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Antarctic micrometeorite collection at a bare ice region near Syowa Station by JARE-41 in 2000

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Abstract: We collected Antarctic Micrometeorites (AMMs) at a bare ice field near Syowa Station in the austral fall and spring seasons of 2000. The facility for the AMMs collection introduced by the 39th Japanese Antarctic Research Expedition (JARE-39) was improved to increase the filtering rate of the melt water. The filtering rate became 4–5 times quicker than the previous system, ~1000 liter/hour, by the addition of a new water pump in parallel with the previous pump. About 50 tons of melt water were formed, of which about 40 tons were filtered using this new system, and 18 holes were made in the bare ice region in 23 days. We obtained particles in which abundant micrometeorites should be included.

1. Introduction

Cosmic dust (less than ~1 mm) is believed to contain independent information of the planetary system formation which cannot be deduced from other extraterrestrial materials. Due to their small size, it is easy for then to reach the Earth from various planetary bodies from a dynamical point of view (Brownlee *et al*., 1997). On the other hand, it has also been suggested that cosmic dust collected in the stratosphere (Interplanetary dust particles: IDPs) originates from very limited sources in the asteroid belt (Kortenkamp and Dermott, 1998). Even if this is not taken into account, it is naturally expected that some cosmic dust originates from comets. The flux of cosmic dust to the Earth may be higher than that of meteorites, which is estimated to be 4×10^4 tons/year from the number of craters formed by the hypervelocity impact of dust on the surface of artificial satellites (Love and Brownlee, 1993).

There are two main sampling sites of cosmic dust: one is on the surface of the Earth such as in polar ice or in deep sea sediments, and the other is above the surface of the Earth such as in the stratosphere (Brownlee, 1985). 100–200 μm-sized particles, usually the commonest size fraction in cosmic dust, are collected on the surface of the Earth but not in the stratosphere (Brownlee, 1985; Maurette *et al*., 1987). Cosmic dust collected from polar ice are called micrometeorites (MMs), are less altered than those from deep sea sediments, and contain various kinds of dust including unmelted particles which escaped frictional heating during atmospheric entry (*e.g.*, Maurette *et al*., 1987). Antarctic micrometeorites (AMMs) are less contaminated with Earth materials compared with MMs from Greenland (Maurette *et al*., 1991). Different from IDPs, MMs are much more abundantly collected and include much larger particles than IDPs.

AMMs were collected at a bare ice region (Cap Prudhomme) near the French Station (Dumont d'Urville) in 1988 (Maurette *et al.*, 1991) and at the South Pole in 1995 (Taylor *et al.*, 1998). The former collection is performed at a coast range and the latter collection is carried out at several tens meter depth ice-melted water well in inland area. Vigorous studies of AMMs have been carried out by many researchers (*e.g.*, Maurette *et al.*, 1991; Kurat *et al.*, 1994; Genge *et al.*, 1997). In a bare ice region around the Yamato Mountains, where there is a meteorite concentrated field, a systematic collection of AMMs was conducted by the 39th Japanese Antarctic Research Expedition (JARE-39) during 1997–1999 (Yada and Kojima, 2000). Terada *et al.* (2001) estimated that ~5000 AMMs, which are larger than 40 μm and collected from the melt water of ~36 tons of ice, were recovered during JARE-39. Prior to this collection, ~230 AMMs were successfully recovered from the water tank used for daily life at Dome Fuji Station, located on the top of the Queen Maud Land (77°19′01″S, 39°42′12″E, 3810 m height) during the JARE-37 (1995–1997) and JARE-38 (1996–1997) expeditions (Nakamura *et al.*, 1999; Noguchi *et al.*, 2000). AMMs from Dome Fuji Station are derived from recent snow, several tens of years old.

Following the previous JARE collections, a party of 3 or 4 men from the wintering members of JARE-41 (1999–2001) tried to collect AMMs at another sampling site, a bare ice region near Syowa Station, using the improved JARE-39 facility. This AMM collection from the coastal range may be more comparable to that of the French expedition at Cap Prudhomme (Maurette *et al.*, 1991) rather than that of JARE-39 at a bare ice region around the Yamato Mountains (Yada and Kojima, 2000). In the present study, we intended to collect a smaller size fraction of AMMs (10–40 μm). We planned to filter all of the melt water and to monitor the volume of filtered water using a water meter. In addition, to consider the physical and chemical conditions of the ice containing the AMMs, Global Positioning System (GPS) observations, weather observations and measurements of sublimation rates at the bare ice surface were performed. It is believed that the new collection will play an important role for the clarification of the petrogenesis of AMMs. Here, we present a preliminary report about the procedures and results of the AMMs collection by JARE-41 in 2000.

2. Sampling points

In the coastal regions of Lützow-Holm Bay, bare ice regions are widespread on the continental ice sheet below an altitude of ~500 m (Watanabe, 1978). The ice was made by the compaction of snow that fell in accumulation areas such as the Mizuho Plateau and flowed towards the coastal regions. The snow is blown off by strong wind and so does not accumulate in the region. In addition, ice sublimates by the wind and the elevated temperatures in the summer seasons melts the ice. Thus the bare ice is constantly exposed at the edge of the ice sheet along the coastline.

We collected AMMs at a bare ice region near Tottuki Point on the Sôya Coast (Fig. 1). The sampling sites are located ~17 km away from Syowa Station around a point called N7 (68°55.3′S, 39°51.0′E) on the Tottuki Point–S16 route, where S16 corresponds to the starting point of the inland trip. N7, was situated on the plateau (~1.5 km inland

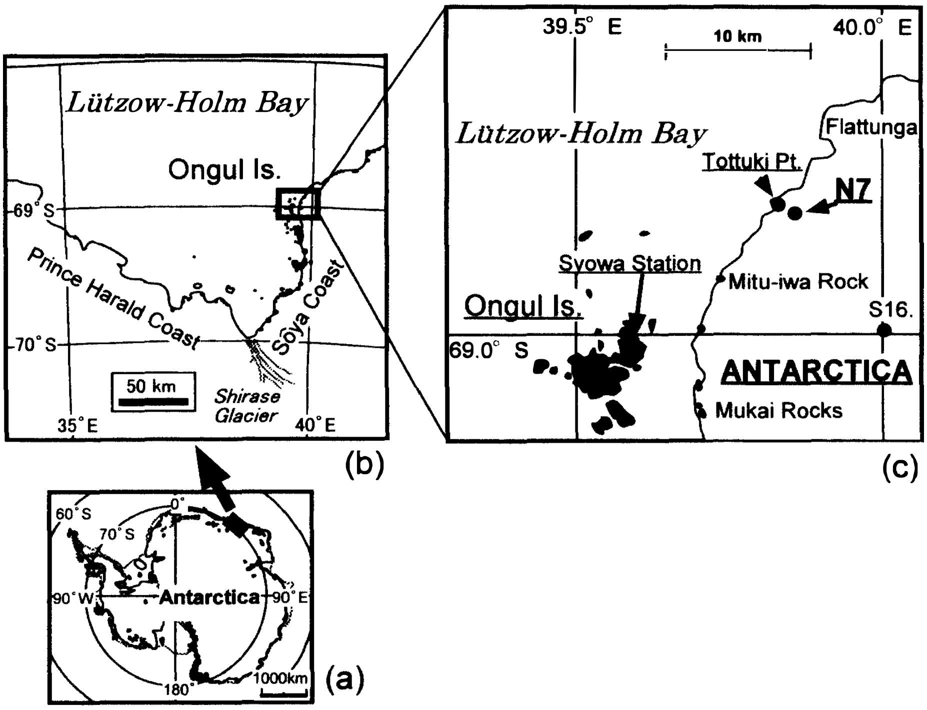

Fig. 1. (a) A map of the Antarctic continent. (b) An enlarged map of the northeastern part of the Lützow-Holm Bay. (c) A close-up map of the bare ice region around the Tottuki Point.

from the coastline at an elevation of ~140 m) on the coastal ice-sheet slope, and was sufficiently away from the source of terrestrial materials (moraines).

The plateau around the N7 area was relatively large (~500 m × ~500 m) compared with other bare ice areas in this region. Thus, it was considered that this plateau was a suitable place for the collection of AMMs, though large amounts of small (width=1–2 cm) cracks occurred on the ice surface at the sampling sites. The majority of these cracks were filled with apparently fresh ice that might have crystallized from ice/snow melt water. Since these cracks may cause the outflow of melt water during the AMM collection experiment, we carefully searched for crack-free ice surfaces at the sampling location before the tented sledge was set up for AMMs collection.

3. Facilities

Figure 2 shows schematic illustration of the facility for the collection of AMMs. The facility used in the present experiment was first developed by JARE-39 and details of this system have been reported by Yada and Kojima (2000). During our experiment, we improved the previous facility and used the modified facility after the 1st trip of 5 trips.

The collection procedure was divided into two parts: melting of ice and filtering of the melt water. Ice on the surface of the bare ice field was melted by a radiator of copper pipe with a fin (765 × 765 × 200 mm, 39 kg) that was suspended by a chain block. The radiator was heated by circulation of a warm non-freezing liquid (60% ethylene glycol solution). The non-freezing liquid was stored in a storage tank (~270 liter:

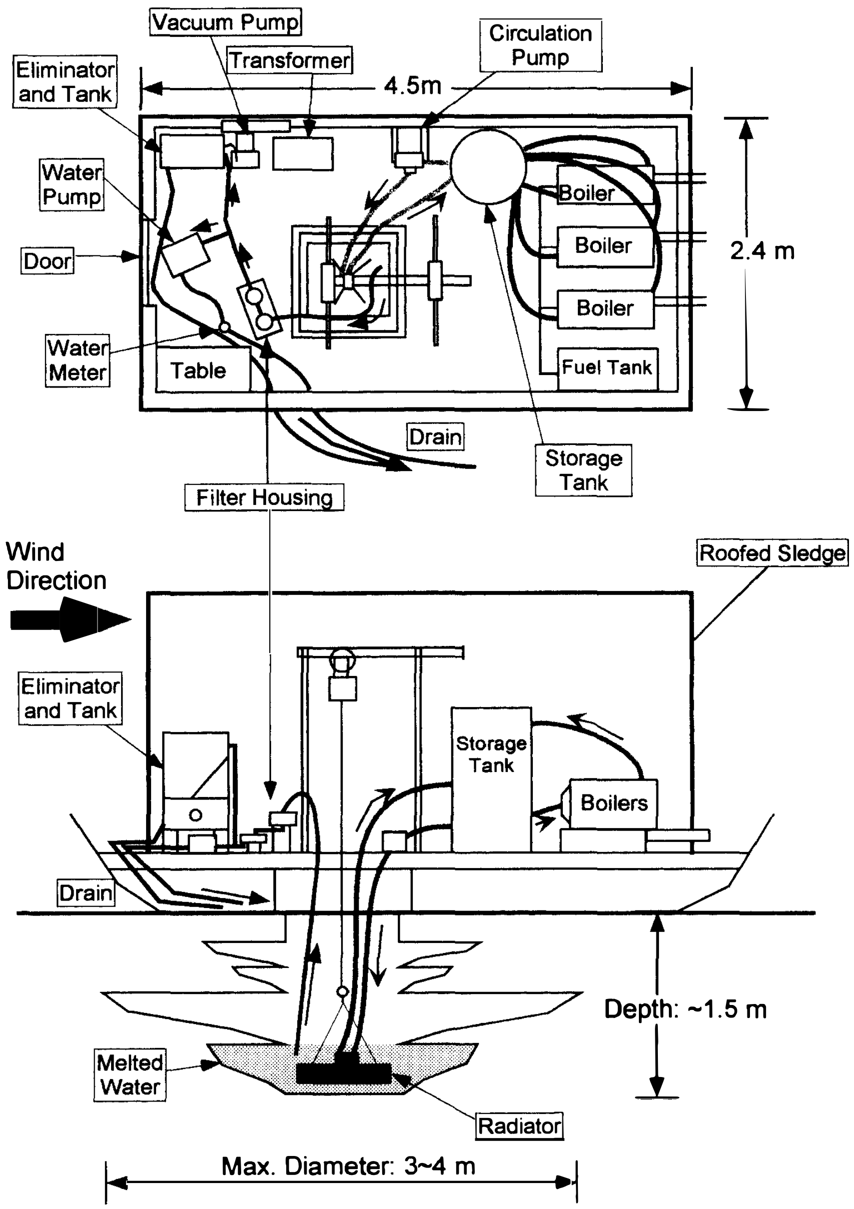

Fig. 2. Schematic illustration of the improved facility for AMMs collection in JARE-41. Upper figure indicates top view and lower figure indicates side view of the sledge.

Fig. 2) and heated by three boilers (Mikuni, 160 WHK) which were connected to the storage tank by plastic hoses. The non-freezing liquid was circulated by a water pump between the radiator and the storage tank, at the same time, the liquid was circulated by small built-in water pumps of the boilers between the storage tank and the boilers. The melt water was pumped up from a pond and was sieved by four filters made by stainless steel (diameter: 14.2 cm) in a filter housing unit to collect particles in the water. The stainless steel filter housing unit consists of two filter holders. Three stainless steel filters whose openings are 40, 100 and 238 μm were stacked in the first holder. The second holder with a filter of 10 μm openings was connected to the first holder by a Teflon tube

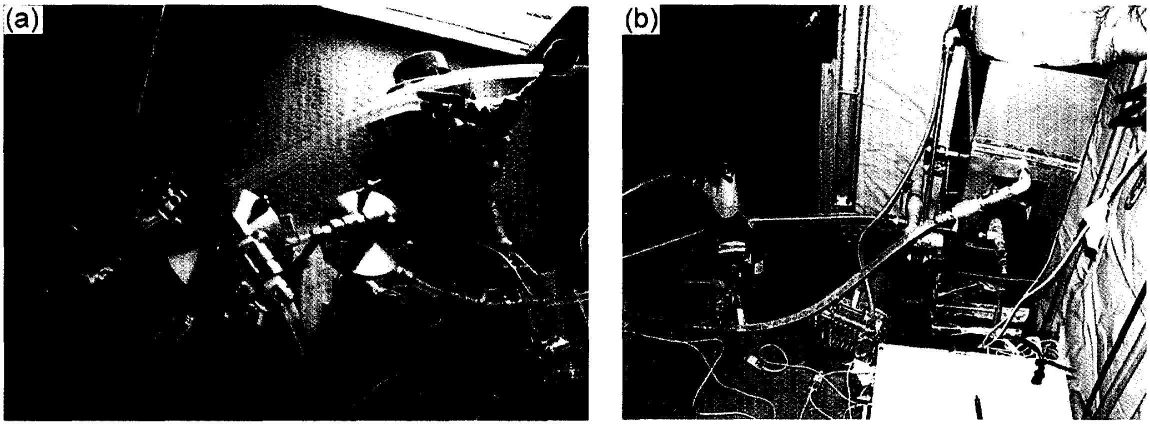

Fig. 3. (a) Picture of a filter housing and a black water pump. Teflon tube from the melt water pond was connected to the filter housing. A water meter was connected to the drainage from the water pump. (b) Picture of the water pump and vacuum pump-water/air eliminator-water tank connection. In front of the water pump, a valve was connected in order to change the pump for water drainage. The large silver colored box was divided into two parts: upper water/air eliminator and lower water tank.

with an inner diameter of 3/4 inch (Fig. 2 and Fig. 3a). A set or two sets of these four filters were used during each experimental trip.

In the previous system, the filtering of melt water was carried out only by a vacuum pump connected to a water tank through a water/air eliminator, so the water filtering rates were limited to about 200 liter/hour. Since this rate was insufficient to filter all of the melt water, precipitated particles were recovered mainly from the bottom of the pond. Volume of the filtered water was estimated to be about 10% of all of the melt water. Terada *et al.* (2001) indicated that the amount of irregularly-shaped unmelted AMMs smaller than 100 μm were scarce relative to that of round spherule AMMs in the JARE-39 samples. They pointed out the possibility that the irregularly shaped AMMs experience greater friction within the melt water and so they may take a longer time to settle to the bottom of the pond. Thus, in comparison with spherules, unmelted AMMs might have been less efficiently collected.

In order to clarify the above hypothesis, it was essential to filter all of the melt water in our experiment. Thus, to increase the rate of filtering, we connected a water pump in parallel with the previous pump line after following the advice of by Dr. T. Yada (Fig. 2 and Fig. 3). The water pump has a large drainage rate, and so it worked effectively for pumping out large amount of melt water in deep ponds. On the other hand, vacuum pump has small drainage speed, but can pump out air mixed water from shallow melt water ponds. Actually, these two types of pump were used alternatively depend on the depth of melt water pond. As a result, the rate of filtering in the new system became 4–5 times quicker than that of the previous system, ~1000 liter/hour, and was capable of filtering all of the melt water. In addition, to estimate the volume of filtered water accurately, we installed a water meter to the drain of the water pump (Fig. 2 and Fig. 3).

4. Procedure

The typical daily procedure of AMM collection was as follows. First, ~270 liter of the non-freezing liquid was heated by the three boilers and stored in the large storage tank in the early morning (around 08:00). When the temperature of the non-freezing liquid reached to about 40°C, the non-freezing liquid was circulated between the radiator, the storage tank and the boilers. The warm radiator melted the ice and caused a melt water pond in the ice. At the beginning of the ice melting, melt water was pumped up using the vacuum pump. Usually, the duration of this pumping was shorter than 15 min. The radiator was suspended on the ice surface or in the melt water pond for several hours and continuously melted the bare ice. When the pond was filled with melt water, the water pump was used for filtration. In the late afternoon (around 17:00), we raised the radiator up from the water pond, and continued the pumping until the pond had dried up. We often stirred the melt water pond using a copper pipe and swept the upper part of the radiator with a plastic brush before pumping, in order to minimize the amount of descended particles on the ice surface in the pond and on the radiator. Typical duration of heating was about eight hours in a day. Filtering by the water pump was performed 2–3 times within a day, which was different from the case of JARE-39 (one time at a sampling point; Yada and Kojima, 2000), in order to reduce the damage of sudden melt water leakage.

Melt water often leaked from the melt water pond through small hidden cracks of bare ice during the experiments and so part of the water could not be sieved. When the water leakage occurred, we moved the AMM facility on the sledge to another sampling point. Sometimes, the water leakage stopped by itself and made pockets in the melt water pond. If that happened, we continued the melting process using the same melt water pond.

Duration of pumping by the water pump varied from 5 min to ~170 min depending on the volume of the melt water. Typical duration was 30–60 min. The shape of the pond formed by JARE-39 was like an upside-down cowboy hat (Yada and Kojima, 2000). On the other hand, in the present case it was like a stack of 3–5 upside-down cowboy hats with various diameters (Fig. 2). Maximum depth of the pond was ~1.5 m and maximum diameter of the pond was ~4 m (Fig. 2). The temperature of the melt water ranged from 5–50°C depending on the volume of the water. Drained water was directed into a crack several meters away from the AMM sledge to avoid recycling the filtered water.

5. Results

5.1. AMM collections

Five experimental trips were carried out during the austral fall and spring seasons in 2000 (Table 1). Results of the AMM collection are summarized in Table 1. The first trip, between April 10–15, was the practice run for the AMM collection during JARE-41. We searched for a suitable sampling site on the bare ice region around point N7 and tested the efficiency of the new water pump. Since several problems with the sampling facility occurred during this trip, we modified the facility at Syowa Station between the

Table 1. Results of AMM collection by JARE-41.

Hole No.	Date	Position	Volume of filtered water (liter)	Filter No.	Heating duration (h: hour, m: minute)	Estimated volume of lost water (liter)
First trip: April 10 – 15						
1-1	Apr., 12	South of N7	0	1	50 m	300
1-2	Apr., 12	South of N7	0	1	2 h 20 m	700
1-3	Apr., 13	South of N7	0	1	2 h 30 m	800
1-4	Apr., 13-14	North of N7	913	1	7 h 20 m	1,400
Second trip: April 26 – May 6						
2-1	Apr., 27	68°55.195'S, 39°51.467'E	1,966	2	6 h 10 m	0
2-2	Apr., 28	North of N7	1,524	2	6 h 00 m	300
2-3	May, 1	North of N7	242	3	1 h 20 m	200
2-4	May, 1-2	North of N7	3,152	3	10 h 00 m	0
2-5	May, 3	North of N7	10	3	1 h 20 m	400
2-6	May, 3	North of N7	247	3	1 h 30 m	200
2-7	May, 4	North of N7	270	3	1 h 40 m	200
2-8	May, 4-5	North of N7	3,460	3	13 h 20 m	700
Third trip: August 14 – 19						
3-1	Aug., 15	68°55.268'S, 33°51.233'E	88	4	2 h 00 m	500
3-2	Aug., 15	North of N7	0	4	50 m	300
3-3	Aug., 15-16	North of N7	590	4	4 h 30 m	800
3-4	Aug., 16-18	68°55.202'S, 39°51.261'E	5,367	4	19 h 00 m	0
Fourth trip: September 11 – 16						
4-1	Sep., 11-12	68°55.240'S, 39°51.212'E	1,377	5	6 h 40 m	700
4-2	Sep., 12-13	68°55.236'S, 39°51.251'E	1,389	5	5 h 00 m	200
4-3	Sep., 13-15	68°55.246'S, 39°51.292'E	8,813	5	27 h 30 m	0
Fifth trip: September 18 – 23						
5-1	Sep., 18-20	68°55.245'S, 39°51.288'E	5,760	6	21 h 10 m	800
5-2	Sep., 20	68°55.241'S, 39°51.285'E	22	6	10 m	50
5-3	Sep., 20-22	68°55.232'S, 39°51.201'E	4,515	6	18 h 00 m	1,100
Total			39,705		159 h 10 m	9,650

N.B.

Detailed positions were measured by a handy GPS receiver.

first and second trips. We filtered 913 liters of melt water and obtained a set of filters. We had planned two trips between April 24–April 29 and May 1–May 6, but a severe blizzard in Lützow-Holm Bay prevented us from leaving Syowa Station. As a consequence, we replaced two one-week trips into a ten-day trip to avoid a reduction of work time. The second trip took place from April 26 to May 6. However, another blizzard during April 29 to 30, meant we could only worked for 10 days. During this trip, the improved AMM facility worked well. We filtered 10871 liters of melt water and obtained two sets of filters. On the third trip, from August 14 to 19, we had no severe trouble. We filtered 6045 liters of melt water and obtained two sets of filters. The fourth trip took place between September 11–16. On the last experimental day of this trip, the water meter was accidentally broken. Although we could not measure the volume of filtered water directly, we estimated the volume by the relationship between the water flux and the filtering duration measured by our previous trips. We filtered 11579 liters of melt water and obtained a set of filters. On the last trip, between September 18–23, we filtered 10297 liters of melt water and obtained a set of filters.

We estimated that the total amount of filtered water was 39.7 tons, from the 18 holes during 23 days. The data of the AMM collection experiment is summarized in Table 1. Based on the duration of ice melting and the volume of filtered water from four water leakage-free ponds (holes nos. 2-1, 2-4, 3-4 and 4-3), we could estimate an average rate of ice melting, ~310 liters/ hour. Using this rate, we could estimate the amount of water

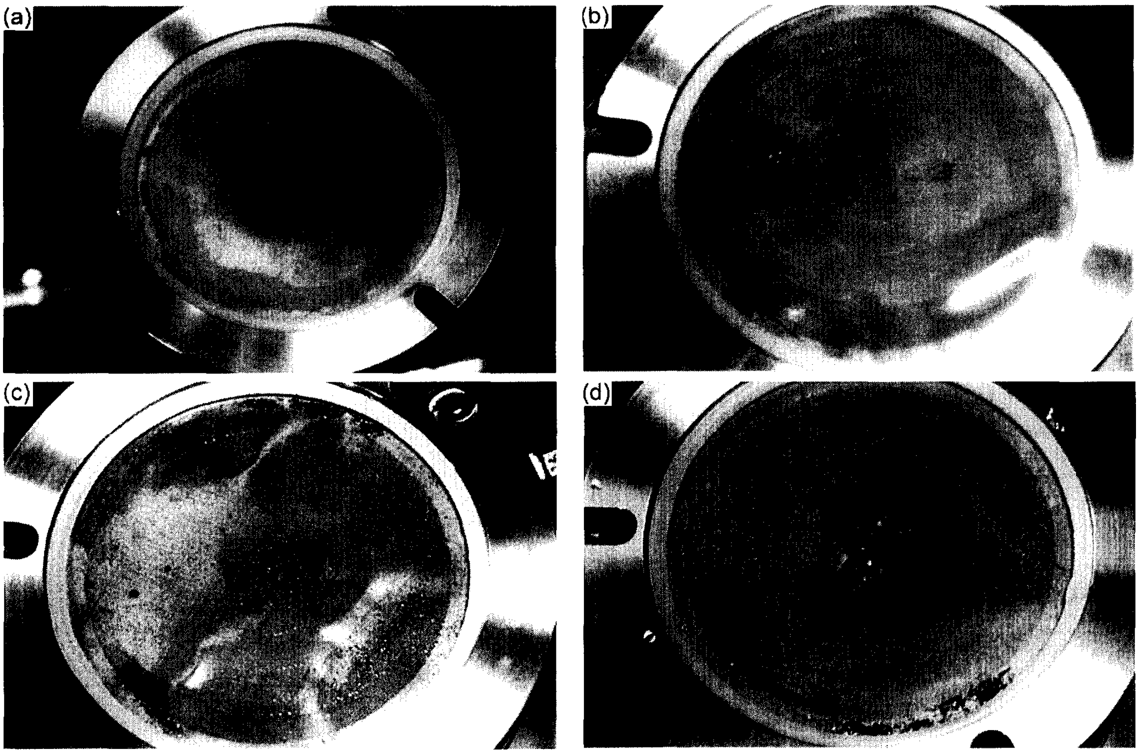

Fig. 4. Photographs of a set of obtained filters (Filter No. 6). Openings of filters are (a) 10 μm, (b) 40 μm, (c) 100 μm and (d) 238 μm, respectively.

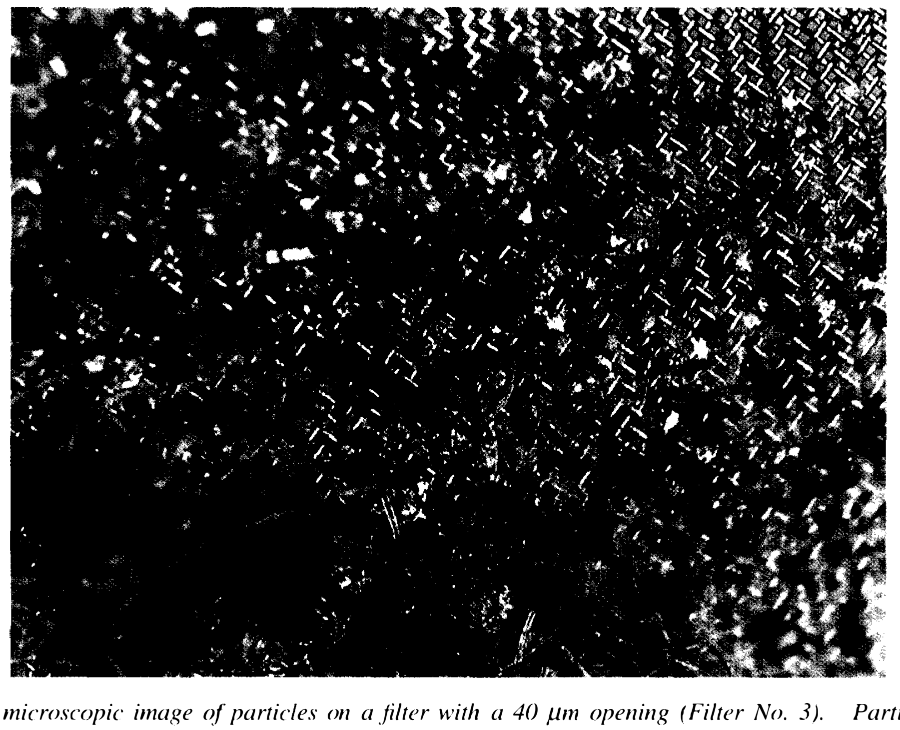

Fig. 5. A microscopic image of particles on a filter with a 40 μm opening (Filter No. 3). Particles on the filters include not only possible AMMs, but also terrestrial materials, fibers and artificial materials.

that couldn't be filtered from each melt water pond (Table 1). The total amount of lost water was calculated as ~10 tons.

Water leakage from cracks did not occur during the AMM collection at the bare ice field around the Yamato Mountains during JARE-39 (T. Yada, personal communication). On the other hand, Maurette *et al.* (1994) reported the presence of many open microcracks at Cap-Prudhomme, but did find areas where the ice was not full of the cracks. Although we have no strict reason why these small cracks occur, we speculate that their presence resulted from the fluctuation of ice flow direction at our sampling site.

After sampling, the filter housing was opened at Syowa Station, and the stainless steel filters containing the particles were dried off, and sealed in polyethylene bags. Fig. 4 shows pictures of some of the obtained particles on a set of filters and Fig. 5 shows an example of a microscopic picture of obtained particles on filter No. 3 with 40 μm openings. They were kept at room temperature during their transportation from Syowa Station in Antarctica to the Antarctic Meteorite Research Center (AMRC) of the National Institute of Polar Research, Japan.

5.2. *GPS observation and the ice sublimation experiment*

To recognize the physical and chemical conditions of the ice surface around the AMMs sampling sites, Global Positioning System (GPS) observations, weather observations, and measurements of the sublimation rate of the bare ice surface were thus performed during the collection of the AMMs. These data may provide information about unknown AMM concentration effects which were reported by Maurette *et al.* (1994), and the age of the ice which has flowed from inside the Antarctic continent.

GPS observations were carried out during the AMM sampling at point N7 in order to determine ice sheet movement around the AMM sampling points. These observations were performed by the relative positioning method between Syowa Station and N7. Results of these observations indicate that the horizontal position of N7 has moved ~2.2 m in a WNW direction and has been lifted up by a few centimeters during 145 days from April to September, 2000. Weather observations were carried out using an Automatic Weather Station (MAWS of Vaisala). Temperature, humidity, wind speed, wind direction and air pressure were measured during the experimental period (See Appendix). The rate of ice sublimation was measured from the direct measurement of the change in the stake length. About 2.1 cm of sublimation was observed during 160 days from April to September, 2000. Average sublimation rate was estimated as 12.0 mg cm^{-2} day^{-1}. On the other hand, using the weather data, we can calculate the average sublimation rate by the empirical formula method (Fujii and Kusunoki, 1982) as 100.9 mg cm^{-2} day^{-1} during this period.

5.3. *Estimation of ice age*

Since the age of the ice, which includes the AMMs, may be related to the alteration of the AMMs (Terada *et al.*, 2001), the estimation of ice age is important. The age of the ice at Cap-Prudhomme, a French AMM collection site (*e.g.* Maurette *et al.*, 1991), is estimated as ~50000 years (Maurette *et al.*, 1994). In contrast, ages of the ice around the Yamato Mountains, the locality of the JARE-39 sampling sites (Yada and Kojima, 2000), were estimated as ~30000 years for the Kuwagata Nunatak area (Terada *et al.*, 2001) and

~50000 years for the JARE-IV Nunataks area (Azuma *et al.*, 1985). These ages were estimated on the basis of the oxygen isotope data of the ice combined with the data of ice movement. This kind of data, however, was not obtained for the ice from the Tottuki Point area. Thus, the exact age of the ice in the sampling site is still unknown.

5.4. Weighing, storage and curation of obtained samples

For the convenience of sample handling, the majority of the particles were removed from the stainless steel filters and were placed on Millipore filters at the AMRC of NIPR.

The sample transfer was carried out in a clean room (class 10000). Particle transportation took place as follows: (1) the stainless steel filter was washed carefully with distilled water, and the water that contained the particles was stored in a glass beaker. (2) the water which contained the particles was filtered through a Millipore filter (25 mm in diameter with a pore size of 1.2 μm or 47 mm in diameter with a pore size of 0.8 μm) using a vacuum filter holder. However, some of the particles remained on the stainless steel filters after washing by distilled water. To collect them, ultrasonic treatment of the filter in distilled water proved to be effective. The ultrasonic treatments have been performed for selected stainless steel filters.

Table 2. Weights of obtained particles in this AMM collection.

Filter No.	Volume of filtered water (liter)	Weight of particles (mg) 10-40 μm	40-100 μm	100-238 μm	238 μm <
1	913	6.16 ± 0.06	*27.20 ± 0.08	*62.79 ± 0.04	66.56 ± 0.03
2	3,490	1.77 ± 0.07	6.94 ± 0.05	8.11 ± 0.02	14.61 ± 0.03
3	7,381	2.33 ± 0.08	5.68 ± 0.08	15.82 ± 0.08	58.24 ± 0.09
4	6,045	2.06 ± 0.06	7.96 ± 0.11	17.23 ± 0.09	35.79 ± 0.08
5	11,579	10.86 ± 0.10	30.72 ± 0.03	28.37 ± 0.29	39.91 ± 0.04
6	10,297	10.15 ± 0.13	32.75 ± 0.06	40.55 ± 0.14	88.25 ± 0.09

N.B.
* Weights of particles on two filters, 40–100 μm and 100–238 μm of Filter set No.1, include the weights of particles that were recovered by ultrasonic treatment.

Subsequently, the weights of the obtained particles were measured (Table 2). Some fractions of the particles remained on the stainless steel filters during the replacement, and the weighed particles comprised not only micrometeorites but also terrestrial materials, fibers and artificial materials. Thus, the weights shown in Table 2 do not represent AMM weights only. We estimate that the weights in Table 2 contain errors of 0.1–20%, incurred mainly during the weighing of the petri dishes.

The obtained particles are now stored at the AMRC. Later, the micrometeorite working group in Japan will carry out the initial preparation of the collected samples. Filter set No. 4 will be distributed to members of the group and separation of the AMMs will begin.

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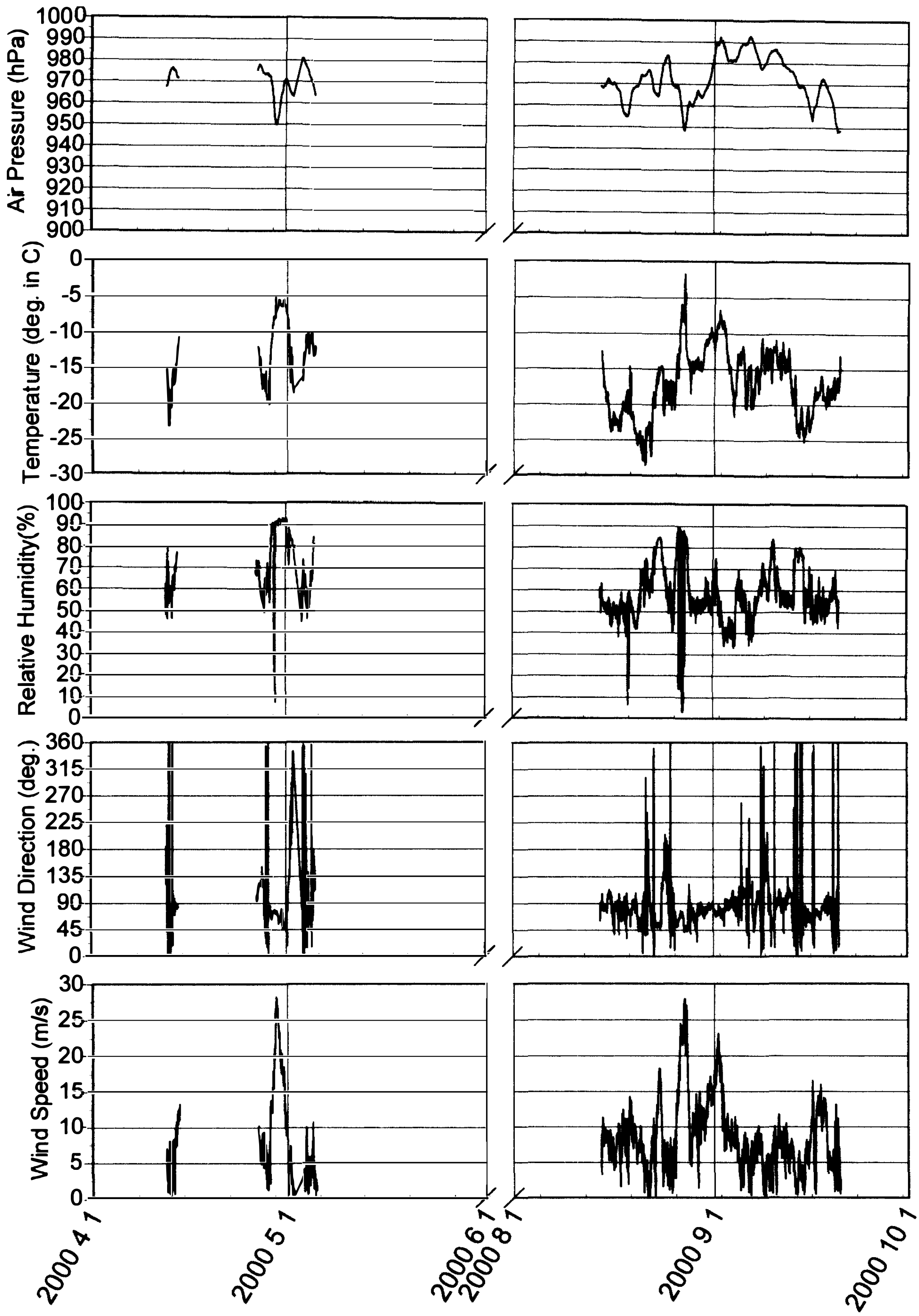

Fig. A-1. Weather condition at point N 7. Air pressure, temperature, relative humidity, wind direction and wind speed at point N 7 are shown for the austral fall (left panels) and spring (right panels) season of 2000.