The Origin of Organic Matter in the Solar System: Evidence from the Interplanetary Dust Particles

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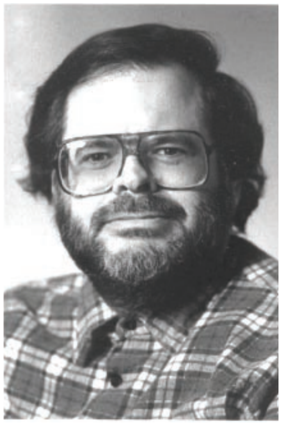
Researchers from SUNY-Plattsburgh, the NASA Johnson Space Center, and Stony Brook University measured the types and abundances of organic matter in interplanetary dust particles, originating from asteroids and comets, that NASA research aircraft collected from the Earth's atmosphere. They found the same amount and types of organic matter in both anhydrous and hydrated interplanetary dust particles. This suggests that aqueous processing, long believed to have played an important role in the production of organic matter, was much less important, and that most of the pre-biotic organic matter in the Solar System formed at about the same time as the first dust that condensed from the Solar Nebula. It is also possible that this matter formed even earlier, in circumstellar or interstellar space.

Extraterrestrial materials, including asteroids, comets, and grains in interstellar space, contain organic compounds that may have been important starting materials for the origin of life. How this pre-biotic organic matter formed is not known, but a wide variety of processes, ranging from catalyzed reactions on the surfaces of grains to reactions involving liquid water, have been proposed. If this organic matter was produced by the aqueous alteration of elemental carbon, which is believed to happen on wet asteroids, then we would expect to see organic matter occurring preferentially in interplanetary materials that exhibit evidence of aqueous activity, such as the presence of hydrated silicates. If the organic matter were produced either during the nebula phase of Solar System evolution or in the interstellar medium, we would expect this organic matter to be incorporated into the dust as it formed, so that it would be present in the anhydrous interplanetary materials as well. Earlier studies of meteorites showed abundant organic matter in the hydrated meteorites, but mostly amorphous carbon, with little or no organic matter, in the anhydrous meteorites. This suggested aqueous activity was important in the production of the pre-biotic organic matter. However, all the anhydrous, carbon-rich meteorites show significant depletions of the moderately volatile elements in a pattern that indicates these meteorites were once exposed to temperatures as high as 1200 degrees Celsius, hot enough to destroy any organic matter initially present. To make a proper comparison, we were forced to examine interplanetary dust particles (IDPs) like the one shown in **Figure 1**, which are fragments from asteroids and comets, approximately 10 micrometers in size, that NASA collects from the Earth's stratosphere. These particles are so small that we required the high sensitivity of the synchrotron-based instruments at the National Synchrotron Light Source to perform the analyses. We mapped the carbon distribution in approximately 100 nanometer (nm) thick slices of seven anhydrous and four hydrated IDPs, determining the carbon abundance, and we performed carbon x-ray absorption near-edge structure (XANES) and infrared spectroscopy, both of



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which identify specific carbon functional groups. The carbon-XANES spectra of the hydrated and anhydrous IDPs (**Figure 2**) are very similar, with strong absorptions at about 285 electron volts (eV), identifying C=C, and at about 288.5 eV, identifying C=O. The infrared spectra of the hydrated and anhydrous IDPs are also very similar (**Figure 3**), with the pair of features near the 2926 and 2854 cm^{-1} wavelengths identifying aliphatic CH_2, and the feature near 2960 cm^{-1} identifying aliphatic CH_3 (where 'aliphatic' refers to organic compounds containing short-chain arrangements of carbon atoms). In some anhydrous IDPs the individual mineral grains are coated with this carbonaceous material, apparently the "glue" holding the aggregate particle together. We found that organic matter is present in similar types and abundances in both the anhydrous and the hydrated IDPs, indicating that the bulk of the pre-biotic organic matter in the Solar System did not form by aqueous processing. Instead, this organic matter had already formed at the time that primitive, anhydrous dust was being assembled. The hydrated meteorite, Murchison, has a higher ratio of aliphatic CH_3 to CH_2 (indicating a shorter mean aliphatic chain length) and Murchison also contains more aromatic C-H (the broad absorption at approximately 3050 cm^{-1} in **Figure 3**) than either type of IDP, consistent with Murchison being more thermally processed than the hydrated IDPs.

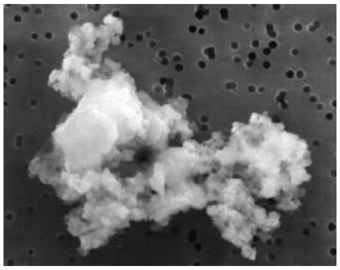

Figure 1. Scanning electron microscope image of an approximately 10 micrometer-diameter interplanetary dust particle, showing many small grains that aggregated to form the particle. (NASA photo)

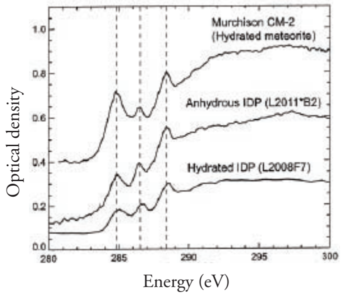

Figure 2. Carbon XANES spectra of typical anhydrous and hydrated IDPs and the organic residue extracted from the Murchison hydrated meteorite.

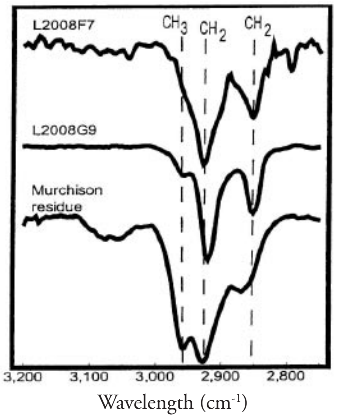

Figure 3. Infrared spectra of typical anhydrous and hydrated IDPs and the organic residue extracted from the Murchison hydrated meteorite.