results and Discussions: A summary of preliminary results of cosmogenic ^{10}Be concentrations as well as textures, major minerals, and major chemical compositions (Mg, Al, Si, Ca, and Fe-wt %) of 12 AMMs is shown in table 1. KS 005 was extremely fragile and we were unable to identify it after dissolving the resin. Indeed, the AMS ^{10}Be result was identical to our chemistry blank, so it is likely that this sample was lost. KS 007 was also fragile and we were unable to make a polished surface for EPMA. The SXRD analysis indicated that AMMs are fine-grained and are probably decomposed hydrous minerals. The exceptions to this are KS 002 and 013, which are coarse-grained. We believe these particles were originally anhydrous. Evidence supporting this is the non-porous igneous textures consisting of Mg-rich euhedral olivine and low-Ca pyroxene. Nakamura *et al.* [4] examined 56 MMs by XRD and suggested that most MMs had been hydrous particles and were decomposed by the brief heating during atmospheric entry.

Previous work has shown that ^{36}Cl is depleted in the fusion crust. Laboratory heating experiments also indicated high volatility of ^{36}Cl from carbonaceous chondrites. We measured ^{36}Cl concentrations in 3 AMMs, KS 003, 006, and 009. However, our ^{36}Cl measurements, which are only 1 σ higher than blank level, are not useful for reconstructing the heating history of these samples during atmospheric entry.

If we assume that the pre-atmospheric size of the AMMs in space is similar to the recovered size, the production rate of ^{10}Be by galactic cosmic rays (GCR) is ~8 atom/min·kg [6]. Since all AMMs contain ≥6 dpm/kg of ^{10}Be, even though some of them have large

uncertainties, the ^{10}Be exposure age is ≥3 Myr. This is consistent with ^{21}Ne exposure ages in MMs from Greenland (0.5-20 Myr) [7] but is longer than the ^{21}Ne exposure ages of AMMs, which are typically <1 Myr [8, 9].

The ^{10}Be concentration in KS 003, 16±2 dpm/kg, is twice the saturation values for small particle in space. One possibility is that this particle was exposed to GCR in a small meteoroid, which fragmented in the atmosphere. This particle was at least partially melted as well. Another possibility is that this AMM was exposed to GCR at >30 AU, perhaps near the inner boundary of the Kuiper belt, where the GCR flux is a factor of 2 higher than at 1 AU. This scenario requires rapid transport to Earth though.

Yet another intriguing possibility is that some of the AMMs are cometary in origin. Yada *et al.* [10] found a high abundance of presolar silicates in AMMs picked from the same set of AMMs used for this study. If the AMM is cometary in origin, the particles must have been exposed in the outer solar system as part of a larger body. An exposure such as this in the inner solar system would be characterized by a production rate ~12 atom ^{10}Be/min·kg, still lower than that observed in KS 003.

Exposure scenarios can be further constrained with additional radionuclide measurements, particularly ^{26}Al, which is produced prodigiously by solar cosmic rays (SCR). Preliminary ^{26}Al results indicate 80±40 dpm/kg for KS 011 and 120±50 dpm/kg for KS 013. Cosmogenic ^{26}Al is produced by SCR and GCR and while the activity measured in these samples is slightly lower than many other AMMs [1] it nevertheless clearly indicates exposure to SCRs as small bodies, ≤ a few mm, in space after ejection from their parent bodies (asteroid or comet).

The ^{10}Be exposure ages for these AMMs is >3 Myr, assuming exposure as a small body. At 1 AU the ^{26}Al saturation value is 400-700 dpm/kg [6], considerably higher than that measured. Taken together, our measurements are consistent with the particle's exposure in the vicinity of the asteroid belt for most of its lifetime. There are other possible exposure scenarios but one or two nuclides cannot constrain a unique exposure condition.

In this study, we measured ^{10}Be (≤10^5 atoms) in micrometeorites weighing 5-10 μg. These micrometeorites are a factor of 10 less in mass than previous MM analyses. Although the detection limit is not low enough for measurement of cosmogenic radionuclides in IDPs or Stardust samples, this work, combining SEM, XRD, EPMA, and AMS in a same small sample, clearly demonstrated our capability of analysis for small samples such as Hayabusa or future asteroid or planetary sample return missions.

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Table 1. Cosmogenic ^{10}Be concentration and major chemical composition of AMM.

	Mass (μg)†	^{10}Be (dpm/kg)	Size (μm)§	Melt (#)	Text. (*)	Major Minerals	Mg (%)	Al (%)	Si (%)	Ca (%)	Fe (%)
KS 001	2.0	13±18	190x320	2	1	Ol, Px, M	10.7	1.9	16.1	0.5	17.4
KS 002	14.8	6.2±4.0	160x250	1	2	Ol, Px, M	19.1	1.2	22.0	1.1	10.6
KS 003	10.2	16±2	180x280	4	1	Ol, M	15.9	2.4	19.2	1.6	7.5
KS 004	7.3	10±3	230x260	1	1	Ol, Px, M	9.9	4.4	12.8	0.4	23.3
KS 005	-	-	210x280	2	1	Ol, M	13.4	1.6	14.8	0.6	20.2
KS 006	9.6	10±2	220x440	3	1	Ol, Px, M	10.1	3.4	12.3	0.4	22.5
KS 007	2.8	19±13	200x320	2	1	Ol, M	n.d.	n.d.	n.d.	n.d.	n.d.
KS 009	4.2	5.7±5.3	270x320	2	1	Ol, Px, M	8.9	4.3	15.5	0.8	20.8
KS 010	22.1	8.6±1.0	180x220	3	1	O, M	17.4	4.9	18.9	0.3	11.8
KS 011	6.7	6.8±3.5	180x260	3	1	Ol, Px, M	12.2	6.5	13.5	0.4	18.4
KS 012	1.4	22±20	150x170	2	1	Ol, Px, M	13.4	1.3	18.4	0.1	16.0
KS 013	5.3	7.7±2.9	210x260	1	2	Ol, Px, M	15.4	0.8	17.2	0.3	4.6

†Mass for cosmogenic radionuclide measurement. §Size before mount on resin.

Degree of melting: 1-Unmelted, 2-Unmelted core and partially melted rim, 3-Partially melted, 4-Partially to totally melted, 5-Totally melted.

* Texture: 1-Fine grained, 2-Coarse grained. Major minerals: Ol-olivine, Px-low Ca pyroxene, M-magnetite.