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Submicron scale element mapping in IDPs: Constraints on dust formation and aqueous alteration

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Interplanetary dust particles (IDPs), which are ~10 micrometer in size from asteroids and comets, have been collected by NASA from the Earth's stratosphere since the 1970's. Detailed study of these particles has demonstrated that some of the anhydrous IDPs are the most primitive (i.e., least altered by thermal or aqueous processing) samples of early Solar System material available for laboratory study. Details of the chemistry and mineralogy of these primitive particles allows testing of models of nebula condensation by comparing the IDP minerals and trace elements composition to the predictions of condensation models. The hydrated IDPs provide the opportunity to observe the effects of aqueous processing on the primitive starting material, constraining the conditions (composition, temperature, pH, etc.) of the fluid.

We began a program to map major and minor element distribution in ultramicrotome sections, ~70 to 150 nm thick, of both primitive anhydrous and hydrated IDPs and to determine each element's host using Analytical Transmission Electron Microscopy (ATEM). Element mapping was performed using an X-Ray Microprobe (XRM) on Beamline ID-2-D of the Advanced Photon Source at Argonne National Laboratory, for X-ray fluorescence analysis on elements from Mg to Zn on a spatial scale of ~200 nm. This resolution is comparable to the size of individual mineral grains as well as the Glass with Embedded Metal and Sulfides (GEMS), which have been suggested to be surviving interstellar silicates.

In the first effort we have mapped the element distributions in three IDPs, two anhydrous -- L2009F3 and L2011*B2 -- and one hydrated -- L2008U13. In the ultramicrotome section of one of the anhydrous IDPs, L2009F3, Zn occurs mainly in a S-rich phase, probably Zn-sulfide, and Cr is concentrated in a single, sub-micron grain, possibly a chromite. Both Ca and Ti are enriched in a single spot that contains little or no Fe, possibly a high-temperature oxide. In both the anhydrous and the hydrated IDPs the Ni occurs mainly in Fe-sulfides, with the anhydrous IDP, L2009F3, having only high-Ni sulfide, while the hydrated IDP, L2008U13, has both high-Ni and low-Ni sulfides. In L2008U13 the Ca is concentrated in a phase that also contains Mg and Mn, possibly carbonate. L2011*B2, a fragment from a cluster IDP, is dominated by a silicate mineral with an unusually high K content. ATEM identification of the host minerals of the minor elements in these IDPs is in progress.

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From dust to planets: Reading the chemical code

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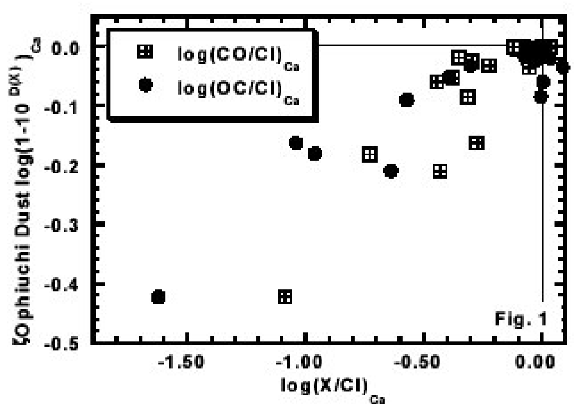
The pronounced moderately volatile element depletion (MOVED) relative to the average solar composition is a characteristic signature in most primitive chondrites and bulk terrestrial planets. None of the remaining planets or even meteorites shows an enrichment of volatile elements that would balance the depletion in the inner Solar System. Whether this depletion occurred in the solar nebula stage or in the planetary formation stage has been the subject of long lasting debate. Here I show that the MOVED patterns demonstrate a clear connection between the rocky materials of the inner solar system and the interstellar dust. The inheritance of interstellar materials in the solar system is not only documented by the presence of presolar grains, various isotopic anomalies, but also expressed in the chemical element distribution in the inner solar system materials.

The basic arguments have been presented recently by Yin (2002). Shown in Fig. 1 is the ISM dust composition that is positively correlated with that of primitive meteorites for moderately volatile elements (CO and ordinary chondrite, OC, are used as examples). Dust composition is calculated from the observed ISM gas composition using the widely held assumption that gas+dust = solar. ζ Ophiuchi Cool Gas is used as an example. Both data sets are normalised to CI and Ca.



As long as we conceive planets formed from the disk of gas and dust surrounding the young Sun, and not all dust underwent complete vaporisation, it is inevitable that the chemical composition of interstellar dust will be reflected in the rocky bodies of inner solar system.

Reference

[1] Yin, Q.-Z. (2002) LPSC XXXIII #1436