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The collection of micrometeorites in the Yamato Meteorite Ice Field of Antarctica in 1998

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Abstract: In austral summer season of 1998, we collected micrometeorites at the Meteorite Ice Field around the Yamato Mountains, Antarctica. It was the first attempt to collect micrometeorites at inland bare ice in Antarctica and to use a filter with 10 μm openings; it can capture particles that overlap in size with interplanetary dust particles collected in stratosphere. At the inland bare ice of the Antarctic Continent, an ancient flux of extraterrestrial dust is thought to be preserved in contrast with bare ice along the shore of the continent. For collecting micrometeorites from the bare ice, we used a tented sledge equipped with appliances for melting ice and filtering the melted water. We melted ~36 tons of ice and obtained particles containing micrometeorites at 24 points in three areas of the Meteorite Ice Field.

1. Introduction

Cosmic dust is one of the most important constituents of the Solar System. From the estimation based on the observation of Love and Brownlee (1993), 40000 ±20000 tons of cosmic dust are falling to the Earth every year. Cosmic dust is thought to fall equally across the Earth's surface, so that places where the accumulation rate of lithic terrestrial material is low are relatively abundant in cosmic dust, such as deep sea floor (Murray and Renard, 1883), the Polar Regions (Shima and Yabuki, 1968) and stratosphere (Brownlee and Hodge, 1973). Cosmic dust has been collected in Antarctica from 1960's. In the early studies, researchers had mainly concerned about cosmic dust melted during atmospheric entry called "cosmic spherules" (Shima and Yabuki, 1968; Koeberl and Hagen, 1989). In the last decade, researchers have begun to focus on unmelted micrometeorites (MMs), for they retain information of their precursor materials better than fully melted "cosmic spherules". The first successful collection of unmelted MMs at the Polar Regions was Maurette *et al.* (1986). They collected MMs at the edge of the ice sheet of the Greenland. Maurette and co-workers also succeeded in collecting MMs at Cap-Prudhomme in Antarctica (Maurette *et al.*, 1991). Zolensky *et al.* (1989) found particles with titanium carbide and titania phases, probable extraterrestrial origin from pre-industrial aged Antarctic ice. Taylor *et al.* (1998) collected MMs from the bottom of the water well of the Amundsen-Scott Station at the South Pole.

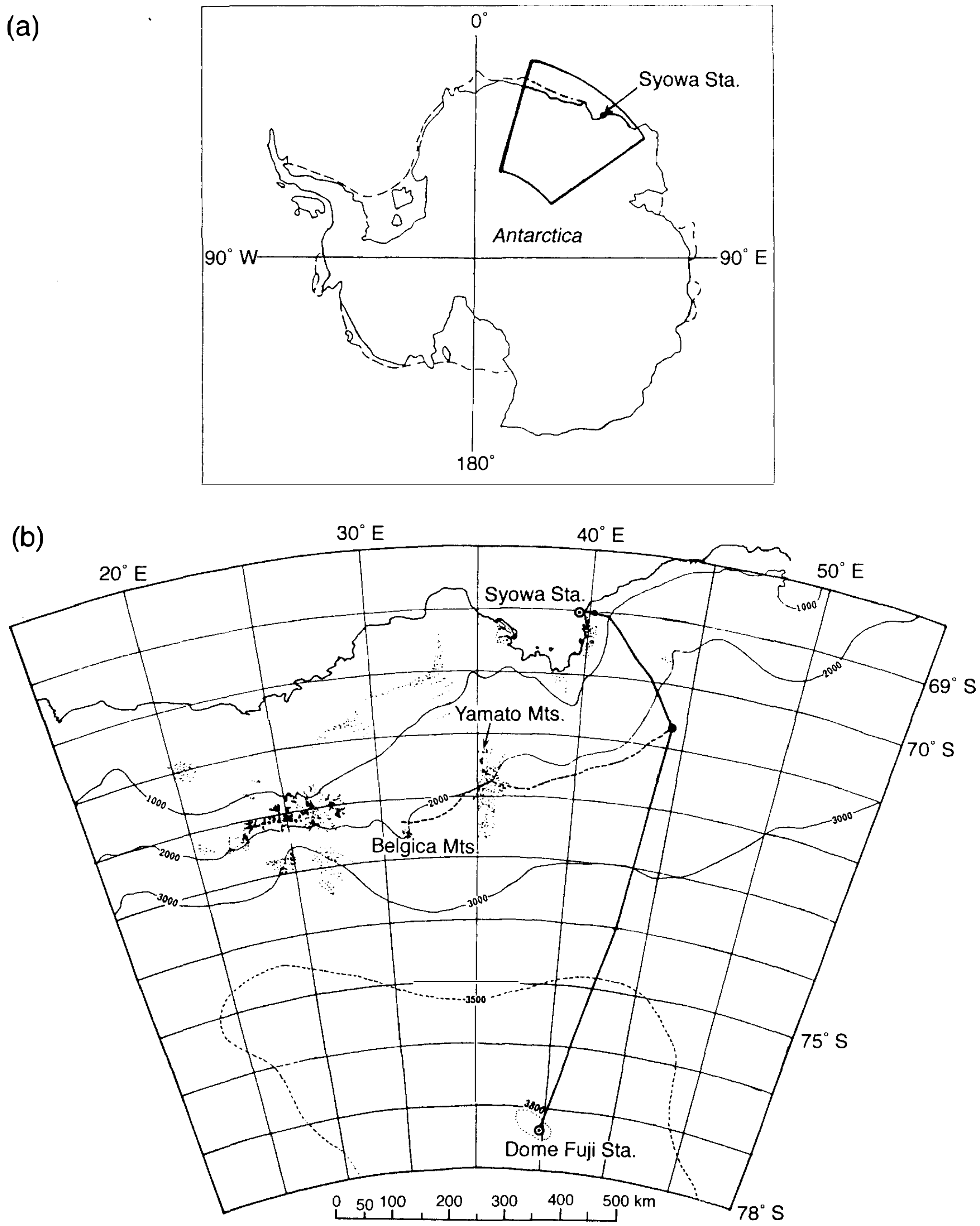


Fig. 1. (a) A map of the Antarctic Continent. (b) A close-up map of the fan-shaped section in the map of (a). In the map, black marks stand for mountains and nunataks, and small dots for bare ice areas.

In the Dome Fuji Station in Antarctica (Fig. 1), where ice cores of 2500 m in depth have been drilled, MMs were collected from sediments at the bottom of a water tank (Nakamura *et al.*, 1999).

The Meteorite Ice Field around the Yamato Mountains is a known meteorite-accumulation site in Antarctica (Yanai, 1978). It is located 300 km away from the Syowa Station to south-southwest (Fig. 1). Seven massifs (A to G) of mountains of 2300 to 2500 m in height are distributed south to north 50 km long on ice sheet

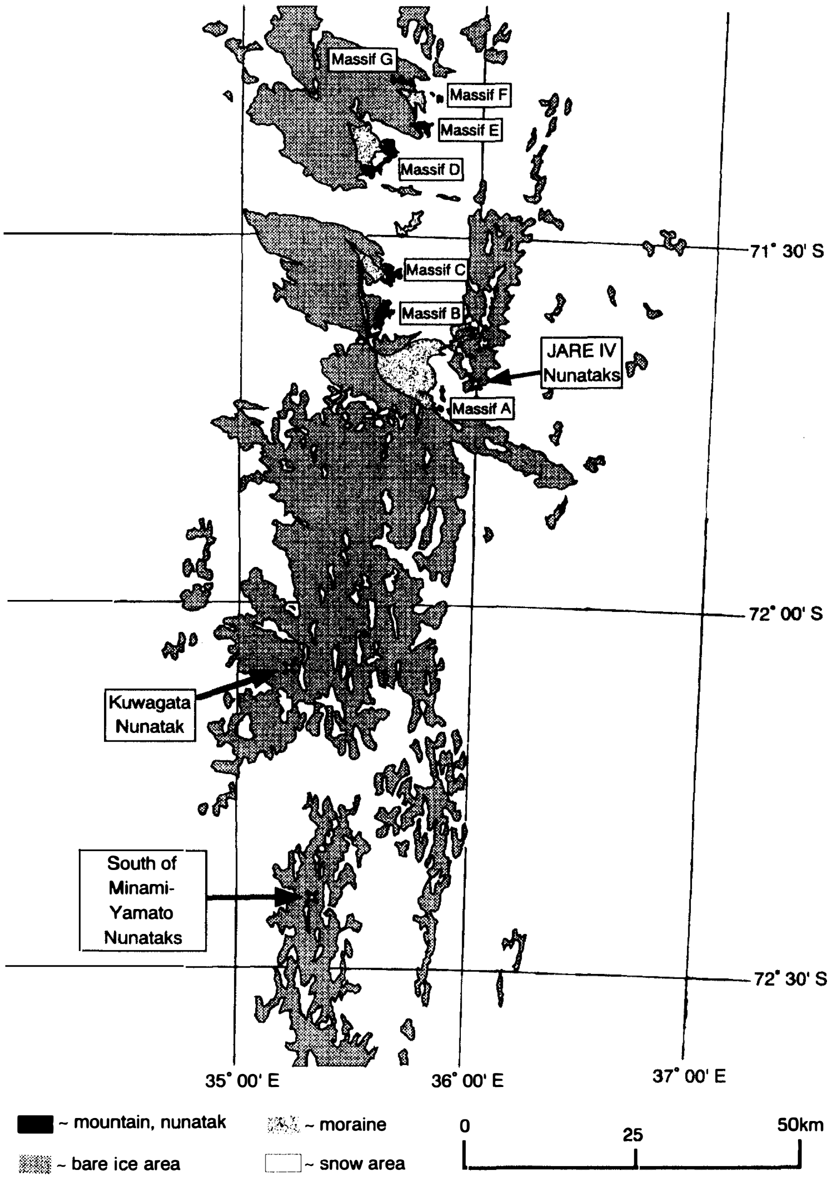


Fig. 2. A map showing the Yamato Mountains and the Meteorite Ice Field. The bare ice area is totally 4000 m² around the Yamato Mountains. Three areas where we collected AMMs are also shown in the map.

of 1800 to 2200 m in altitude (Fig. 2); these hold bare ice field of 4000 m^2 in total. Since the discovery of nine meteorites in 1969 (Kusunoki, 1975), about ten traverse parties have visited there for geological and glaciological surveys and collecting meteorites (*e.g.*, Yanai, 1978). The 39th Japanese Antarctic Research Expedition (JARE) sent a traverse party to the Yamato Mountains and the Belgica Mountains, which are located 200 km southwest of the Yamato Mountains, in the austral summer season of 1998 in order to collect meteorites and Antarctic micrometeorites (AMMs). This was the first attempt to do a large-scale collection of AMMs at an inland bare ice area. Here we report about the process of collecting AMMs.

2. Collection of AMMs at Meteorite Ice Field

In Antarctica and Greenland, continuous snowfall at the central area of the continent compresses accumulated snow to form thick ice sheets on the bedrock. The ice sheets gradually flow down from inland to coast and then break at the ocean to form icebergs. Where mountains prevent the ice flow to the coast, ice sheets rise up in front of the mountains. As a result, the compressed ice deep inside the ice sheets is exposed to the surface and is consumed by ablation. This is the model for the formation of inland bare ice (Yanai, 1978). Even in summer, temperature rises to less than $-10^{\circ}C$ at the inland bare ice owing to its high altitude. Accordingly, the surface ice never melts, rather it is ablated away because of physical erosion with a strong, constant katabatic wind and sublimation with solar irradiation. Therefore, the situation of the surface layer of the bare ice is never disturbed by ice melt. For this reason, the inland bare ice retains bubbles of ancient atmosphere even at the surface. AMMs in the ice are constantly exposed to the ice surface and blow away once exposed, so that they never accumulate at the surface layer of the inland bare ice, unlike meteorites. The phenomenon described above provide us two advantages for AMM collection compared with bare ice along the shore of Antarctica; preservation of the ancient flux of cosmic dust and an estimation of the age of ice by analysis of gas composition in the bubbles (*e.g.*, Machida *et al.*, 1996).

On the other hand, at bare ice regions along the shore of Antarctic Continent, Maurette *et al.* (1994) reported that an unknown concentration process of AMMs occurs. From the viewpoint of efficient collection of AMMs, it is suitable to perform collection along the shore, but the concentration process disturbs an ancient flux of extraterrestrial dust there. Furthermore, the surface of ice melts due to the temperature rising above $0^{\circ}C$ in summer along the shore of the Antarctic Continent. It results in loss of bubbles containing an ancient atmosphere. That dates the terrestrial ages of AMMs in bare ice there. Besides, terrestrial contamination from exposed bedrock and organic materials of Antarctic lives is far more pronounced near the coast than the inland.

3. Methods

The process of collecting AMMs can be separated into two parts: melting bare ice and filtering melted water (Fig. 3). All of our equipment was set into a tented sledge; therefore we could do the work without being bothered by the strong katabatic wind. Heat sources for melting ice were three boilers originally designed for warming non-freezing liquid circulated in a snow vehicle. In the sledge, non-freezing liquid which is mainly consist of ethylene glycol was circulated by a pump in a closed system; it was composed of the boilers, a storage tank, the circulation pump and a radiator connected by polyvinyl-chloride hoses. The storage tank was made of stainless steel, covered with thermal insulation and 300 liters in volume. We usually stored 250 liters of non-freezing liquid in it during melting ice.

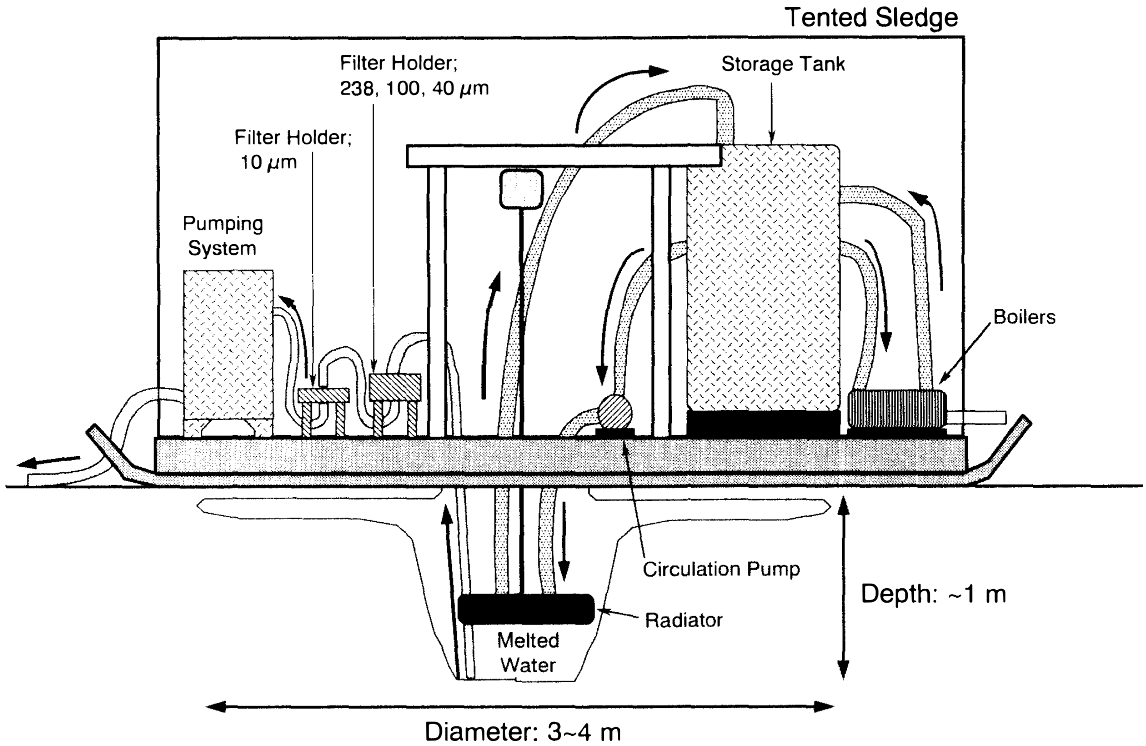


Fig. 3. A figure of the system for collecting AMMs in bare ice. All of the equipment are set inside a tented sledge.

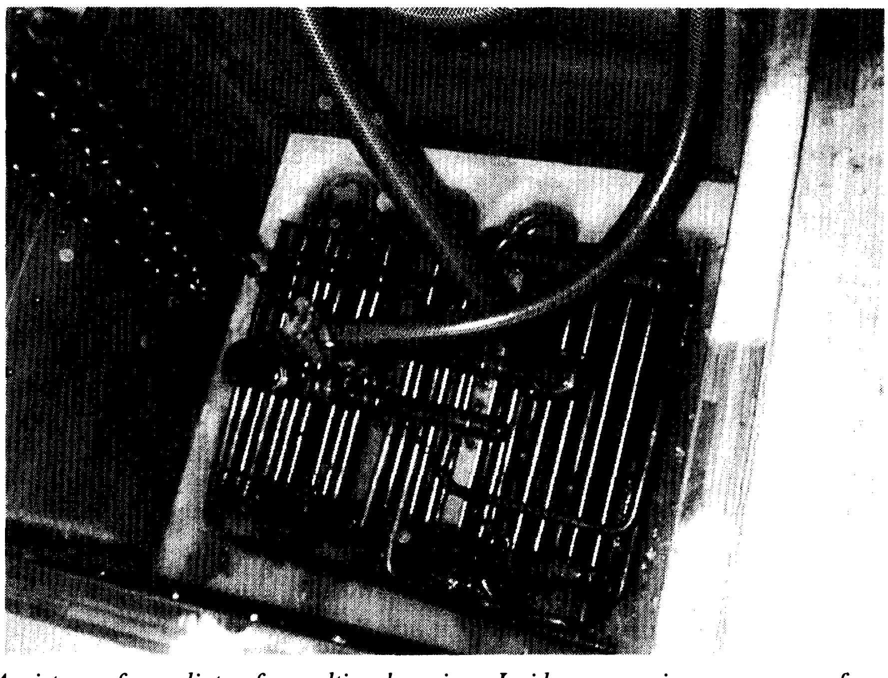


Fig. 4. A picture of a radiator for melting bare ice. Inside copper pipes, warm non-freezing liquid is circulated. Through two polyvinyl-chloride hoses, hot liquid is sent to the radiator and cooled liquid is brought back to the storage tank.

The radiator was made of copper pipes of 19 mm in diameter and stainless steel frames, and was 70×70×20 cm in size (Fig. 4). It was hung under a rail supported by steel frames and was laid on bare ice surface through a square pit equipped at the center of the sledge's floor. A wood hatch was set inside the pit to protect the melted-water-filling pond from the wind and to decrease contaminants blown with the wind (Fig. 4). The radiator laid on the bare ice surface would sink below the ice surface in one hour and form about 1m-depth pond under the sledge in about 6 hours. The shape of the pond was like an "upside-down cowboy hat" (Fig. 3), because water temperature was higher at the surface layer than at the bottom of the pond. The temperature of the melted water was 9.2°C in average, however it depended on weather, especially on wind speed. The temperature of non-freezing liquid in the storage tank was constant within a range from 40 to 50°C and the difference in temperature between outgo and income liquid was ranged from 14 to 20°C.

After pulling up the radiator from the pond, the melted water was filtered to collect particles in the bottom of the pond. First, the melted water was pumped through a Teflon tube to the first filter holder (Fig. 3). Three types of stainless-steel filters whose openings are 238, 100 and 40 μm were set in the first filter holder. Next, the melted water went to the second filter holder with a filter of 10 μm openings. Finally, the filtered water flowed into a tank, which had been suctioned by a vacuum pump, and flowed out from the sledge. The diameter of the filters is 14.2 cm. We could pump and filter only 200 liters of melted water in each pond before it began to freeze about in one hour later. In order to maximize particle collection, we swept water at the bottom of the pond and pumped up most of the particles descending to the bottom. The maximum duration in which the particles contacted with liquid water ranged from 5 to 14 hours because heating duration in each collection point was different (Table 1). New filters were used for new ponds and the used ones were preserved in sealed pouches made of polyethylene one by one. All the filters were kept in frozen condition and delivered to National Institute of Polar Research (NIPR) in Japan.

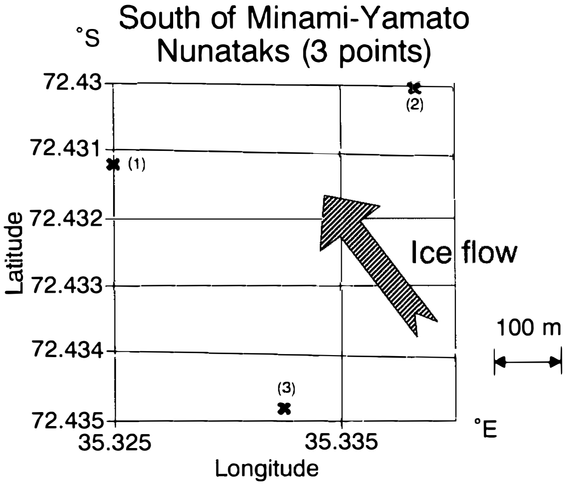
At the end of August 1998, all of the equipment had been tested once at a bare ice region at Tottsuki Point, which is 17 km north-northeast from the Syowa Station, before the departure to the Yamato Mountains traverse. The weather condition was −15°C in temperature with in a wind speed of 10 m/s.

4. Sampling points

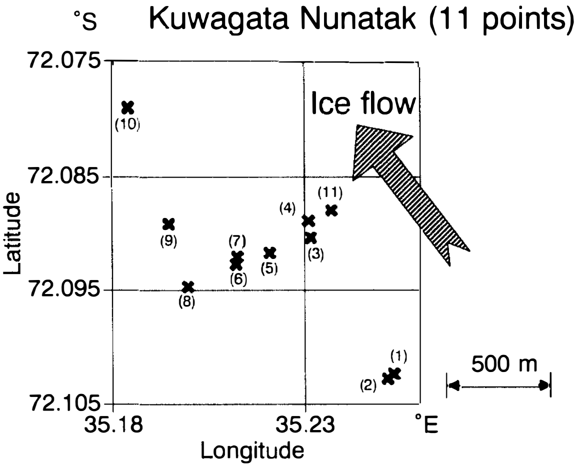
We collected AMMs in three areas of the Meteorite Ice Field around the Yamato Mountains; those were south of Minami-Yamato Nunataks, Kuwagata Nunatak and JARE IV Nunataks (Fig. 2). In the three areas, we accomplished AMMs collection at 24 points; 3 points in south of Minami-Yamato Nunataks, 11 points in Kuwagata Nunatak and 10 points in JARE IV Nunataks (Fig. 5a–c).

1) South of Minami-Yamato Nunataks (72°26′ S, 35°20′ E)

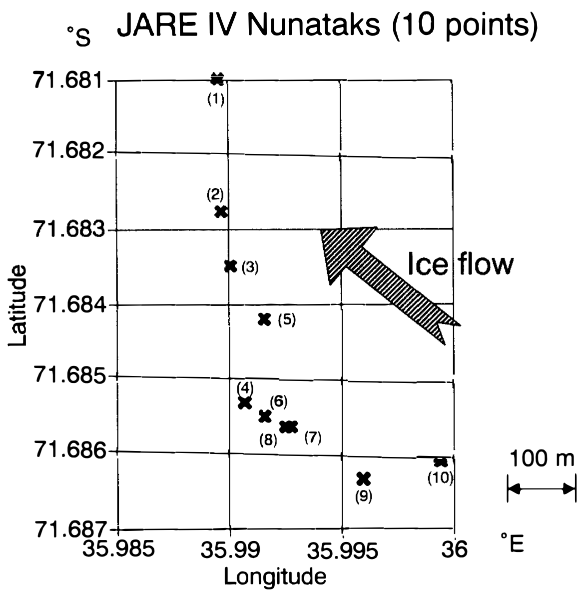
From November 20th to 22nd in 1998, we collected AMMs at 3 points in this



(a)



(b)



(c)

Fig. 5. Field maps of three AMMs collection areas in the Meteorite Ice Field. AMMs' collection points are displayed as symbols in each area of the map. Numbers beside the symbols correspond with the numbers shown in Table 1. Scale bars are shown beside each map. (a) A field map of the south of Minami-Yamato Nunataks area. (b) A field map of the Kuwagata Nunatak area. (c) A field map of the JARE IV Nunataks area.

area (Fig. 5a), 30 km away from the nearest nunatak. The altitude is about 2400 m, the temperature was $-21.1^{\circ}C$ and the wind speed 13.6 m/s. In this section, temperatures and wind speeds are averages of values at 0730 AM and 0730 PM (sometimes 0800 PM) during the works.

2) Kuwagata Nunatak (72°06′ S, 35°15′ E)

From December 3rd to 9th in 1998, we collected AMMs at 11 points in this area (Fig. 5b), 2 km southwest from the most southern nunatak in Meteorite Ice Field, Kuwagata Nunatak. This area is located on side flow of ice sheet avoiding the nunatak. The altitude is about 2200 m, the temperature was $-19.6^{\circ}C$ and the wind speed 13.2 m/s.

3) JARE IV Nunataks (71°41′ S, 35°59′ E)

From January 5th to 11th in 1999, we collected AMMs at 10 points (Fig. 5c). This area is about 50 km away to north-northeast from Kuwagata Nunatak and on

Table 1. Heating duration and estimated weight of melted ice at each AMMs' collection point.

Collection point	Heating duration	Weight of ice (tons)
Tottuki Point (test)	9hours40minutes	2.02
South of Minami-Yamato Nunataks 1	4h45m	0.99
2	5h20m	1.11
3	4h30m	0.94
Kuwagata Nunatak 1	10h	2.09
2	4h25m	0.92
3	9h55m	2.07
4	5h25m	1.13
5	12h55m	2.7
6	5h55m	1.24
7	12h45m	2.66
8	6h	1.25
9	9h45m	2.04
10	6h20m	1.32
11	9h15m	1.93
JARE IV Nunataks 1	9h45m	2.04
2	7h15m	1.52
3	4h40m	0.98
4	6h20m	1.32
5	6h50m	1.43
6	5h15m	1.1
7	6h30m	1.36
8	7h	1.46
9	5h30m	1.15
10	5h	1.04
Total (without Tottuki)	171h20m	35.79

the upper side of ice flow against the JARE IV Nunataks. The altitude is about 2100 m, the temperature was $-16.1°C$ and the wind speed 11.4 m/s.

Table 1 shows duration of ice melting and estimated weights of melted ice in each point. In the table, the weight of melted ice at the Tottuki Point was calculated from the measured size of the pond. From the data of the Tottuki Point, this equipment can melt ice with a rate of 0.21 t/hour; the weights for the other sites were calculated based on this ice-melting rate. This estimation indicated that we have melted about 36 t of ice in total for this work (Table 1).

In the Meteorite Ice Field, the katabatic wind direction is mainly from east-southeast and ranges within $\pm 30°$. The directions of ice flow shown in Fig. 5 almost overlap with the katabatic wind direction. In the direction of the katabatic wind, no mountains or nunataks exist within the south of Minami-Yamato Nunataks and the Kuwagata Nunatak area. Only the JARE IV Nunataks area is located at the downstream of both the katabatic wind and the ice flow coming from the Motoi Nunatak.

5. Concluding remarks

We collected AMMs from 36 t of bare ice of Meteorite Ice Field of the Yamato Mountains, Antarctica in the austral summer season of 1998.

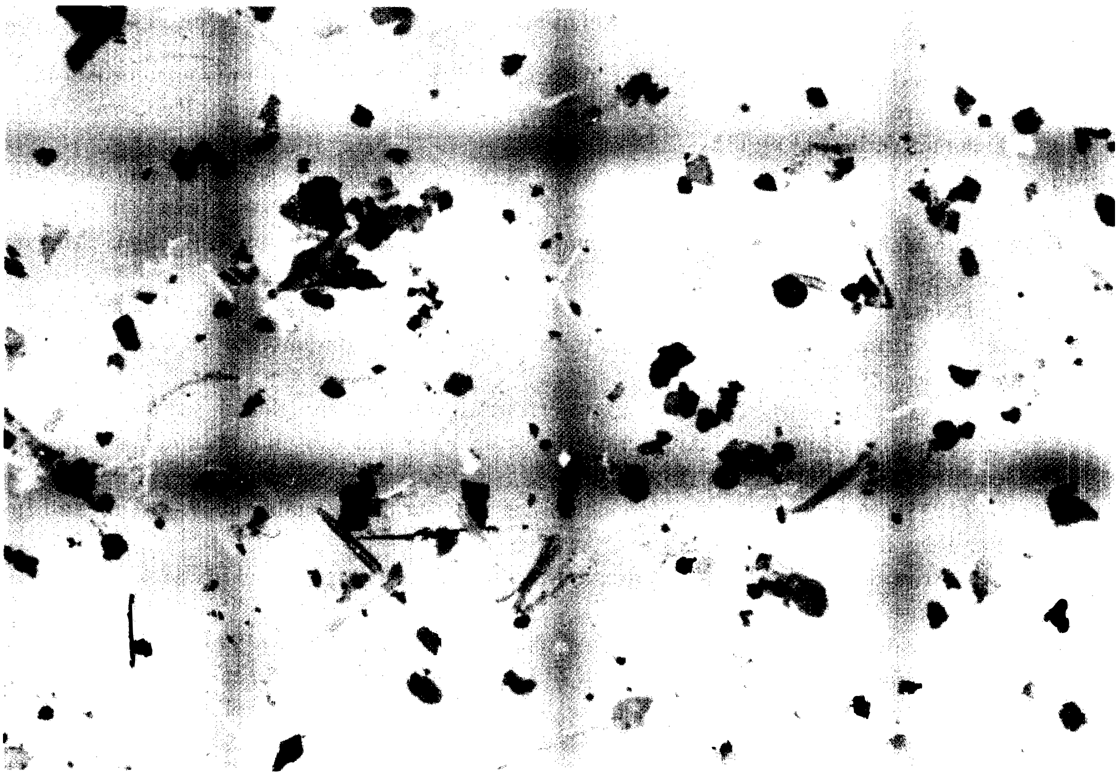


Fig. 6. A stereo microscope image of particles captured on a filter of 40 μm in openings, sampled at Kuwagata Nunatak 1. Vague blue meshes shown in background of the particles are 1-mm interval. Black spheres and irregular black particles with dull surface are possibly AMMs.

A stereo microscope image of particles on one of the filters with openings of 100 μm is displayed in Fig. 6. We can observe possible AMMs under a stereo microscope, which suggests that the collection has been very successful.

AMMs less than 50 μm in diameter are important because they overlap interplanetary dust particles (IDPs) from stratosphere in size, but are mineralogically and isotopically distinct from IDPs (Brownlee *et al.*, 1982; Engrand and Maurette, 1998; Engrand *et al.*, 1999). In this work we used a filter whose openings were 10 μm, in the hope of identifying AMMs similar to IDPs. To date, the collected samples are receiving preparation for curation in NIPR, Japan.

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