X-ray fluorescence microtomography of interplanetary dust particles

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Introduction

Interplanetary dust particles (IDPs), which are fragments of asteroids and comets ranging from 2 to 35 micrometers in size, are collected from the Earth's stratosphere by NASA. The bulk chemical compositions of IDPs larger than ~10 micrometers have been determined using the x-ray microprobe on beamline X26A of the National Synchrotron Lights Source (NSLS) [1]. However, the minimum beam spot of the NSLS instrument is comparable in size to an IDP. This precludes measurement of the spatial distribution of elements in the IDPs, which is necessary to understand element partitioning between mineral phases.

In addition, volatile element abundances can be used to distinguish IDPs that were severely heated during atmospheric deceleration (resulting in loss of volatile elements and mineralogical transformations) from less heated IDPs [1]. However, the loss temperature of a volatile element (e.g., Zn) varies depending on the host mineral.

Methods and Materials

Conventional x-ray computed microtomography (CMT) provides three-dimensional images of the x-ray absorption coefficient distribution (a function of element-Z and density) within a specimen. Element-specific imaging can be accomplished by either of two techniques:

- Acquire transmission tomograms above and below an absorption edge of an element.
- Acquire characteristic fluorescence x-rays from the element.

The latter technique has the advantages that fluorescence x-rays from several elements can be collected simultaneously and that the sensitivities are greatly improved. We employed this technique to image the internal element distributions in four IDPs.

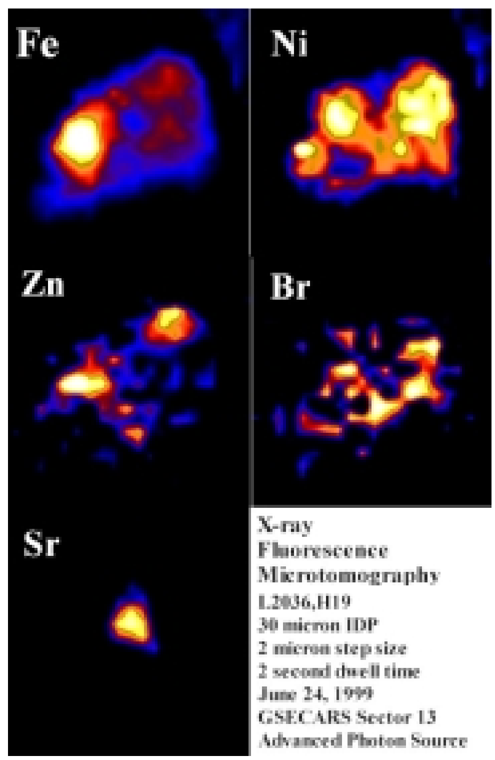
These measurements were made using the x-ray microprobe of GSECARS (sector 13) at the Advanced Photon Source (APS) at Argonne National Laboratory, using undulator synchrotron radiation focused to an ~3 micrometer beam with Kirkpatrick-Baez mirrors. Each IDP (~25 micrometers in size) was mounted on the tip of a pure silica quartz fiber, and then the fiber was mounted on the rotation axis of a x-y-theta stepping motor stage.

The tomography data were obtained by translating the particle through the x-ray beam and collecting fluorescence x-rays at each 2 micron step. The sample was then rotated by 0.5 degrees about the vertical axis and the line scan repeated. The process continued until the particle had been rotated through a total of 180 degrees, at the end of which a two-dimensional plane had been sampled. By translating the sample vertically by small increments and repeating the data collection procedure at each height interval, a three-dimensional data stack was generated.

One complication in this element-specific imaging technique is the escape depth of the fluorescence x-rays. In chondritic material, the 1/e escape depths for K-line fluorescence x-rays is ~0.2 microns for C, ~6 microns for Si, ~10 microns for S, ~30 microns for Ca, ~100 microns for Fe, etc. Thus, this technique can map elements above Fe in the large IDPs in this preliminary study, but could be extended to lighter elements in smaller IDPs.

Results

Two of the four IDPs were imaged using an x-ray energy just above the Zn K-edge (to maximize sensitivity for Zn) and the distributions of Fe, Ni, and Zn were mapped. The other two were mapped using an x-ray energy just above the Sr K-edge; distributions of Fe, Ni, Zn, Br, and Sr were obtained. The element maps in a plane through IDP L2036H19, a compact particle measuring ~30 microns in its largest dimension, are shown in Figure 1.



Discussion

The elements Fe and Ni are not strictly correlated in L2036H19. In particular, the particle includes a high Fe region that is not enriched in Ni (Fe/Ni in this region, ~4 times than that in the remainder of the particle). One possible interpretation is that this few micron region is dominated by pyrrhotite, since pyrrhotite from the Orgueil meteorite has Fe/Ni = 50. Strontium is concentrated in a single region near the center of this slice, a spot where the Fe and Zn contents are quite low. The Zn is concentrated in two regions, both adjacent to Ni-rich regions. The size is consistent with the large (micron-sized) sphalerite grains reported in transmission electron microscopy studies of IDPs. The distribution of Br is particularly important since IDPs, on average, contain unusually high concentrations of Br, which some investigators suggest are contaminant acquired in the stratosphere. No obvious Br-rich rim was detected in L2036H19.

These results demonstrate the capability of the APS x-ray microprobe to map the distribution of trace elements in IDPs on the scale of a few microns.

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Reference

[1] G.J. Flynn and S.R. Sutton, *Proceedings of Lunar and Planetary Science* **22**, 171–184 (1992).