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Cometary particle recovered from a deep firn/ice drilling in central Antarctica. J. Duprat¹, E. Dartois², C. Engrand³, L. Delauche³, O. Alemani⁴, P. Possenti⁴, F. Fortuna², S. Hervé², S. Mostefaoui¹, L. Rémusat¹, M. Verdier-Paoletti¹, C. Sandt⁵, F. Borondics⁵, T. Nakamura⁶, ¹IMPIC, MNHN, CNRS, Sorbonne Univ, Paris, France (Jean.Duprat@mnhn.fr), ²ISMO, CNRS, Univ. Paris-Saclay, Orsay, France, ³IJCLab, CNRS -Université Paris-Saclay, France, ⁴IGE, CNRS-Univ. Grenoble-Alpes, Grenoble, France, ⁵Synchrotron SOLEIL, CNRS, CEA, Paris-Saclay, France, ⁶Dept. Earth. Sci., Tohoku Univ, Japan.

Introduction: The flux of cosmic dust at 1 AU is constantly replenished by both asteroidal and cometary sources [1]. Numerical models indicate that up to 80% of the dust entering the upper atmosphere should originate from comets, possibly from Jupiter family comets [2, 3]. While the composition of cometary dust is enriched in carbon compared to the chondritic composition by about a factor of 5 [e.g. 4], most cosmic dust particles recovered at Earth surface (i.e. micrometeorites) have a bulk chondritic composition [5, 6], and mostly differ by their degree of modification induced by heating at atmospheric entry [7]. However, some particles substantially deviate from this average chondritic component, among which Ultra-carbonaceous Antarctic MicroMeteorites (UCAMMs), which show exceptionally high concentration of organic matter (see e.g. [8–11]). Since 2000, we collect micrometeorites from surface snow at the vicinity of the French-Italian Station CONCORDIA [12]. We report here on the first identification of a UCAMM from deep firn/ice from a borehole in Antarctica and discuss its implications on the multiplicity of UCAMM parent bodies and the input of this specific type of cometary dust at Earth surface.

Materials and methods: In January 2019, we recovered about 500 kg of firn/ice chips extracted during a core drilling process (performed by O.A. and P.P. [13]). The firn/ice chip were collected from depth below 20 meters down to about 100 meters, corresponding to ages ranging from 300 to 2500 years before present. The chips were carefully melted and immediately filtered in a dedicated clean melter. Considering the snow accumulation rate at Dome C [14], the total volume of water obtained correspond to an equivalent exposition parameter of about 18 m².yr. The particles were recovered on a nylon filter subsequently dried and sealed under inert, dry N₂ atmosphere. The micrometeorite candidates were handpicked under a binocular microscope in IJCLab micrometeorite clean-room. Each candidate was split in several fragments, one fragment was analyzed by scanning electron microscopy (SEM) equipped with EDX. The EDX spectra of most micrometeorites (or cosmic spherules) identified exhibit the usual chondritic pattern, except one particle, DC19-GL86, noticeably departing from this composition with an abundance in carbon well above the chondritic values. A

complementary fragment of DC19-GL86 was transferred on a diamond compression cell and gently flattened to provide the optimal thickness for infrared transmission micro-spectroscopy (μ FTIR).

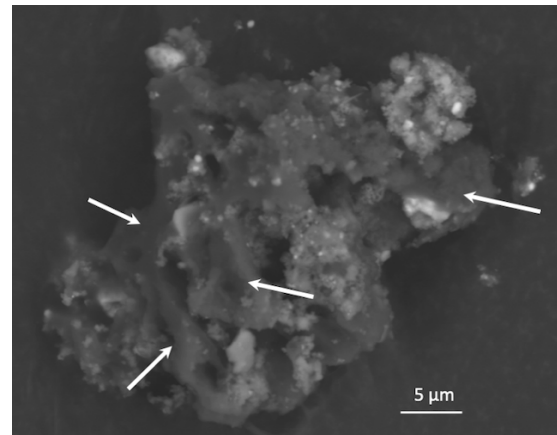


Figure 1: Backscattered electron image of GL86 particle extracted from Dôme C deep firn/ice core. The particle exhibits large carbon-rich patches (dark grey areas), some of them highlighted by white arrows.

μ FTIR measurements were performed on the SMIS beam line at the synchrotron SOLEIL. The synchrotron beam was coupled to a Nicolet Nic-Plan infrared microscope. The infrared spot size was optimized close to the diffraction limit ($\sim 6 \times 6 \mu\text{m}^2$). A Thermo Fisher DXR spectrometer was used to record Raman spectral maps on the same areas, using a 532 nm laser at minimum power to prevent laser-induced sample alteration. Ten scans with integration times of 20 s each were co-added for each spectrum. The spot size of the Raman spectra was of the order of one micron. The hydrogen isotopic images were obtained on several areas of DC19-GL86 using the NanoSIMS instrument at MNHN. The D/H maps were derived from the H⁺ and D⁺ secondary ion emissions, using a 16 keV Cs⁺ primary beam rastered over a $20 \times 20 \mu\text{m}^2$ area (256×256 pixels). Multi-stack images were acquired with a probe dwell time 1 ms/px. A type III kerogen and several D-rich polymers were used for the IMF calibration [15].

Results: The DC19-GL86 particle was $60 \times 75 \mu\text{m}$ in size. The analysis of the $20 \times 30 \mu\text{m}$ fragment mounted for SEM revealed the carbon-rich nature of the particle (see Fig. 1). Mineral-depleted areas appear as large

carbon-rich smooth patches surrounded by areas with chondritic-like composition. Both the μ FTIR and Raman analysis confirm the high concentration of carbon in DC19-GL86. Most of the surface of the crushed fragment exhibits the typical IR and Raman spectra of UCAMMs, the IR being dominated by the organic matter signatures reported in [11]. The broad Raman *D* band (associated to the degree of “disorder” in the polyaromatic carbon backbone structure) and intensity ratio of the *D* and *G* bands are typical of the carbonaceous network in UCAMMs’ organic matter. Specific areas exhibit mineral signatures (see Fig. 2 top left and bottom-right) where typical IR and Raman pyroxene signatures are observed.

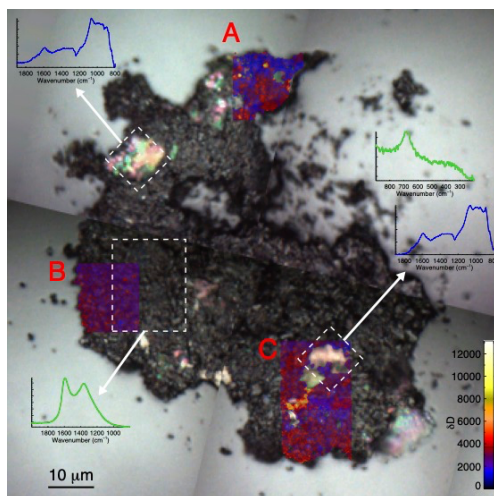


Figure 2 : Optical image of DC19-GL86 particle crushed on a diamond window with overlaid nanoSIMS maps (A, B and C). The μ FTIR (in optical depth) and Raman spectra of specific areas (indicated by white dashed rectangles) are reported in blue and green respectively. The NanoSIMS D/H images are reported in δ D (‰) values (right scale bar) in 3 zones (A, B and C).

The isotopic images of DC19-GL86 revealed large δ D anomalies with hotspots larger than 5,000 ‰ (zone A and C) and an average value of about 2,000‰ typical of UCAMMs [9, 16]. Together, these observations clearly demonstrate that DC19-GL86 is a UCAMM.

Discussion: Altogether, the chemical, mineralogical and isotopic characteristics of UCAMMs clearly indicate that their parent(s) body(ies) originate from the cometary reservoir [9, 10], most probably from beyond the nitrogen snow line [11, 16]. While the cometary origin of UCAMMs is clear, the multiplicity of their parent bodies remains uncertain as the majority of the samples analyzed so far were accreted by Earth over a rather short period of time. UCAMMs identified in CONCORDIA [9, 11] and Dome Fuji collections [10, 17] were recovered from surface snow down to depth

lower than 10 meters, corresponding to ages of fall within the last century. All these particles belong to the contemporary flux, similarly to the C-rich IDPs identified in stratospheric collections [18], raising the question of a potential unicity of the parent body of these C-rich particles.

Noticeably, 3 others UCAMMs were recovered from Antarctic blue ice fields, 2 at Tottuki point near Showa station [8, 19] and 1 at Kuwagata point [8]. The age of the ice at Tottuki point is not constrained [20] but that of Kuwagata point is estimated between 27-33 kyr [21]. The terrestrial age of these 3 UCAMMs are thus most probably ancient although it cannot be ruled out, at least for the 2 from Tottuki point, that they might have fallen recently on the spot of collect. The finding of UCAMM DC19-GL86 within a deep firm/ice core with a terrestrial age older than a few centuries demonstrate that these organic-rich particles were indeed part of the interplanetary flux at 1 UA over periods longer than the last century. This result indicates that multiple dust accretions events including UCAMMs occurred over at least centuries. The relative abundance of UCAMMs (about 1% of the MMs recovered) in the flux at 1 AU should thus result from the accumulation of multiple events. It is thus more likely that the UCAMMs abundance is associated to the input from several parent bodies rather than that from a unique one. The finding of a UCAMMs in a deep drilling firm/ice core opens the perspective to extend the search for particles originating from such remote icy organic-rich objects over large periods of time covering the last million of years.

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References: [1] Peucker-Ehrenbrink, B. et al. (2001) Springer, [2] Nesvorný, D. et al. (2010) ApJ. 713, 816–836, [3] Carrillo-Sánchez, J.D. et al. (2016) Geophys. Res. Lett. 43, 11,979-11,986, [4] Bardin, A. et al. (2017) MNRAS. 469, S712–S722 [5] Kurat, G. et al. (1994) GCA. 58, 3879–3904 [6] Engrand, C. et al. (1998) MAPS. 33, 565–580 [7] Genge, M.J. et al. (2008) MAPS. 43, 497–515 [8] Nakamura, T. et al. (2005) 68th MetSoc. Meeting, id.5086 [9] Duprat, J. et al. (2010) Science. 328, 742 [10] Yabuta, H. et al. (2017) GCA. 214, 172–190 [11] Dartois, E. et al. (2018) A&A. 609, A65 [12] Duprat, J. et al. (2007) ASR. 39, 605–611 [13] Bès de Berc, M. et al. (2020) AGU Fall Meeting, 2020, id.S046- 0003 [14] Rojas, J. et al. (2021) EPSL. 560, 116794 [15] Bardin, N. et al. (2014) 45th LPSC, id.2647 [16] Dartois, E. et al. (2013) Icarus. 224, 243–252 [17] Noguchi, T. et al. (2017) GCA. 208, 119–144 [18] Bradley, J.P. (2014). pp. 287–308. Elsevier, [19] Yada, T. et al. (2008) MAPS. 43, 1287–1298 [20] Iwata, N. et al. (2002) Ant. Met. Res. 15, 25 [21] Yada, T. et al. (2004) Earth Planet Sp. 56, 67–79