EPSC Abstracts
Vol. 12, EPSC2018-38, 2018
European Planetary Science Congress 2018


# Organic Rims on Individual Grains in CP IDPs: Evidence for Organic Formation in the Solar Protoplanetary Disk

**George Flynn (1),** Sue Wirick (2) and Lindsay Keller (3)
(1) Dept. of Physics, SUNY-Plattsburgh, 101 Broad St., Plattsburgh, New York, 12901 USA (george.flynn@plattsburgh.edu),
(2) Focused Beam Enterprises, Westhampton, NY 11977 USA (3) NASA Johnson Space Center, Houston, TX 77058.

## Abstract

We identified ~100 nm thick organic coatings on individual grains, having a diverse range of mineralogies, in primitive aggregate interplanetary dust particles. These coatings formed after grain condensation from the Solar Protoplanetary Disk, but before aggregation into early Solar System dust particles. This is inconsistent with formation by mineral-specific surface catalysis, but consistent with formation by irradiation and subsequent heating of carbon-bearing ices accreted onto grain surfaces in the cold outer Solar System.

## Introduction

Chondritic porous interplanetary dust particles (CP IDPs) from comets and asteroids, collected by NASA from the Earth's stratosphere, are unequilibrated aggregates of mostly submicron mineral grains. CP IDPs range from ~5 to ~25 µm in size and each has a major element composition roughly similar to CI meteorites ("chondritic"). Most CP IDPs show no evidence of significant post-accretional parent body alteration, which overprints the record of formation processes in meteorites. CP IDPs never experienced significant hydrous or thermal parent body processing, gravitational compaction, or impact shock, and many were minimally heated during atmospheric deceleration. CP IDPs are the most cosmochemically primitive astromaterials available for laboratory study [1], ideal to decipher the record of processes that occurred in Solar Protoplanetary Disk and similar disks around other stars.

### 1.1 Mineralogy of CP IDPs

The equilibrium condensation temperatures of mineral grains in the Solar Protoplanetary Disk were modeled by Lodders [2] using Solar element abundances and a gas pressure representative of 1 AU. No individual mineral in this condensation sequence has chondritic composition, so each CP IDP is an aggregate of minerals formed over a wide temperature range, from 1300 K for silicates to 700 K for sulfides. CP IDPs are dominated by olivines and pyroxenes, with a wide range of Mg/Fe ratios, Fe- and Zn-Fe-sulfides, and glass with embedded metal and sulfides (GEMS), with other minor phases. Grain aggregation must have been inhibited in the formation region, or we would see aggregates of minerals that formed at similar temperatures. A few phases preserve non-solar isotopic ratios, identifying rare pre-Solar grains that survived disk processing.

### 1.2 Organic Grain Coatings

The individual mineral grains in CP IDPs are generally not in direct contact. Transmission Electron Microscope examination shows that many grains are coated by carbonaceous material [3]. X-ray absorption mapping at the C K-edge using a Scanning Transmission X-ray Microscope (STXM) established that the diverse variety of individual grains, including silicates, sulfides, and carbonates, in many CP IDPs are each rimmed with a thin coating of organic matter (Fig. 1 left), ~100 nm thick, independent of the grain composition [4]. X-ray Absorption Near-Edge Structure (XANES) spectroscopy identified both C=C and C=O functional groups in the organic rims [5].

Astronomical observations indicate the vast majority of grains in interstellar space are amorphous [6], so the abundant crystalline grains in CP IDPs must have formed in the Solar Protoplanetary Disk. The organic rims must have been emplaced by processes in the disk after grain condensation, but before aggregation of the grains into dust particles. Organic rims likely aided in aggregation since bare mineral grains stick only in low speed collisions, while organic coatings increase the range of sticking speeds [7].

XANES spectroscopy of organic rims demonstrates the presence of C, N, and O, with N:C and O:C ratios significantly higher than the ratios in meteoritic insoluble organic matter, plotting on the extension of the trend of increasingly primitive organic matter in carbon-bearing meteorites, suggesting these rims are very primitive organic matter (Fig. 1 right) [5].

The silicates in the CP IDPs are believed to have formed in the warm inner region of the Solar Protoplanetary Disk. The size-frequency distributions of the Mg-rich silicates (olivine and pyroxene) and Fe-sulfides show a size-density relationship in different CP IDPs consistent with aerodynamic sorting operating in the disk prior to grain aggregation [8]. This suggests aerodynamic transport of the crystalline mineral grains from the warm inner disk to a region where grains from different formation environments were mixed together.

Our observation that these grain coatings are present on silicates, sulfides, carbonates and GEMS demonstrates that mineral-specific catalysis is not the mechanism of formation. Modeling shows processing by ionizing radiation of ice coated grains in the cold, outer Solar Nebula can produce complex organic molecules [9]. Our identification of organic rims on the surfaces of crystalline mineral grains in the CP IDPs is consistent with this modeling by Ciesla and Sandford [9], providing evidence for the formation of organic matter early in the evolution of the Solar Protoplanetary Disk, after grain formation but before these grains aggregated into dust.

## Summary and Conclusions

In CP IDPs, the best preserved samples of Solar Nebula products, organic coatings forming the contact surfaces between grains implies a three-step

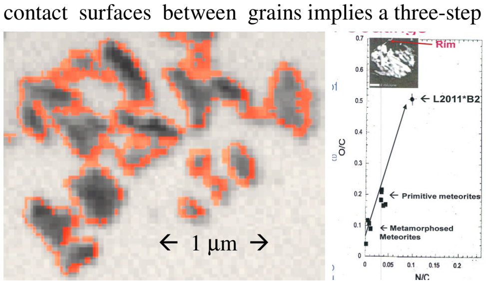


Figure 1: (Left) Absorption image of grains with organic rims in red. (Right) N/C vs. O/C for IDP rim organic, metamorphosed and primitive meteorites.

formation: mineral condensation, emplacement of organic rims, and grain aggregation. These organic rims are the earliest identified organic matter known to have formed in our Solar System. Organic coating of a diversity of minerals is inconsistent with mineral-specific catalysis but consistent with formation by irradiation/heating of carbon-bearing ices that condensed on grain surfaces. Similar processes likely ocurred in other protoplanetary disks.

## Acknowledgements

This work was supported by NASA Emerging Worlds grant #NNX17AE59G.

## References

[1] Ishii, H., Bradley, J. P., Dai, Z. R., Chi, M., Kearsley, A. T., Burchell, M. J., Browning, N. D., and Molster, F.: Comparison of Comet 81P/Wild 2 Dust with Interplanetary Dust from Comets, *Science*, 319, 447-450, 2008.

[2] Lodders, K.: Solar System Abundances and Condensation Temperatures of the Elements, *The Astrophysical Journal*, 591, 1220-1247, 2003.

[3] Keller, L. P., Thomas, K. L., and McKay, D. S.: Carbon in Primitive Interplanetary Dust Particles, in Analysis of Interplanetary Dust, AIP Conf. Proc., 310, 159- 164, 1994.

[4] Flynn, G. J., Wirick, S, and Keller, L. P.: Organic grain coatings in primitive interplanetary dust particles: Implications for grain sticking in the Solar Nebula, *Earth, Planets, Space,* 65, 1159-1166, 2013.

[5] Flynn, G. J., Keller, L. P., Wirick, S., and Jacobsen, C.: Organic matter in interplanetary dust, in *Organic Matter in Space* (ed. S. Kwok), Proc. IAU Symp. 251, 267-276, 2008.

[6] Min, M, Waters, L. B. F. M., de Koter, A., Hovenier, J. W., Keller, L. P., and Markwick-Kemper, F.: The shape and composition of interstellar silicate grains, *Astronomy & Astrophysics,* 462, 667-676, 2007.

[7] Kouchi, A., Kudo, T., Nakano, H., Arakawa, M., Watanabe, N., Sirono, S., Higa, M., and Maeno, N.: Rapid growth of asteroids owing to very sticky interstellar organic grains. *The Astrophysical Journal*, 566, L121-L124, 2002.

[8] Wozniakiewicz, P. J., Bradley, J. P., Ishii, H. A., Price, M. C., and Brownlee, D. E.: *The Astrophysical Journal*, 779:164, 2013. doi:10.1088/0004-637X/779/2/164

[9] Ciesla, F. and Sandford, S. A.: Organic Synthesis via Irradiation and Warming of Ice Grains in the Solar Nebula. *Science*, 336, 452–454, 2012.

After having finished your paper in your word-processing program, please create a respective pdf file out of the document. The correct page settings of 237 (height) x 180 (width) mm are included in the template document. **Please make sure that the generated pdf file actually has a page size of 237 x 180 mm.** This is the only way to guarantee the proper inclusion of your paper in the Copernicus Office database. Please note that you are asked to upload a pdf file during the abstract submission in Copernicus Office. No other file type than .pdf is accepted for the file upload. The actual citation header will be added automatically!

Please make sure that your pdf conversion results in a document with a page size of 237 x 180 mm!