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Statistical properties of the Transantarctic Mountains (TAM) micrometeorite collection

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Abstract

Micrometeorites have been recovered from traps located at the summit of nunataks in the Transantarctic Mountains (TAM), Antarctica. They constitute the TAM micrometeorite collection. Micrometeorites accumulated by direct infall for hundreds of thousands of years. This long collection duration is confirmed by the wide range of weathering by dissolution of olivine in the stony micrometeorites from the TAM collection. A statistical study of the size distribution and frequency by type of this collection, and comparison with other Antarctic micrometeorite collections (the South Pole Water Well collection and the Walcott Névé collection), suggest that the TAM collection is essentially unbiased. Thanks to the very long exposure of the traps, large diameter (>1000 μm) micrometeorites are present in sufficiently large numbers to allow a statistically meaningful estimate of their size distribution in this size range for the first time. We found that the slope of the size distribution remains constant in the 100−1600 μm size range. Therefore, the size distribution of micrometeorites in this size range is controlled by a single process.

Keywords: Antarctica; Micrometeorites; Size distribution; Weathering

1. Introduction

Micrometeorites are terrestrially collected extraterrestrial particles smaller than about 2 mm (Taylor et al., 2007). They constitute the main part of the mass flux of extraterrestrial matter accreted on Earth (Love and Brownlee, 1993; Taylor et al., 1998). Micrometeorites can be recovered from any terrestrial surface provided that the accumulation time is sufficient, weathering is low, and discrimination from terrestrial particles is feasible. Studied collections comprise samples taken from deep-sea sediments, seasonal lakes in Greenland, Antarctic eolian sedimentary traps, ice and snow, and continental sands (see review in Taylor and Lever, 2001; Duprat et al., 2007). Thanks to the very dry climatic conditions and the limited contamination by industrial or volcanic particles, Antarctica is one of the most productive areas for the recovery of micrometeorites. However, concentration processes or sampling methods can introduce biases in the collections. In order to study the influx of extraterrestrial matter to the Earth in terms of mass and composition, it is necessary to avoid these biases, or at least to quantify them. Biases in the particles' size in collections

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can be evidenced with the study of the size distribution of micrometeorites. The exponent factor of the cumulative size distribution allows to estimate potential deficits by comparison with the least biased collections. Biases in the composition of the flux can be evidenced by a study of the frequency by type of melted micrometeorites (cosmic spherules), and with the ratio of unmelted to melted micrometeorites.

Rochette et al. (2008) reported the discovery of a new type of trap for micrometeorites at the summit of the Transantarctic Mountains (TAM) nunataks and presented a new collection: the TAM micrometeorite collection. The main characteristic of this collection is the very long exposure of the sedimentary traps, as evidenced by cosmogenic nuclides measurements (e.g., Rochette et al., 2008; Welten et al., 2008) and the presence of ~0.8 Myr old microtektites (Folco et al., 2008, 2009). Thanks to this long exposure, large micrometeorites are present in large numbers: 3500 micrometeorites with diameter > 400 μm, and 128 micrometeorites with diameter > 800 μm were counted as to date (December 2008). Based on the study of the cumulative size distributions of micrometeorites from Frontier Mountain in the >240 μm size range, Rochette et al. (2008) argued that the TAM collection is essentially unbiased. Indeed, the exponent slopes are close to that of the least biased micrometeorite collection known: the South Pole Water Well (SPWW) collection (Taylor et al., 2000, 2007). According to Taylor et al. (2007), the ratio of unmelted to melted micrometeorites is <0.1 for diameters > 150 μm, and it falls to <0.008 for diameters > 425 μm. In this study, we present in greater details the statistical properties – size distribution in the 100–1600 μm size range, distribution by type of cosmic spherules, weathering grade and fracturing – of the TAM collection. In order to highlight the singularity of the TAM collection, we compared it with the Walcott Névé collection.

2. Samples: origin and preparation

The TAM micrometeorite collection was recovered during the 2003 and 2006 *Programma Nazionale di Ricerche in Antartide* (PNRA) expeditions. The first samples were collected in 2003 at the summit (2700 masl) of Frontier Mountain (72°59.282′S–160°20.166′), from weathering pits (sample 3) or eroded granitic joints (samples 2, 4, 5, and 6). Fig. 1 features examples of such traps. More samples were collected in 2006 from joints at the summit (2600 masl) of Miller Butte (72°42.751′–160°11.994′, sample 15), and from another location at the summit of Miller Butte (72°42.645′S–160°12.119′E), in weathering pits (samples 18a, 18b, 18c, 18d, and 18e) or eroded granitic joints (samples 19, 19a).

Micrometeorites were also extracted from ~180 g of sediment from a Walcott Névé moraine in order to compare with the TAM collection. The setting of the extraterrestrial particles rich sediments was described by Harvey and Maurette (1991). Concentration of extraterrestrial particles occurs at different locations around the Walcott Névé area of the Transantarctic Mountains, Victoria Land, Antarctica (Fig. 2). After they fall on fresh snow in Antarctica central regions, micrometeorites travel in the ice flow. When they reach the ablation zone of the glacier, they are transported downwind and downslope by strong katabatic winds to the eolian sediment traps: crests of moraines, weathering debris around boulders and exposed areas of snow.

Sediment samples were wet sieved at 100, 200, 400, 800 μm for Frontier Mountain and Walcott Névé samples, and at 400, 800 μm for Miller Butte samples. Fractions were separated using magnetic extraction for some samples (see Table 1). Walcott Névé sample was separated using heavy liquids (methylene iodide MI, $\rho = 3300$ kg/m^3) and the light fraction was further sorted by magnetic extraction. Micrometeorites were hand-picked under a binocular microscope.

3. Analytical methods

Micrographs of the micrometeorites were taken at CEREGE (Aix-en-Provence, France) with a scanning electron microscope (SEM, Hitachi S-3000N) using a 24 kV accelerating voltage, either with secondary electrons (SE) or backscattered electrons (BSE). Bulk chemical analyses were made using a Micro X-Ray Fluorescence (XRF) microscope (Horiba XGT-5000 at CEREGE, accelerating voltage 30 kV). The beam diameter is 100 μm or 10 μm. Beam penetration is of the order of 100 μm, so the analysis is an average of the weathered outer layer and the more pristine inner material. The XRF instrument is calibrated for a semi-infinite medium, therefore these analyses are only semi-quantitative. After these analyses, selected micrometeorites from Frontier Mountain, Miller Butte and Walcott Névé were embedded in epoxy and polished. SEM images of the sections were taken at CEREGE (Hitachi S-3000N, 24 kV acceleration voltage, BSE). Wavelength dispersive spectrometry (WDS) chemical analyses (Cameca SX 50, accelerating voltage 15 kV, beam current 10 nA) were

Fig. 1. The TAM micrometeorite traps. (A and D) eroded granitic joint at the summit of Miller Butte (sample 21 and sample 19 with author L. Folco, respectively). (B) Weathering pit at the summit of Miller Butte (sample 18c with author P. Rochette). (C) Detail image of the bottom of a granitic joint at the summit of Miller Butte (sample 16).

performed at Istituto di Geoscienze e Georisorse, CNR. U. O. Padova (Italy), on polished sections of micrometeorites from Frontier Mountain and Walcott Névé, and at Université Pierre et Marie Curie, Paris (France) on polished sections of Miller Butte micrometeorites.

4. Results

4.1. Types and chemical compositions

Chemical analyses allowed us to discard terrestrial materials and to confirm the extraterrestrial composition of the selected micrometeorites. It was also possible to identify iron cosmic spherules from the chemical analyses results. A major elements ternary plot (Fig. 3) of Frontier Mountain, Miller Butte and Walcott Névé particles with the compositional range of cosmic spherules (Taylor et al., 2000) shows that the particles identified as extraterrestrial have different composition from local volcanic rocks. Fig. 4 shows the distribution of molar Fe/(Mg + Si) for selected Frontier Mountain and Miller Butte micrometeorites, and for Walcott Névé and SPWW micrometeorites. Characteristic surface features of micrometeorites can be identified in whole particle SEM images. SEM images of the polished sections enabled classification of the micrometeorites into different categories (Genge

Fig. 2. Sampling site for the Walcott Névé micrometeorite collection, in a moraine downwind of an icefield. The sampling box is ~15 cm across.

et al., 2008) according to the texture: S-type (stony: barred olivine, porphyritic olivine, and cryptocrystalline textures), I-type (iron), G-type (dendritic magnetite in glass), V-type (glass). Table 1 shows the proportions of different types among cosmic spherules.

4.2. Size frequency distribution

The diameters of the spherules were estimated optically under the binocular microscope or from the SEM pictures. We assumed that the particles are ellipsoids with equal minor and intermediate axes ($a \geq b = c$). The diameter used in the size distribution is therefore $\sqrt[3]{a \cdot b^2}$. The slope exponent of the size distribution is calculated by the least squares method. For sample 3, the size distribution (Fig. 5A) only includes micrometeorites from the magnetic fraction. An aliquot of 7.8% of the 100−200 μm size range and the whole >200 μm magnetic fractions were studied. A composite size distribution was obtained by combining the whole >200 μm data with the 100−200 μm data multiplied by 12.8. The exponent slope of the size distribution is −4.5. In order to estimate the bias induced by the magnetic extraction, we compared the exponent slopes for the magnetic fraction and non-magnetic fraction of sample 18c in the 200−400 size range. As shown in Fig. 5B, the exponent slopes are not significantly different (−4.8 for the non-magnetic fraction, and −5.0 for the magnetic fraction). Fig. 5C presents the size distribution of sample 18c in the 200−800 μm size range. As

Table 1
Distributions by type for Frontier Mountain (FRO), Miller Butte (MIL), Walcott Névé (WAL) and South Pole Water Well (SPWW) cosmic spherules.

Sample		Size	Fraction	S-type	G-type	V-type	I-type	Number
FRO	2	>200 μm	*m*	78%	1%	16%	5%	169
	3	>200 μm	−	84%	1%	14%	1%	85
	4	>400 μm	*m*	*na*	*na*	*na*	1%	82
	5	>400 μm	*m*	*na*	2%	*na*	3%	133
	6	>400 μm	*m*	*na*	3%	*na*	5%	116
MIL	15	>400 μm	*m*	*na*	*na*	*na*	7%	87
	18c	>200 μm	*m*	*na*	*na*	*na*	3%	920
	18[a]	>400 μm	*m*	*na*	0.4%	*na*	4%	239
	19	>400 μm	*m*	*na*	*na*	*na*	2%	95
	19b	>400 μm	*m*	*na*	1%	*na*	2%	308
WAL		>100 μm	*hm*	83%	2%	10%	6%	126
SPWW		>100 μm	−	83%	1%	15%	1%	1130

m: only the magnetic fraction was studied; *hm*: separation was made with heavy liquids, the light fraction was further sorted magnetically; *na*: identification of this type was not attempted.
[a] Samples 18a, 18b, 18c, 18d and 18e considered together.

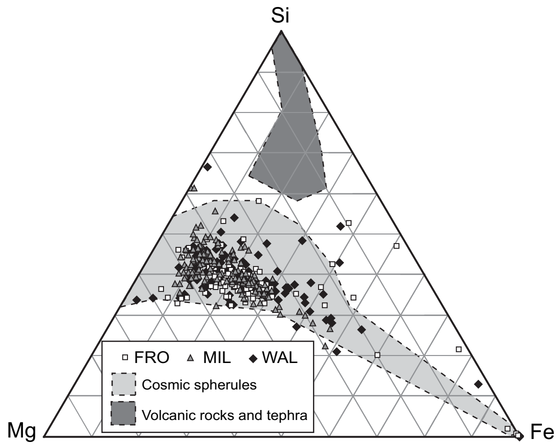

Fig. 3. Mg−Si−Fe (in atoms %, obtained by electron microprobe) ternary diagram showing where Transantarctic Mountain micrometeorites from Frontier Mountain and Miller Butte plot relative to other Antarctic, Greenland and deep-sea cosmic spherules (Taylor et al., 2000), Victoria Land tephra embedded in ice (Curzio et al., 2008) and volcanic rocks (LeMasurier and Thomson, 1990).

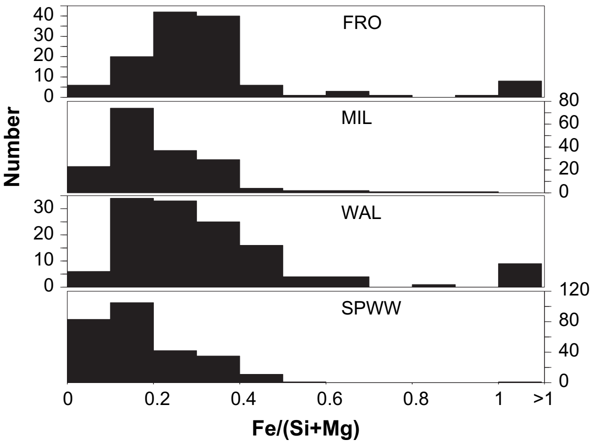

Fig. 4. Molar Fe/(Si + Mg) histograms for of Frontier Mountain (FRO) (magnetic extract), Miller Butte (MIL), Walcott Névé (WAL) (heavy fraction (methylene iodide, $\rho = 3300\ kg/m^3$) and magnetic fraction of the light fraction) and South Pole Water Well (SPWW) (Taylor et al., 2000) micrometeorites.

only half of the 200–400 μm size fraction was searched – whereas the >400 μm size fraction was fully searched – the distribution is a composite obtained by multiplying by 2 the data in the 200–400 μm size range. The exponent slope is −4.8. The size distribution of all TAM micrometeorites in the 400–800 μm size fraction for which diameter was measured (Fig. 5D) gives an exponent slope of −5.2. When only I-type micrometeorites of the TAM collection are considered, the slope is −6.3 (Fig. 5E). Due to the small number of particles available, the size distribution for micrometeorites larger than 1000 μm had never before been estimated reliably. The TAM collection offers a unique opportunity to study large micrometeorites. Fig. 6 shows SEM images of large cosmic spherules and unmelted micrometeorites from the TAM collection. The size distribution of all micrometeorites >800 μm from the TAM collection for which diameter was measured (Fig. 5F) has an exponent slope of −5.2. The Walcott Névé collection shows a −2.9 exponent slope on the 200–400 μm size range (Fig. 7).

4.3. Weathering and fractures

As seen on SEM images of the TAM micrometeorites, surface state indicates only moderate weathering, e.g. partial dissolution of olivine leading to spongy structure near the surface. In order to quantify this weathering, we measured the maximum depth at which olivine is dissolved in stony spherules from Frontier Mountain sample 2 and Walcott Névé sample. The depth was determined optically on SEM images of the polished sections of the particles (Fig. 8A and B). The histograms of maximum dissolution depth are shown in Fig. 8. Fractures are also visible on some spherules, they can be observed externally or on the section of the micrometeorite (Fig. 9). Despite their much younger age, Walcott Névé micrometeorites show more fractures (16% of micrometeorites) than Frontier Mountain sample 2 (6% of micrometeorites).

5. Discussion

From Fig. 4, micrometeorites with a molar Fe/(Mg + Si) > 1 seem to be over-represented in samples collected at Frontier Mountain. This bias is due to the magnetic separation used to collect micrometeorites. This is also the case for Walcott Névé micrometeorite collection, which was sorted by density and magnetism. The molar Fe/(Mg + Si) distribution for a Miller Butte sub-sample that did not experience separation is very close to that of the SPWW collection, except for a relative deficit of micrometeorites with ratios <0.1. This good agreement between SPWW and TAM collections indicates that micrometeorites recovered from the Transantarctic Mountains are representative of the extraterrestrial influx in term of bulk chemistry.

The proportions by types in the TAM collection are very similar to the SPWW collection, except for an enrichment in G- and I-type spherules when only the magnetic fraction was studied (G- and I-type spherules contain larger amounts of magnetite than S- and V-type). From samples for which the non-magnetic fraction was also searched, we can estimate an average proportion of the magnetic extract of 61% of the total number of spherules. Extrapolated G- and I-type proportions for the whole fraction (magnetic + non-magnetic) are closer to the SPWW values. The statistics for sample 3 are given for a representative sub-sample for which the non-magnetic fraction was also searched: the distribution is almost identical to that of the SPWW collection. The Walcott Névé collection shows an enrichment in G- and I-type spherules, and a deficit in V-type spherules. This bias may come from the separation method, but it could also be due to the concentration process, either during transportation in the ice flow, or at a later stage when particles were wind-blown.

The apparent deficit in the smaller and larger size range observed for a number of samples is due to

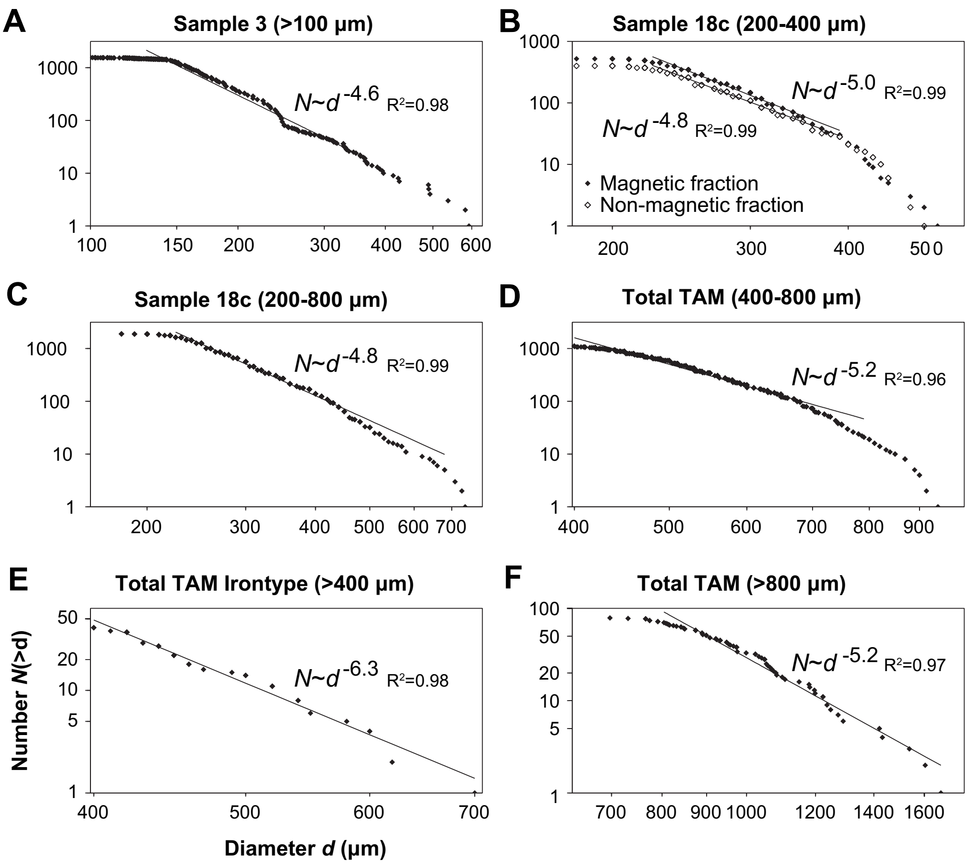

Fig. 5. Cumulative size distributions. A) Magnetic fraction of sample 3 in the >100 µm size range. The slope is calculated on the 130–350 µm size range. B) Sample 18c, 200–400 µm size range. The distributions of the magnetic and non-magnetic fractions are plotted. The slopes are calculated on the 225–400 µm size range. C) Sample 18c, 200–800 µm size range. The number of micrometeorites in the 200–400 µm size range is the estimated number in the sample, as only half of that fraction has been studied. The slope is calculated for micrometeorites with diameter > 225 µm and with $N > 10$. D) Transantarctic Mountains samples, 400–800 µm size range. The slope is calculated on the whole 400–800 µm size range. E) Iron-type micrometeorites from the Transantarctic Mountains collection with diameter > 400 µm. The slope is calculated on the whole size range. F) Transantarctic Mountains samples, >800 µm in size. The slope is calculated for all samples with diameter > 800 µm.

sieving: particles with a diameter slightly smaller than the mesh size may be retained in the smaller size fraction. Conversely, particles larger than the mesh size can break into the sieve thanks to an elongated shape, or mesh imperfections. This is the reason why the distribution curves are fitted only in the central part of the distribution.

The size distribution of samples 3 and 18c (200–800 µm size range) are slightly less steep than the −5.0 to −5.4 slopes of the SPWW collection (Taylor et al., 2007), which is the least biased collection known for cosmic spherules. The size distributions of sample 18c (200–800 µm size range), and of all TAM micrometeorites (400–800 µm and >800 µm size ranges), match very well that of the SPWW collection. Furthermore, the total numbers of micrometeorites counted (including cosmic spherules for which the diameter was not measured on SEM images): 3500 with diameters > 400 µm, and 128 with diameters > 800 µm, give a slope of −4.8. These results indicate that the TAM collection is essentially unbiased: no significant size bias (due to e.g. wind sorting) is affecting the TAM collection in the investigated sites.

The oscillation observed around 250 µm in the size distribution of the magnetic fraction of sample 3 may come from the method used to obtain a composite sample: as only part of the 100–200 µm fraction was actually searched, we had to multiply the number of spherules in the small fraction to scale it to that of the larger fraction. The effect of sieve mesh size is visible above the nominal threshold (200 µm) because

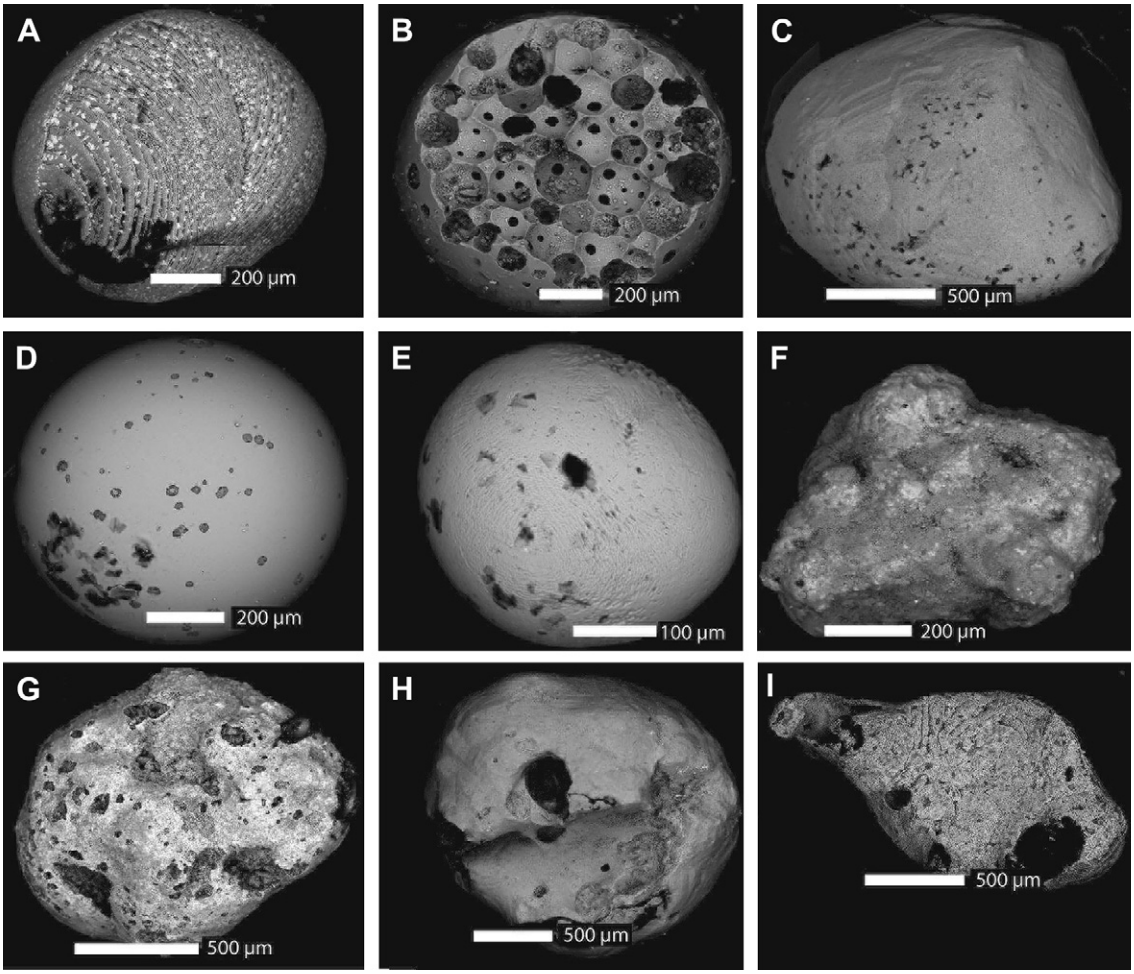

Fig. 6. Backscattered electron images of large micrometeorites. (A) Barred olivine cosmic spherule. (B) Glass cosmic spherule with "bubbles". (C) Barred olivine cosmic spherule with fine grains. (D) Glass cosmic spherule. (E) Iron cosmic spherule. (F and G) Large unmelted micrometeorites. (H) Barred olivine cosmic spherule with a flattened shape. (I) Barred olivine cosmic spherule with a "tail".

elongated spheroids can pass through a mesh size smaller than their long axis and because of imperfections of the mesh (some being significantly larger than 200 μm).

The fact that the exponent slopes for the distribution of the magnetic and non-magnetic fractions are similar indicates that the physical process controlling the size distribution is independent from the chemistry and density of the spherules. Indeed, the non-magnetic fraction is dominated by less dense glassy spherules, while the magnetic fraction is dominated by barred olivine (with porphyritic, G- and I-types) spherules. When only I-type micrometeorites are considered, the slope of the distribution is steeper, which was also noticed by Taylor et al. (2000).

The fact that the slope of the distribution is consistent in the 100–1600 μm size range suggests that a single process controls the size distribution of extraterrestrial particles in this size range. It is also a strong evidence to discard the breakup of larger meteoroids as the origin of the largest micrometeorites of the TAM collection, as the size distribution for meteorites has a very different −1.5 slope (calculated from Jull (2006)), which is the consequence of both preatmospheric size distribution and breakup during atmospheric entry.

Unlike the TAM samples, the Walcott Névé collection shows a strong deficit in smaller particles that cannot be accounted for by a sieving bias. Wind may blow smaller particles away and prevent them

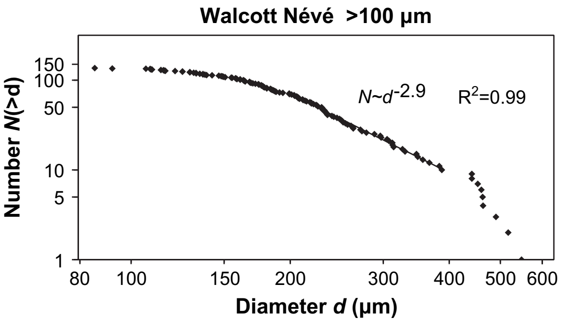

Fig. 7. Cumulative size distribution of Walcott Névé cosmic spherules. The slope is calculated on the 200—400 µm size range.

from settling down in the moraines. Assuming that micrometeorites with diameter > 400 µm are not affected by this effect, the deficit would be 75% for 200 µm micrometeorites, according to the slope difference. The superficial dissolution observed in all Walcott Névé spherules is consistent with a likely young age. The range of dissolution is much wider for the TAM collection, as expected for micrometeorites with ages ranging from present to ~1 Myr. The exposure ages for the traps (Rochette et al., 2008) were estimated with cosmogenic nuclides measurements, and from the total number of micrometeorites in the weathering pits of samples 3 and 18c normalized to pit surface and known accumulation flux, i.e. the collection duration.

Surface fractures on micrometeorites from the Walcott Névé may result from impact after wind transportation, while the penetrative fractures may be due to swelling or cryoclasty. Lower fracturing of the TAM collection is consistent with our assumption of negligible secondary wind transport, and the fact that the deposits are devoid of ice. The snow precipitation is removed by wind and sublimation without passing through liquid state.

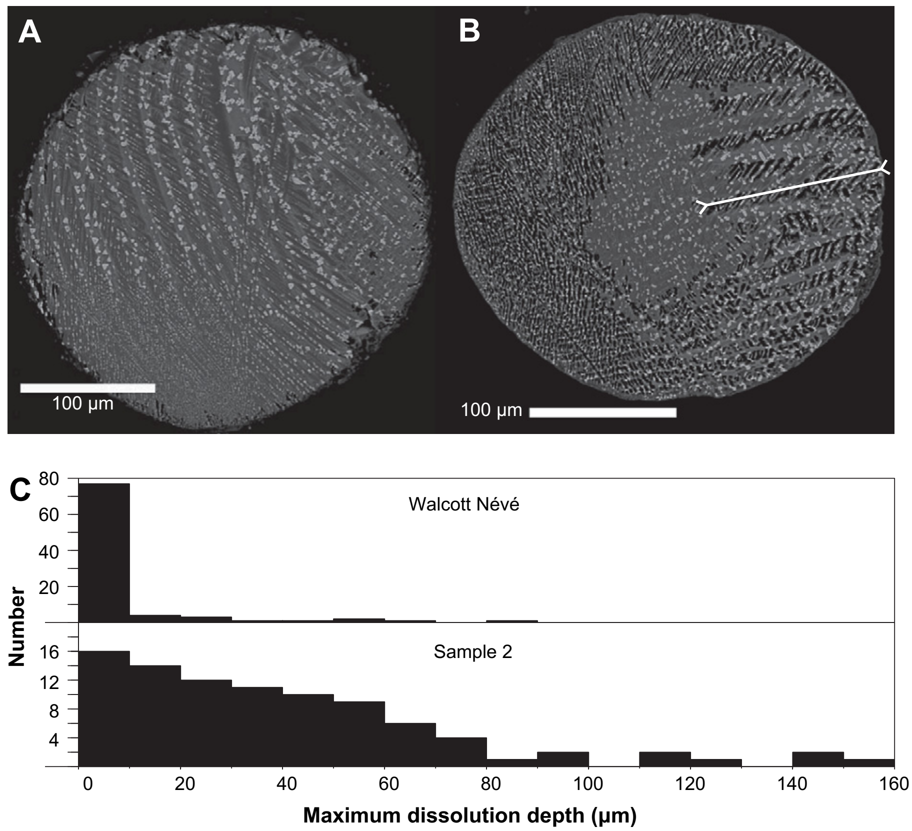

Fig. 8. A) Backscattered electron image of barred olivine cosmic spherule from Frontier Mountain that suffered little weathering. B) Backscattered electron image of barred olivine cosmic spherule from Frontier Mountain for which olivine has been etched by weathering, leaving only glass and magnetite grains. The ''maximum dissolution depth'' used for the histogram is indicated. C) Maximum dissolution depth distribution for TAM sample 2 (Frontier Mountain) and Walcott Névé collection.

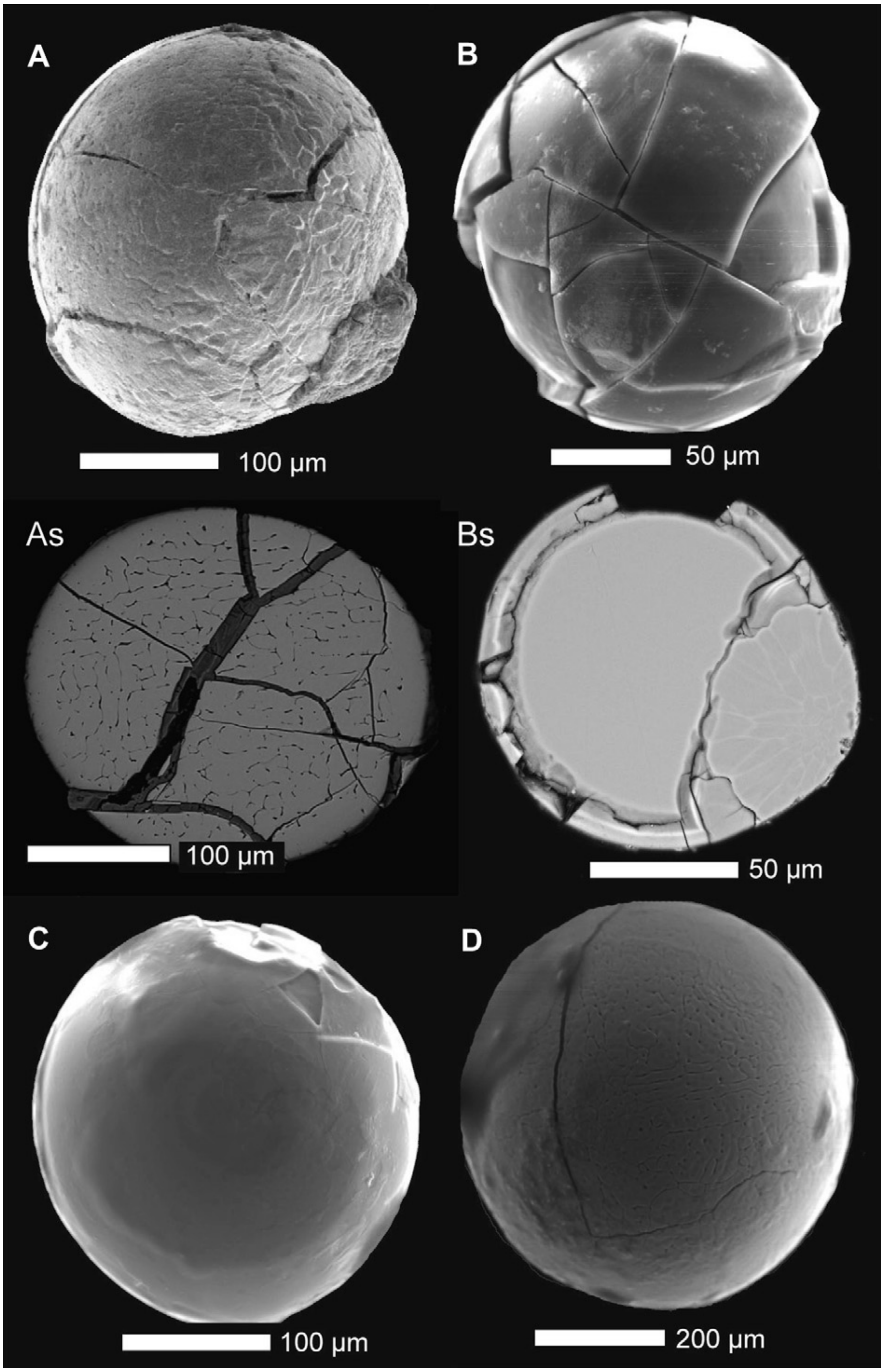

Fig. 9. Backscattered electron images of cosmic spherules from Frontier Mountain (A) and Walcott Névé (B, C and D) showing penetrative fractures (polished sectionc images As and Bs) and surface fractures (C and D).

6. Conclusion

The study of the distribution by type and size distribution of the TAM collection shows that this collection is essentially unbiased. The proportions for each type of cosmic spherules are similar to the least biased collections. Particularly, no deficit in glassy cosmic spherules seems to occur. The ~ -5 exponent slope of the size distribution is similar to that of the least biased collections, and it is the same for the whole 100−1600 μm size range, which suggests that the size distribution of micrometeorites in this diameter range is controlled by a single process. The contrast with the features exhibited by the Walcott Névé secondary wind-blown concentration demonstrates that secondary concentration is very limited in the TAM collection.

The TAM collection provides researchers with a huge amount of micrometeorites, including a statistically significant number of particles with large diameters (>800 μm). The availability of such samples opens new horizons for destructive analyses such as laser-ablation oxygen isotope measurements on single micrometeorites or magnetic measurements (Suavet et al., 2008, 2009). The TAM collection also offers a great opportunity to study the composition of the flux of micrometeorites on the ∼1 Myr time scale.

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References

Curzio, P., Folco, L., Laurenzi, M.A., Mellini, M., Zeoli, A., 2008. A tephra chronostratigraphic framework for the Frontier Mountain blue-ice field (northern Victoria land, Antarctica). Quat. Sci. Rev. 27, 602−620.

Duprat, J., Engrand, C., Maurette, M., Kurat, G., Gounelle, M., Hammer, C., 2007. Micrometeorites from Central Antarctic snow: t he CONCORDIA collection. Adv. Space Res. 392, 605−611, doi:10.1016/j.asr.2006.05.029.

Folco, L., Rochette, P., Perchiazzi, N., D'Orazio, M., Laurenzi, M.A., Tiepolo, M., 2008. Microtektites from Victoria Land Transantarctic Mountains. Geology 36, 291−294, doi:10.1130/G24528A.1.

Folco, L., D'Orazio, M., Tiepolo, M., Tonarini, S., Ottolino, L., Perchiazzi, N., Rochette, P., 2009. Transantarctic Mountain microtektites: geochemical affinity with Australasian microtektites. Geochim. Cosmochim. Acta 73, 3694–3722, doi:10.1016/j.gca.2009.03.021.

Genge, M.J., Engrand, C., Gounelle, M., Taylor, S., 2008. The classification of micrometeorites. Meteorit. Planet. Sci. 43, 497−515.

Harvey, R.P., Maurette, M., 1991. The origin and significance of cosmic dust from the Walcott Névé, Antarctica. Lunar Planet. Sci. 21, 569−578.

Jull, A.J.T., 2006. Terrestrial ages of meteorites. In: Lauretta, D.S., McSween Jr., H.Y. (Eds.), Meteorites and the Early Solar System II. The University of Arizona Press, Tucson, pp. 889−905.

LeMasurier, W.E., Thomson, J.W., 1990. Volcanoes of the Antarctic Plate and Southern Oceans. In: Antarctic Res. Series 48. American Geophysical Union, Washington, pp. 487.

Love, S.G., Brownlee, D.E., 1993. A direct measurement of the terrestrial mass accretion rate of cosmic dust. Science 262, 550−553.

Rochette, P., Folco, L., Suavet, C., van Ginneken, M., Gattacceca, J., Perchiazzi, N., Braucher, R., Harvey, R.P., 2008. Micrometeorites from the Transantarctic Mountains. Proc. Natl. Acad. Sci. USA 105, 18206−18211, doi:10.1073/pnas.0806049105.

Suavet, C., Rochette, P., Gattacceca, J., Folco, L., 2008. Micrometeorites: a possible bias on the sedimentary magnetic record. Geochem. Geophys. Geosyst. 9, Q11002, doi:10.1029/2008GC002160.

Suavet, C., Gattacceca, J., Rochette, P., Perchiazzi, N., Folco, L., Duprat, J., Harvey, R.P., 2009. Magnetic properties of micrometeorites. J. Geophys. Res. 114, B04102, doi:10.1029/2008JB005831.

Taylor, S., Lever, J.H., 2001. Seeking unbiased collections of modern and ancient micrometeorites. In: Peucker-Ehrenbrink, B., Schmitz, B. (Eds.), Accretion of Extraterrestrial Matter Throughout Earth's History. Kluwer Academic/Plenum Publishers, London, pp. 205−219.

Taylor, S., Lever, J.H., Harvey, R.P., 1998. Accretion rate of cosmic spherules measured at the South Pole. Nature 392, 899−903.

Taylor, S., Lever, J.H., Harvey, R.P., 2000. Numbers, types and compositions of and unbiased collection of cosmic spherules. Meteoritics Planet. Sci. 351, 651−666.

Taylor, S., Matrajt, G., Lever, J.H., Joswiak, D.J., Brownlee, D.E., 2007. Size distribution of Antarctic micrometeorites. Paper presented at Workshop on Dust in Planetary Systems, National Aeronautics and Space Administration, Kaua'i Hawai'i, 26−30 September.

Welten, K.C., Folco, L., Nishiizumi, K., Caffee, M.W., Grimberg, A., Meier, M.M.M., Kober, F., 2008. Meteoritic and bedrock constraints on the glacial history of Frontier Mountain in northern Victoria Land, Antarctica. Earth Planet. Sci. Lett. 270, 308−315.