TOF-SIMS ANALYSIS OF COMET WILD 2 PARTICLES EXTRACTED FROM STARDUST AEROGEL.

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Introduction: Dust from comet 81P/Wild 2 was collected in January 2004 and safely returned to Earth two years later by NASA's *Stardust* mission [1–3]. Low-density silica aerogel with a total exposed surface area of 1039 cm^2 was the primary capture medium for the cometary dust.

Individual fragments of cometary particles were extracted from the aerogel, in order to determine their elemental, isotopic, mineralogical, and organic properties. The grains were embedded in epoxy and microtome slices were prepared to provide samples for a multitude of analytical techniques.

Time-of-flight secondary ion mass spectrometry (TOF-SIMS) is one of the techniques that was used to analyze sections of cometary fragments provided as microtome slices or potted butts that remained after sectioning about one half of the respective particle.

This study is part of efforts by the bulk composition, organics, and mineralogy-petrology teams of the *Stardust* Preliminary Examination, which recently reported their results [4–6].

Samples: Eight samples from seven cometary fragments that were extracted from three different tracks in *Stardust* aerogel were investigated in this study. All tracks showed fragmentation that occurred during impact of the original cometary particle.

Two samples are from Track 2 from a loose aerogel chip (FC3) that has not been tied to a specific cell. Three terminal grains from this track were removed from the aerogel. Samples FC3,0,2,1,0 and FC3,0,2,2,3 are from the first and the second grains, respectively.

Two samples are from Track 44 from cell C2004. This track is the largest impact in the entire cometary tray. The impacting cometary particle had struck the edge of the tray frame covered by Al foil before bouncing into the aerogel. Without removing the cell from the tray, five grains were pulled from the track. Samples C2004,1,44,4,0 and C2004,1,44,4,5 are from the fourth grain.

Four different fragments from Track 35 from cell C2054 were investigated (Fig. 1). C2054,0,35,16,9 and C2054,0,35,24,5 were extracted from the wall of the bulbous part of the track. C2054,0,35,44,0 and C2054,0,35,45,0 are from the stylus that leads towards the terminal grain.

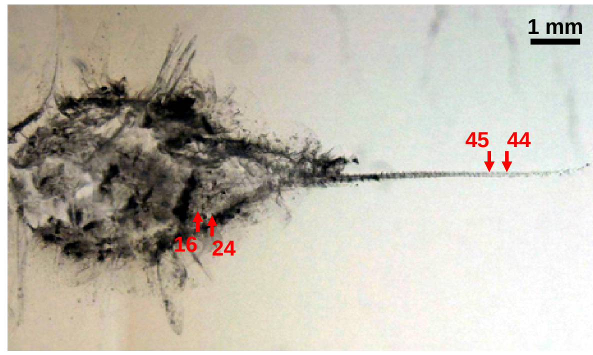

Fig. 1. Track 35 from cell C2054. Particles 16, 24, 44, and 45 were extracted from the aerogel and investigated in this study.

Experimental Procedures: During TOF-SIMS analysis, the particle sections were raster-scanned for ~12 hours with an intermittent Ga^+ primary ion beam with a beam diameter of ~0.2 µm, a pulse length of ~1.5 ns, and a repetition rate of 10 kHz. Prior to the measurement, all analyzed surfaces were cleaned by Ar^+ sputtering. Both polarities were analyzed in two consecutive measurements. Further details on the TOF-SIMS technique are given by [7].

For quantification, relative sensitivity factors obtained from glass standards were applied [7]. All quantitative results in this study are given as atomic element ratios relative to Fe. Systematic uncertainties are expected to be on the order of a factor of <1.5.

Results and Discussion: All particles have rather heterogeneous chemical compositions. Exemplarily, Fig. 2 shows secondary ion distribution images for sample FC3,0,2,1,0. This cometary fragment has a large Ti enrichment in an unidentified mineral phase. Al and Ca together with some Na and Mg are concentrated in another region, about 1 µm in diameter. This region may be attributed to some Ca,Al-rich mineral, such as observed in another Wild 2 sample [6]. An Fe hotspot also shows high Mg and Ti. K forms an outer rim that is indicative of a surface correlated enrichment present in the aerogel. Si from the aerogel dominates the composition of the sample. The Si/Fe-ratio is ~30. Because the lateral distribution of Si (Fig. 2) shows high concentrations not only at the rim of the particle but also in the interior, it can be deduced that this sample consists of fine-grained material intermingled with aerogel.

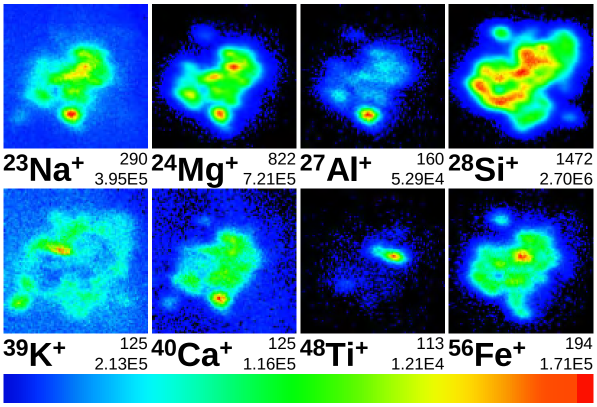

Fig. 2. TOF-SIMS secondary ion images for sample FC3,0,2,1,0. The field of view is 9×9 µm². All individual ion images use the same linear color scale shown, where black corresponds to zero counts and red is used for the maximum intensity given below every image (e.g., 290 counts for $^{23}Na^{+}$). The other number underneath each image is the integrated intensity of the entire field of view (e.g., 3.95×10^{5} for $^{23}Na^{+}$).

Sample C2004,1,44,4,0 has a small grain on the rim that seems to be pure Al (Fig. 3). Since the impacting particle hit the Al foil on the *Stardust* tray frame before entering the aerogel, it seems plausible that the particle has acquired some Al contamination from the foil.

This cometary fragment also contained polycyclic aromatic hydrocarbons (Fig. 3) that seem to be indigenous to the sample. This is further discussed in [5].

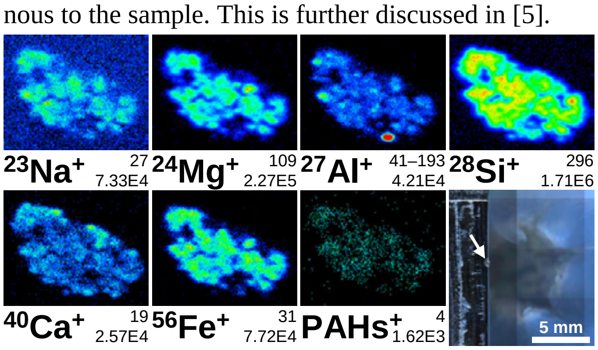

Fig. 3. TOF-SIMS secondary ion images for sample C2004,1,44,4,0. The field of view is 25×20 µm². The lower left is an optical image of Track 44, the largest impact feature on the entire cometary tray. The impacting particle struck the edge of the tray frame (white arrow) before bouncing into the aerogel.

From the composition of the four fragments investigated from Track 35 (Fig. 1), it can be inferred that the projectile was rather heterogeneous. While two Mg-rich grains with Mg/Fe-ratios of 1.8 and 2.1, respectively were found in the bulbous part of the track, both fragments close to the terminus have relatively higher Fe contents with Mg/Fe-ratios of 0.4 and 1.1, respectively.

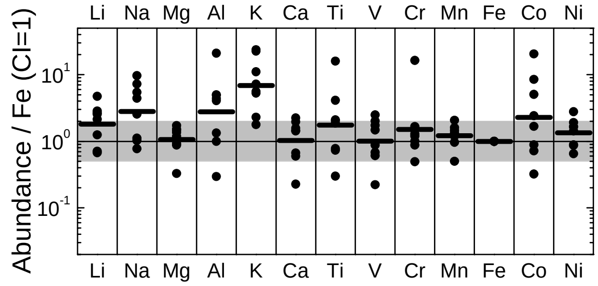

Fig. 4. Element abundances of eight cometary fragments extracted from Stardust aerogel relative to Fe and normalized to CI chondritic values. Horizontal bars represent geometric mean values.

All cometary fragments are dominated by Si, with Si/Fe-ratios raging from 30 to 110. However, for other elements, the overall composition is close to CI chondritic values (Fig. 4).

Conclusions: The TOF-SIMS investigation of samples from seven cometary fragments from three different tracks in *Stardust* aerogel clearly confirmed the heterogeneity of Wild 2 cometary matter. None of the grains showed monomineralic composition, but they all consist of various sub-grains that are intimately mixed with aerogel.

Although large deviations from CI chondritic composition were observed for individual particles, the average composition reflected by the geometric mean values shown in Fig. 4 is close to bulk CI chondritic values that seem to represent the bulk composition of comet Wild 2 [4]. Taking into account that only eight particles were investigated in this study, this might be a surprising result.

From the fine-grained nature of all investigated samples, their CI chondritic bulk composition, the lack of hydrated mineral phases [6], and the presence of organic matter, the cometary fragments seem to resemble chondritic porous interplanetary dust particles, which have previously been suggested to originate from comets [8, 9].

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