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Identification and Characterization of Early Solar system Organic Matter Preserved in Chondritic Porous Interplanetary Dust Particles

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The chondritic porous interplanetary dust particles (CP IDPs), collected by NASA from the Earth's stratosphere, have experienced minimal aqueous or thermal alteration since their formation. These CP IDPs are the best preserved samples of the minerals and organic matter that was present in the primitive Solar Nebula that are currently available for laboratory analysis [1]. The $\sim$10 μm CP IDPs are aggregates of tens-of-thousands of mostly submicron grains of diverse compositions and mineralogies. Many of the individual mineral grains are coated by a 50 to 200 nm thick rims of carbonaceous material, and other carbonaceous material occurs as larger, discrete subunits within the particles [2]. We characterize this carbonaceous material using two high-resolution, synchrotron-based instruments: a Scanning Transmission X-ray Microscope (STXM) to locate and map the carbon and to identify its major functional groups by X-ray Absorption Near-Edge Structure (XANES) spectroscopy, and a micro-Fourier Transform Infrared (μ-FTIR) spectrometer to further characterize the functional groups by mid-infrared spectroscopy.

Carbon-XANES spectroscopy identifies the rims coating the individual grains in CP IDPs as organic matter, dominated by the C=C, likely C-rings, and the C=O functional groups [3]. This structure, with the organic rims being the contact surfaces between the grains, implies a 3-step formation sequence: grain condensation, organic rim emplacement, and, finally, aggregation of the grains to form the dust particles. This suggests these organic rims formed very early in the evolution of the Solar Nebula, after grain condensation but before grain aggregation [3].

These organic rims coat grains of diverse compositions, including silicates, sulfides, and carbonates, which is inconsistent with formation by Fischer-Tropsch-like, mineral-specific catalysis, one of the mechanisms suggested for the formation of primitive organic matter. Our observations are consistent with an alternate model where carbon-bearing ices condense on the surfaces of grains, the ices are irradiated by ionizing radiation, and subsequent heating removes the ices leaving more refractory organic matter on the grain surfaces, as described by Bernstein et al. [4].

In one case we obtained C-, N-, and O-XANES spectra on the rim material. The O-XANES confirmed the presence of C=O. We found high N:C and O:C ratios that plot on the extension of the N:C vs. O:C correlation line, found in analysis of meteoritic organic matter [5], towards even more primitive organic matter than found in any meteorite.

The organic rims are too thin for μ-FTIR spectroscopy, which is diffraction limited to about the wavelength/2, or $\sim$2 μm for the aliphatic C-H stretching features. However, mid-infrared spectra obtained on CP IDPs show the presence of aliphatic C-H, C=O, C-C, and O-H, as well as crystalline and amorphous silicates [6]. Aromatic C-H is rarely detected in CP IDPs. Neither the organic rims nor the bulk organic matter in CP IDPs show the graphite exciton feature, whose strength in meteorite organic matter correlates with increasing parent body thermal metamorphism [7], indicating the organic matter in CP IDPs experienced minimal metamorphism after it formed. The spectra show variation in the aliphatic –C-H_2- to –C-H_3 and C=O to aliphatic C-H ratios from spot to spot on the same particle. C-XANES of ultramicrotome sections of CP IDPs also show significant variability, particularly in the C=O to C=C ratio. Variability in the C-XANES and the mid-infrared spectra indicates the organic matter in primitive CP IDPs consists of several compositionally distinct components. Our C-XANES and μ-FTIR results indicate ***the organic matter in CP IDPs is extremely primitive*** and ***that much of the pre-biotic organic matter of our Solar System formed early in the evolution of the Solar Nebula, by a process that preceded parent body aqueous processing***.

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