BIO Web of Conferences 2, 03003 (2014)
DOI: 10.1051/bioconf/20140203003

Cometary micrometeorites and input of prebiotic compounds

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Abstract. The apparition of life on the early Earth was probably favored by inputs of extraterrestrial matter brought by carbonaceous chondrite-like objects or cometary material. Interplanetary dust collected nowadays on Earth is related to carbonaceous chondrites and to cometary material. They contain in particular at least a few percent of organic matter, organic compounds (amino-acids, PAHs,…), hydrous silicates, and could have largely contributed to the budget of prebiotic matter on Earth, about 4 Ga ago. A new population of cometary dust was recently discovered in the Concordia Antarctic micrometeorite collection. These "Ultracarbonaceous Antarctic Micrometeorites" (UCAMMs) are dominated by deuterium-rich and nitrogen-rich organic matter. They seem related to the "CHON" grains identified in the comet Halley in 1986. Although rare in the micrometeorites flux (<5% of the micrometeorites), UCAMMs could have significantly contributed to the input of prebiotic matter. Their content in soluble organic matter is currently under study.

1 Introduction

Interplanetary dust originating from asteroids and comets could have contributed to the origin of life on Earth [e.g.1; 2 and references therein]. They could have brought prebiotic material that was used to favor the origin of life on Earth. Cosmic dust also seeded other planetary bodies where life could have emerged as well, such as Mars, Titan, Europa or Enceladus…

The origin of interplanetary dust is dual, from asteroids and comets [e.g. 3; 4; 5]. To understand the differences between cometary and asteroidal material, we need to investigate samples that are representative of interplanetary material. The analysis of micrometeorites (MMs), which are submillimetric dust particles recovered on the Earth surface in the size range of ~ 20 to 300 µm, can contribute to this issue. Micrometeorites represent the dominant input of extraterrestrial matter on Earth nowadays. With the logistic support of the French and Italian polar institutes IPEV & PNRA, we collect them in Antarctic ice and snow in very clean conditions. We have shown that micrometeorites represent a new population of extraterrestrial matter: they are related to the primitive meteorites, the carbonaceous chondrites, but also show differences (size and abundance of minerals, isotopic composition of hydrogen… [e.g. 6; 7; 8]. Chondritic micrometeorites contain hydrous minerals and about 2 wt% of carbonaceous matter [6; 9]. Their contents in carbonaceous matter and in volatile elements are especially interesting for an input of prebiotic matter on the primitive Earth. A new population of ultracarbonaceous particles discovered in the Concordia Antarctic micrometeorite collection is also considered as an interesting vector of prebiotic material.

2 Interplanetary dust as representative sampling of interplanetary matter

For the following reasons, micrometeorites could represent a less biased sample of interplanetary matter than meteorites:

- The dynamical evolution of cosmic dust in interplanetary space is less biased than that of meteorites. It is dominated by non-gravitational forces like Poynting-Robertson drag [10], whereas meteorites are delivered to Earth as a result of interactions with resonances, and their accretion is biased through gravitational focusing by the Earth [11].

- The high proportion of carbonaceous-chondrite like objects (related to C-type asteroids) in the cosmic dust population (> 80% [e.g. 6; 7; 8; 12]) better agrees with the proportions of C-type (> 55%) over S-type (< 20%) asteroids [13]) than that in the meteorite collections (~ 5%). The proportion of C-type asteroids in the main asteroid belt is currently revisited and could in fact dominate the asteroid population and provide a better match to the characteristics of MMs [14 and personal communication]. The meteorite collections under-represent the carbonaceous chondrites (CC) with regard to ordinary chondrites (linked to S-type asteroids [15-18]), as these fragile CC meteorites may be preferentially destroyed during atmospheric entry and by weathering at the Earth's surface before recovery (e.g. [19]).

- There are evidences of an invariance of the composition of the flux of micrometeorites as a function of time [20-23] or toward smaller sizes [24; 25].

On the other hand, recent dynamical models propose a preferential formation of large amounts of dust from Jupiter family comets that could explain the high abundance of carbonaceous-chondrite-like objects in the micrometeorite collections [5; 26]. This work would thus imply that most (if not all) micrometeorites with sizes < 500 µm are of cometary origin. This in turn would not contradict the relationship of micrometeorites with carbonaceous chondrite-like objects, as cometary material returned from the STARDUST mission from the Jupiter family comet Wild2 is close to that of carbonaceous chondrites as well [e.g. 27; 28]. Antarctic micrometeorites also show large similarities to Wild 2 samples [29].

3 Search for organic matter in micrometeorites

Chondritic micrometeorites contain a few wt% of insoluble organic matter (IOM). Raman microspectroscopy and high-resolution transmission electron microscopy studies of this IOM show a primitive and very disorganized structure of this organic compound [30; 31].

Soluble organic matter was searched for in micrometeorites collected from Antarctic blue ice fields at Cap-Prudhomme. They contain organic molecules such as PAHs and possibly amino acids, particularly AIB [32; 33] (Fig. 1 and Table 1). The presence of AIB in micrometeorites was confirmed by Matrajt *et al.* [34] (Table 2), after several negative attempts [35; 36]. However, micrometeorites analyzed to date show a contamination of amino acids from the Antarctic ice [see 32], and only non-biological amino acids (such as AIB and isovaline) can reasonably be attributed to the sample analyzed.

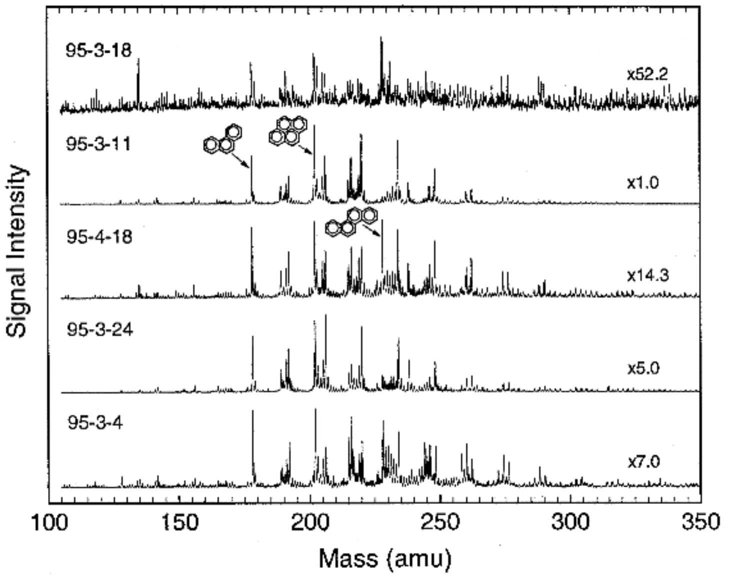

Figure 1: Spectra of PAHs detected in Cap Prud'homme Antarctic micrometeorites [from 33].

Table 1: Determination of concentrations (in ppm) of amino-acids in 5 sets of about 50 Cap Prud'homme micrometeorites [from 32].

Amino acid	A91 (50 μg)	I91 (175 μg)	III91 (310 μg)	IV94 (166 μg)	V94 (259 μg)
D-Aspartate	10	1	18	20	20
L-Aspartate	34	1	30	40	100
L-Serine	85	73	100	7	100
D,L-Glutamate	280	170	40	40	70
Glycine	260	250	210	5	40
D-Alanine	570	73	37	<0.1	<0.6
L-Alanine	620	310	180	60	60
AIB	280	78	22	<0.1	20
D,L-Isovaline	<13	<3	<20	<0.1	<1

Table 2 (top and bottom): Determination of concentrations of amino-acids in micrometeorite sample from the South-Pole Water Well (samples A, B and C) compared to that of rust grains (R1 and R2) used as blanks [from 34].

Amino acid detected	A (MMs) 6.9 mg			R1 (rust grains) 4.8 mg		
	H_2O (nmol/g)[a]	HF (nmol/g)	Total (nmol/g)	H_2O (nmol/g)	HF (nmol/g)	Total (nmol/g)
Glutamic acid	2.3	9.7	12.0	2.8	25	27.8
Glycine	5.8	46.3	52.1	6.3	56.3	62.6
Alanine	3.3	12.3	15.6	7.2	12.5	19.7
AIB	0.5	1.6	2.1	<0.0005	<0.0005	–
Valine	0.7	1.8	2.5	2.1	<0.0005	2.1
Aspartic acid	n.d.	n.d.	–	1.6	n.d.	1.6
Serine	<0.0005	<0.0005	–	~3.2	n.d.	~3.2

[a]nmol/g – nanomol of amino acid per gram of sample (micrometeorite or rust).

Amino acid detected	B (MMs) (5 mg)			C (MMs) (6 mg)			R2 (rust grains) (2 mg)		
	H_2O (nmol/g)[a]	HF (nmol/g)	Total (nmol/g)	H_2O (nmol/g)	HF (nmol/g)	Total (nmol/g)	H_2O (nmol/g)	HF (nmol/g)	Total (nmol/g)
Glutamic acid	2.5	216.3	219.0	20.4	6.6	27.0	79.3	539.6	619
Glycine	7.8	280.6	288.4	34.7	30.1	64.9	193.5	675.6	869
Alanine	5.9	180.6	186.4	23.4	14.6	38.0	151.8	500	652
AIB	<0.0005	<0.0005	–	<0.0005	<0.0005	–	<0.0005	<0.0005	–
Valine	2.1	132	134.0	5.1	10.4	15.5	57.5	143.8	201
Aspartic acid	2.1	n.d.	2.1	21.1	13	34.1	53.2	394.5	448
Serine	1.0	n.d.	1.0	10.5	n.d	10.5	78.5	n.d.	78.5

[a]nmol/g = nanomol of amino acid per gram of sample (micrometeorite or rust).

We recently discovered ultracarbonaceous micrometeorites (UCAMMs) in the collection of micrometeorites from Antarctic snow, in the vicinity of the Concordia Station at Dome C (Fig. 2). These particles have no counterpart in the meteorite collections. They are dominated by carbonaceous matter and have an anomalously deuterium-rich hydrogen isotopic composition. UCAMMs contain a minor amount of minerals intimately associated with the carbonaceous matter [31]. These particles contain up to 85% of organic matter in volume (or 65wt% of C), thus showing carbon contents up to 10 times that of the most C-rich carbonaceous chondrites [37-39]. Three such UCAMMs were also reported in a collection performed at Dome Fuji [40]. Such concentrations of carbonaceous matter are comparable with that of the most C-rich IDPs [41; 42], and compatible with CHON grains detected in comet Halley by the Giotto and Vega spatial missions in 1986 [43; 44].

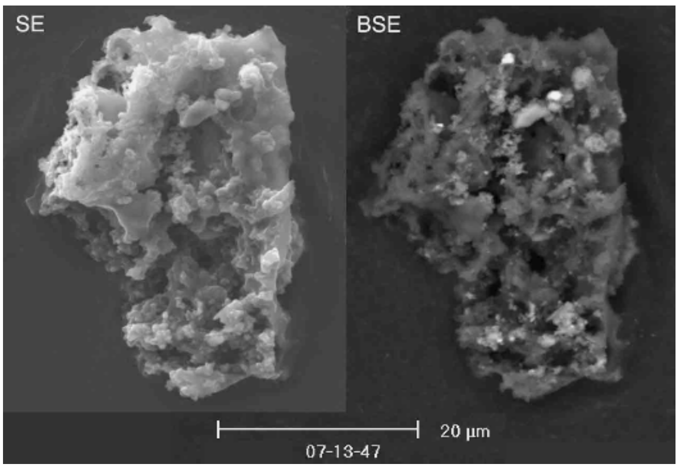

Figure 2: Backscattered electron micrograph of a fragment of CONCORDIA Ultracarbonaceous Antarctic Micrometeorite (UCAMM). All dark grey patches are constituted of organic matter. Brighter flakes are silicates or Fe-Ni sulphides.

The organic matter of UCAMMs show very high D/H ratios, and is significantly enriched in nitrogen compared to meteorites [45-47]. Mineralogical, isotopic and spectroscopic data recently obtained on these particles indicate that they are most likely cometary grains, possibly originating from Oort Cloud comets [45; 46]. Although samples of the comet Wild2 brought back by the STARDUST mission remain the only sample of ascertain cometary origin, we can point three problems concerning the reliability of the characterization of their organic matter: (i) very small amounts material were collected, (ii) the heating during capture has altered organic matter, (iii) the aerogel collector contained detectable amounts of terrestrial contamination of organic matter.

UCAMMS provide access to organic matter of very likely cometary origin, in an unprecedented state of preservation. Concordia micrometeorites (including UCAMMs) have the advantage of having short residence times in the snow (less than 50 years) at very low temperatures (-30 to -80° C), and in areas where life is virtually absent. They are therefore the appropriate samples to search for organics compounds like amino acids. Martin *et al.* [48] have developed a method for analyzing an individual particle of about 50 microns that could be tried to analyze UCAMMs. The orbitrap technique (in collaboration with R. Thissen and V. Vuitton at IPAG Grenoble) will also be tried to search for organic compounds in micrometeorites.

Acknowledgements: During her PhD, Elena Dobrică made significant contributions in the characterization of the UCAMMs, this new family of cometary particles, in collaboration with H.

Leroux, E. Quirico and J.-N. Rouzaud. The collect and analyses of UCAMMs are ongoing at CSNSM with J. Duprat. Michel Maurette was a pioneer in the collection and analyses of polar micrometeorites, and for their implications for the formation of the solar system and for exobiology. Gero Kurat had a crucial role in micrometeorite research. This work was supported by CNRS IN2P3, INSU (PNP), EPOV, IPEV, ANR Jeunes Chercheurs "Micromet", CNES, and FP6 RTN Marie Curie "ORIGINS".

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