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Low-Voltage Transmission Electron Microscopy Analysis of ^{15}N-Rich Organic Matter: Insight into the Origins of Fine-Grained Antarctic Micrometeorites

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Isotopic anomalies in several elements (e.g., H, C, N, O, Si) were reported in primitive extraterrestrial material (e.g., meteorite, and Antarctic micrometeorites (AMMs)). While many of them reflect the presence of presolar inorganic grains [1], the composition and origin(s) of the N and H isotopic enrichments associated with IOM still remain unclear. Isotopic anomalous organic matter occurs as discrete domains, such as nanoglobules, and as µm-sized diffuse material composed of a mixture of carbonaceous matter and silicate/oxide grains [2-4]. However, their origin(s) is still debated and several formation models have been proposed, such as the partial preservation of presolar molecules originally formed in the interstellar clouds or at the edge of the solar protoplanetary disk [2-6]. To further constrain the origin of isotopically anomalous organic matter, we are carrying out coordinated in-situ analyses of organic matter in meteorites and fine-grained AMMs using NanoSIMS, scanning transmission electron microscopy (STEM), energy-dispersive X-ray spectroscopy (EDS) and electron energy-loss spectroscopy (EELS). This work provides information on the diversity of the isotopic composition of C-, H-, and N-bearing molecules, their microstructure and their functional chemistry from different astrophysical settings.

We identified ^{15}N-rich organic matter in a fined-grained AMMs, T98G8 by NanoSIMS ion raster imaging of C and N isotopes. We then extracted electron-transparent cross sections of three hotspots that are characterized by similar moderate enrichments in ^{15}N. The sections were prepared via previously described focused-ion-beam techniques, using the dual-beam Helios NanoLab 660 FIB-SEM at LPL [7]. Subsequently, we analyzed each section using a Hitachi SU9000 SEM/STEM with accelerating voltage capabilities from 500 eV to 30 keV. It is also equipped with an Oxford Instruments X-Max 100LE EDS detector and the newly-designed Hitachi EELS system. The low-voltage STEM, EDS and EELS capabilities of the SU9000 makes it well-suited to analyze low-Z materials like polymers, organics in meteorites, and other electron-beam-sensitive materials. It complements the suite of tools available for the coordinated studied of planetary material by providing us with STEM capabilities over a wide voltage range from 500 eV to 200 keV. Such capabilities will be particularly important for analysis of small materials returned by current and future space missions such as the samples from OSIRIS-REx and Hayabusa missions.

High presolar grain abundances, like those seen in the most primitive carbonaceous chondrites, were recently reported in several fine-grained AMMs, including T98G8 [8]. We identified numerous ^{15}N-rich hotspots in this AMM, and, unlike the matrix in many CR chondrites, it has a bulk ^{14}N/^{15}N ratio close to terrestrial values (^{14}N/^{15}N = 261). The bright-field (BF) and annular dark field (ADF) images and EDS elemental maps show that T98G8 is composed mostly of silicate grains mixed in a fine-grained groundmass of oxide, silicate and C-rich grains, without any sign of hydrous minerals that might otherwise indicate parent-body aqueous alteration (Fig. 1). In addition to the ^{15}N-rich hotspots, the EDS maps show the presence of carbonaceous matter throughout the AMM.

While being all characterized by similar ^{15}N enrichments (δ^{15}N $\simeq$ 200‰), the three hotspots show different structures and compositions. T98G8-C13-2 is composed of a hollow nanoglobule and is surrounded by

GEMS-like material (glass with embedded metal and sulfides) typically identified in interplanetary dust particles (IDPs; Fig. 1) [9, 10]. In comparison, T98G8-C13-1 is larger (1.8 µm long) and more complex with silicate and oxide grains mixed together in diffuse carbonaceous material (Fig. 1). Hotspot T98G8-E4 is characterized by a C-rich globule-like grain with an iron oxide inclusion in the center. Adjacent to the T98G8-E4 hotspot is a small (~500nm) apparently fragmented globule-like grain filled with silicate and oxide grains (Fig. 2). Our initial EELS data on several C-rich regions in hotspot T98G8-E4 suggests that they are mainly composed of aromatic carbon, with a C-K energy-loss near-edge structure containing a sharp rise from edge onset to a peak at 285 eV (the π^* peak) and a delayed maximum at ~290 eV (the σ^* peak). We did not identify any other significant edges (e.g., S, N, or O) in the EELS spectra.

Our observations in T98G8 are similar to previous studies of primitive chondritic porous (CP) IDPs [9,10], suggesting that T98G8 is composed of CP-IDP-like material and might, thus, also have a cometary origin. While its presolar silicate abundance (191 ± 38 ppm) is lower than those observed in IDPs [1], discrete areas in T98G8 are characterized by much higher abundances (~650 ppm) [8,11].

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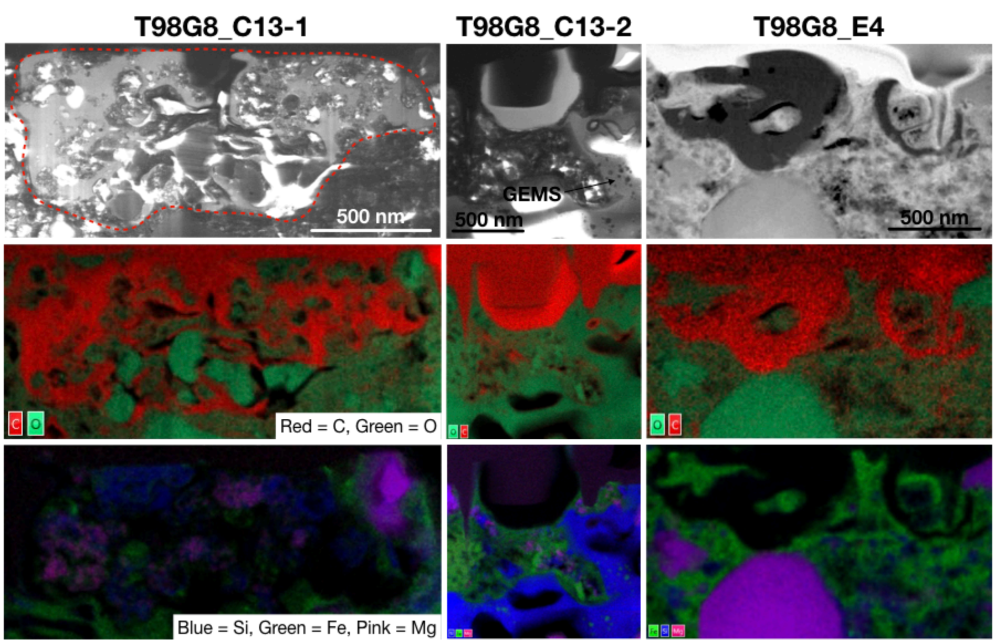

Figure 1. Bright-field (BF) and composite EDS elemental maps of hotspots T98G8-C13-1, T98G8-C13-2 and T98G8-E4.

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