CHEMICAL AND MINERALOGICAL ANALYSIS OF AN EXTRATERRESTRIAL PARTICLE IN AEROGEL.

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Introduction: The NASA Stardust mission is expected to collect in low-density, silica aerogel more than 1,000 dust particles >10 µm in size from the dust coma surrounding Comet Wild-2. It is planned that Stardust will return these samples to Earth early in 2006. Removal of each particle from the aerogel increases the possibility of contamination or loss, thus we are developing a facility to perform in-situ chemical and mineralogical classification of particles while they are still in the aerogel. To do this, we are enhancing the x-ray-microprobe on Beamline X26A of the National Synchrotron Light Source (Brookhaven National Laboratory) to perform a variety of in-situ analyses on the Stardust returned samples, including:

- X-ray Fluorescence Chemical Analyses of ~10 µm Particles,
- X-Ray Diffraction Mineralogical Characterization of ~10 µm Particles.
- Oxidation States by X-ray Absorption Near-Edge Structure (XANES) spectroscopy of ~10 µm particles,
- Chemical Analyses of Fragments and Volatiles Deposited Along the Entry Track,
- Spatial Distribution and Location of ~10 µm Particles, and,
- 3-D Mapping of Individual Particle Fragmentation Fields by Computed Microtomography.

As part of this instrument development effort we are analyzing a variety of particles captured in aerogel.

Samples and Techniques: We examined two aerogel "keystones" which had been extracted from aerogel collectors using the methods described in a companion paper in these proceedings (Westphal et al., 2002). One keystone was extracted from the ODCE collector flown on MIR [1], and contained the complete impact event (track and terminal residue). An image of the keystone is shown in Fig. 4 of the companion paper. The terminal particle (2DO3No.1) is ~8.5 µm in diameter, located at the end of a 1,300 micron long track. The other keystone was extracted from aerogel shot with powdered ALH83100, a CM2 chondrite, at the NASA Ames Vertical Gun Range.

We used the x-ray microprobe to measure the chemical compositions of 2DO3No.1 and one fragment of ALH83100 in aerogel. In each case we also measured a background spectrum, taken within 100 µm of the particle, to assess the contribution to each element from instrumental background and aerogel contamination. We obtained good analyses for Cr, Mn, Fe, and Ni in both particles. The CI and Fe normalized element abundances are shown in Figure 1.

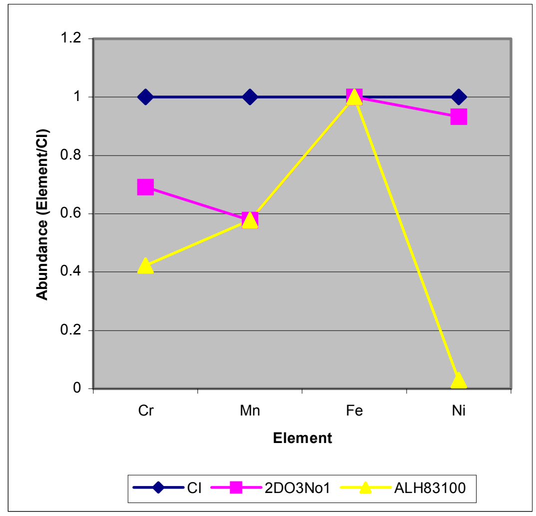

Figure 1: CI and Fe normalized element abundances in 2DO3No.1 and in an ALH84310 fragment, both captured in aerogel.

We also measured X-ray diffraction (XRD) patterns of both particles, detecting the diffracting x-rays using a Bruker CCD camera system. We previously measured the x-ray diffraction pattern of a silica aerogel sample, and determined that it contributed only weak, broad scattering at low angles that does not interfere with the detection of diffraction spots from minerals in small particles. The diffraction pattern for 2DO3No.1 is shown in Figure 2. The diffraction pattern is also plotted as d-spacing vs. azimuth (Figure 3) for comparison with literature tabulations of the d-spacings of various minerals.

Results: The combination of chemical and mineralogical data provides a more comprehensive characterization of each particle than either type of data taken alone.

Chemical Analyses. The "chondritic" chemical composition of unprocessed extraterrestrial material is quite distinctive, and is routinely used by the

Cosmic Dust Curatorial Facility at the Johnson Space Center to perform preliminary classification of the particles collected in the Earth's stratosphere. The Ni/Fe ratio is a particularly useful tool to discriminate between terrestrial and extraterrestrial particles. In chondritic material the Ni/Fe ratio is about 1:18.5, while Ni is lower by several orders of magnitude in natural terrestrial material from the Earth's surface. However, some man-made steel has relatively high Ni, so we use the set of 4 elements, Cr, Mn, Ni, and Fe, to distinguish orbital debris from chondritic extraterrestrial particles.

2DO3No.1, the particle captured in aerogel on the MIR Space Station, has Cr/Fe, Mn/Fe, and Ni/Fe ratios all within a factor of 2 of CI (as shown in Figure 1), demonstrating that 2DO3No.1 is chondritic in composition and extraterrestrial in origin.

The fragment from the ALH83100 meteorite shows more significant deviations from chondritic, with chromium depleted to ~0.4 x CI and Ni depleted to ~0.03 x CI. The low Ni suggests this fragment may be dominated by a metal or silicate grain.

Mineralogical Analyses. The extraterrestrial particle (2DO3No.1) produced diffraction at angles corresponding to d-spacings of 2.45, 2.51, and 2.77 angstroms. These are quite close to the literature values for the three most prominent d-spacings of magnesian fayalite (2.81, 2.49, and 2.55 angstroms).

Of particular interest is the absence of magnetite in the x-ray diffraction pattern of 2DO3No.1. In previous analyses of interplanetary dust particles collected from the stratosphere we have observed three relatively intense magnetite diffraction rings in every chondritic particle. The absence of detectable magnetite in 2DO3No.1 suggests, as we expected, that the bulk of the magnetite in interplanetary dust particles collected from the stratosphere is an alteration product produced on atmospheric entry. Further, it suggests that hypervelocity aerogel capture does not produce detectable magnetite.

The ALH83100 fragment has a prominent diffraction at a d-spacing of 2.90 angstroms, and weaker diffraction spots at 2.55, 2.38, and 2.10 angstroms. While the spot at 2.55 angstroms is consistent with fayalite, indicating that fayalite may be present in the particle, the other d-spacings demonstrate that the particle contains other minerals.

Since the XRD analyses being done at Beamline X26A use a focused beam roughly 10 μm in diameter, the spottiness of the pattern, in contrast to well-defined Debye-Sherrer rings, indicates that the crystallites are either relatively coarse with respect to the beam size or have preferred orientations. Thus,

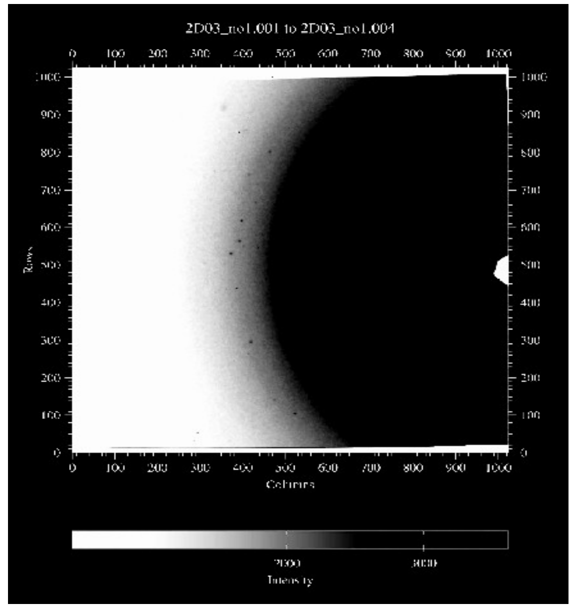

Figure 2: X-ray diffraction pattern of 2DO3No.1, showing diffraction spots (black).

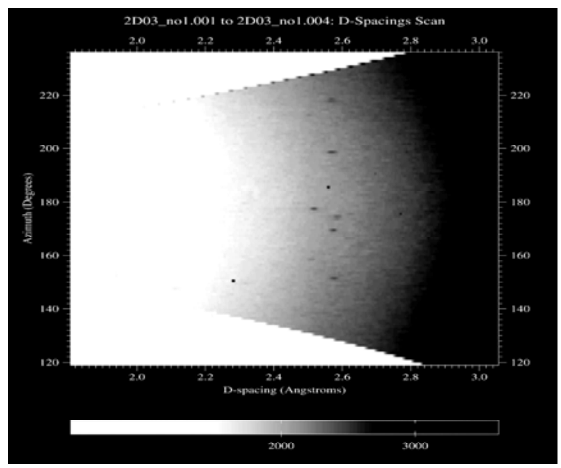

Figure 3: D-spacing plot of the diffraction image shown in Figure 2. Spots aligned along a vertical line have the same d-spacing.

although the d-spacings are well-defined, relative peak intensity cannot be evaluated. We are developing techniques to rotate these samples during analysis in order to better define both d-spacing and intensity data, providing more compelling mineral identification in future analyses.

Conclusions: Particle 2DO3No.1, captured on MIR, is chondritic in its Cr/Fe, Mn/Fe, and Ni/Fe contents, indicating that it is extraterrestrial. This particle exhibits an x-ray diffraction pattern consistent with fayalitic olivine.

References: [1] Horz, F. M. E. Zolensky, R. P. Bernhard, and T. H. See (2000) *Icarus*, **147**, 559-579.