Analysis of organic grain coatings in primitive interplanetary dust particles: Implications for grain sticking and the origin of Solar System organic matter

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Chondritic porous interplanetary dust particles (CP IDPs), the most primitive samples of extraterrestrial material available for laboratory analysis [1], are unequilibrated aggregates of mostly submicron, anhydrous grains of a diverse mineralogy. They contain organic matter not produced by parent body aqueous processing [2], some carrying H and N isotopic anomalies consistent with molecular cloud or outer Solar System material [3]. Scanning Transmission X-Ray Microscope (STXM) imaging at the C K-edge shows the individual grains in ~10 micron aggregate CP IDPs are coated by a layer of carbonaceous material ~100 nm thick. This structure implies a three-step formation sequence. First, individual grains condensed from the cooling nebular gas. Then complex, refractory organic molecules covered the surfaces of the grains either by deposition, formation in-situ, or a combination of both processes. Finally, the grains collided and stuck together forming the first dust-size material in the Solar System.

Ultramicrotome sections, ~70 to 100 nm thick were cut from several CP IDPs, embedded in elemental S to avoid exposure to C-based embedding media. X-ray Absorption Near Edge Structure (XANES) spectra were derived from image stacks obtained using a STXM. “Cluster analysis” was used to compare the C-XANES spectra from each of the pixels in an image stack and identify pixels exhibiting similar spectra. When applied to a CP IDP, cluster analysis identifies most carbonaceous grain coatings in a particle as having similar C-XANES spectra.

Two processes are commonly suggested in the literature for production of organic grain coatings. The similarity in thickness and C-XANES spectra of the coatings on different minerals in the same IDP indicates the first, mineral specific catalysis, was not the process that produced these organic rims. Our results are consistent with this primitive organic matter being produced by the alternative process of condensation of C-bearing ices onto the grain surfaces and production of refractory organic matter by UV or other ionizing radiation bombardment of the ices [4].

The processes by which primitive grains aggregate to form the first dust of our Solar System are not well understood. Collision experiments indicate that bare rocky grains bounce apart at collision speeds <30 to 50 m/s and shatter at larger speeds [5]. However, experiments indicate grains coated with organic matter stick quite easily, even at speeds up to 5 m/s – an order of magnitude higher than the speed at which silicate grains accrete [6]. Thus the organic grain coatings we identified likely played a critical role in dust aggregation in the early Solar System.

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