EPSC Abstracts
Vol. 10, EPSC2015-117, 2015
European Planetary Science Congress 2015

Elemental Composition of Primitive Anhydrous IDPs

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Abstract

We measured elemental compositions of five large anhydrous cluster interplanetary dust particles (IDPs) that show no evidence of significant thermal alteration during atmospheric entry and found their mean composition to be very similar to that of primitive CI meteorites. Our results indicate that the enrichment in moderately volatile elements and the depletion in S found in the ~10 µm anhydrous, chondritic porous (CP) IDPs, the matrix of these cluster IDPs, are not representative of the composition of their parent body. The inclusion of larger (>10 µm) volatile-poor silicates as well as sulfides in the large anhydrous cluster IDPs, which sample the CP IDP parent body at a larger size scale, suggests the large cluster IDPs are unbiased samples of the condensable material of the Solar Nebula.

1. Introduction

The ~10 µm chondritic porous interplanetary dust particles (CP IDPs), dust from asteroids and comets collected by NASA from the Earth's stratosphere, are anhydrous aggregates of $>10^4$ individual grains. On average these CP IDPs are enriched in many moderately volatile elements, including Mn, Cu, Zn, Ga, Ge, Se, and Br, generally by a factor of ~2 to 4 over the CI meteorites, while another moderately volatile element, S, is depleted relative to CI [1, 2, 3]. Various reasons for enrichment of the moderately volatile elements have been proposed. Van der Stap et al. [1] suggested the CP IDPs might be late-stage condensates, sampling a region of the Solar Nebula already depleted in higher temperature condensates. Jessberger et al. [2] suggested the additional volatiles were contaminants acquired while the particles resided in the Earth's atmosphere. Flynn et al. [3] suggested the CP IDPs might be a new type of extraterrestrial material, not represented in the meteorite collection. However, NASA's stratospheric collections include many non-chondritic, mono-mineralic grains -- volatile-poor olivine and pyroxene as well as calcophile-rich sulfides -- collected along with the fine-grained chondritic IDPs. Some of these larger mineral grains (many >10 µm in size), have fine-grained, chondritic material (i.e., small bits of typical CP IDPs) adhering to their surfaces, indicating they are larger fragments of the same parent as the ~10 µm, fine-grained CP IDPs. Thus, the bulk composition of the CP IDP parent body can only be determined by adding to the fine-grained, CP IDPs the *correct amount* of this non-chondritic material. The collection of cluster IDPs, larger IDPs that fragment on impact with the collector, which include both fine-grained CP IDP material and larger mineral grains provides the opportunity to determine the elemental composition of the CP IDP parent body at a significantly larger size scale, since a single large cluster IDP contains >100 times the mass of one ~10 µm CP IDP.

2. Measurements and Results

Using the ~8 µm monochromatic x-ray beam of the X26A microprobe at the National Synchrotron Light Source (Brookhaven National Laboratory), we performed x-ray fluorescence (XRF) and x-ray diffraction (XRD) on all of the material from 8 large cluster IDPs from NASA's L2005, L2008, and L2009 stratospheric collectors. We obtained the bulk composition by adding the point spectra and the bulk mineralogy by adding the x-ray diffraction patterns acquired by raster scanning the entire cluster particle.

Five of the eight cluster IDPs showed minimal evidence of thermal alteration during atmospheric deceleration, i.e., only a very minor amount of magnetite detected by XRD and Zn/Fe >0.3xCI, criteria previously identified as correlating with a low degree of thermal alteration [4]. These five cluster IDPs are dominated by anhydrous phases, since hydrous minerals were below the detection threshold in XRD. The fraction of cluster IDPs that show no evidence of significant atmospheric entry heating (five of eight) is much larger than predicted by modelling, suggesting these anhydrous cluster IDPs have a much lower density than the 1 to 3 gm/cm^3 generally assumed in the modelling.

The XRD patterns of the cluster IDPs show d-spacings consistent with a mixture of pyrrhotite, forsterite and enstatite, which, along with amorphous silicate that gives no XRD pattern, are the common minerals in IDPs. Of the elements enriched over CI in the ~10 µm CP IDPs, Zn is present in the highest amount and is most accurately determined in our XRF analysis. While Zn/Fe in ~10 µm CP IDPs is ~4xCI, the mean Zn/Fe of these five cluster IDPs is ~1.2xCI (Figure 1), presumably from the inclusion of volatile-poor silicates in these large cluster IDPs. This requires that large olivine, pyroxene, and sulfide grains, plus any amorphous silicate, constitute >70% of the mass of the anhydrous cluster IDPs, although the volume fraction of the large mineral grains would smaller because of the density difference between the crystalline grains and the more porous, fine-grained material. The S depletion seen in the CP IDPs is not seen in the large cluster IDPs, presumably from the addition of large sulfide grains. The CP IDPs appear to sample the matrix of a parent body that is dominated by larger crystalline grains, so, like the matrix of chondritic meteorites, the CP IDPs do not reflect the bulk composition of the parent body.

3. Summary and Conclusions

Based on the similarity of the elemental composition of the hydrous CI meteorites to that of the Sun, except for extremely volatile elements (e.g., H, He, and noble gases), the CI meteorites are believed to preserve the elemental composition of the Solar Nebula. The ~10 µm CP IDPs, aggregates of $>10^4$ unequilibrated, mostly sub-micron grains, have been recognized as even more primitive samples of Solar Nebula condensates [5], preserving the mineralogy because they have not experienced aqueous alteration. However the observed enrichment in the moderately-

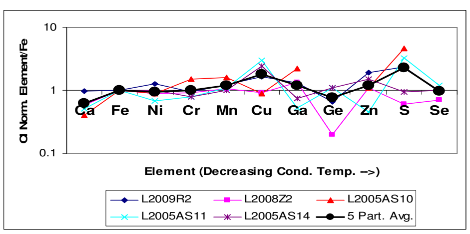

Figure 1. CI- and Fe-normalized element abundances for five large, normal-Zn cluster IDPs and the mean composition of the group of five large, normal-Zn, anhydrous cluster interplanetary dust particles.

volatile elements and the depletion of S relative to CI in CP IDPs has been difficult to understand for particles that are believed to be essentially unmodified samples of the Solar Nebula. Our results on large anhydrous cluster IDPs, which are mixtures of CP IDP material with larger mineral grains, mostly pyrrhotite, which increases bulk S, and volatile-poor silicates, which reduce the bulk volatile content, indicates the parent body of the CP IDPs is CI-like in composition, and is likely the best surviving reservoir of essentially unprocessed material from the early Solar System. The parent bodies of these anhydrous cluster IDPs would be an important target for spacecraft missions designed to collect unprocessed samples of Solar Nebula material.

Acknowledgements

The work was funded by a NASA Cosmochemistry grant NNX10AJ17G (to G.J.F.). Use of the National Synchrotron Light Source, Brookhaven National Laboratory, was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. DE-AC02-98CH10886.

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