

Effects of hypervelocity capture in aerogel ion the compositions of common silicate materials

S.M. Jones¹, N. Heinz¹, A. Westphal²

¹Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109-8099

(Steven.m.Jones@jpl.nasa.gov; ²Space Sciences Laboratory, University of California, Berkeley, Berkeley, CA, 94720.

Introduction: In 2004 the Stardust Mission spacecraft encountered the comet 81P/Wild2 and collected dust from the comet in 132 silica aerogel cells [1]. The spacecraft returned to earth and released the sample return capsule containing the aerogel in 2006. Since that time, aerogel cells have been removed from the flight tray and particles have been extracted from the aerogel. Analyses of the particles have determined that the particles are primarily olivine, pyroxenes, iron-nickel-sulfides, and metals, well as some feldspars and GEMS (glass with embedded metal and sulfides) [2]. While many impact tests have been conducted to test the alterations that mineral grains may experience during hypervelocity capture in very low density silica aerogel, many of the minerals found in the comet have not been tested. Also, many of the tests conducted were done with fairly large projectiles (100 microns) and higher density silica aerogel. For these reasons, it was decided that hypervelocity impact capture tests should be conducted with smaller projectiles (5 – 100 micron diameters) of minerals found in the comet 81P/Wild2 and with Stardust-like 10 – 50 mg/cc gradient density silica aerogel.

Experimental: Gradient density (10 – 50 mg/cc) silica aerogel was produced following production method developed for the Stardust Mission. Minerals were obtained from Minerals Unlimited and Mineralogical Research Co. The minerals used for these impact tests were forsterite (Webster), fayalite (Coso Hot Springs), fayalite (Kajia-Kanagawa ken), knebelite (Highland Bell Mine), monticellite (Crestmore Quarry), hedenbergite (Akadani Mine), hedenbergite (Broadway Mine), laihunite (Kamitaga), enstatite (Mirabel Springs), diopside (Hirado Mine), diopside (Schefferite), clinoenstatite (Astor; AV), clinoenstatite (Shigar Valley; SV), and augite (Oaxaca). The two clinoenstatite samples were in fact augite samples based on XRD and Raman characterization. The minerals required for the impact tests were separated from the bulk sample received as necessary. Portions of each mineral were

ground with a mortar and pestle and sieved (170 mesh). This results in powders with particles ranging from a few microns to approximately 100 microns. Characterization of the mineral projectiles prior to impact tests was done with a Horiba XGT – 7200 X-Ray Analytical Microscope and a Bruker Sentarra Raman Microscope (785 nm and 532 nm laser).

The hypervelocity impact capture tests were done at the Ames Research Center Advanced Vertical Gun Range. The mineral powders (9±3 milligrams) were loaded into a metal carrier cup and launched at a target consisting of four 4 X 3 X 2 cm aerogel cells. The powder dispersed during flight, forming a cloud of particles, most of which struck one of the aerogel cells. The range of the speeds of the carrier cup over the fifteen shots done were from 5.2 to 6.2 km/s, approximating the 6.1 km/s capture speed of the cometary particles in the Stardust cometary collector.

Several dozen mineral particles were manually extracted from the aerogel cells. Most of the extracted particles included attached aerogel, although some of the particles were removed without any attached aerogel. The first three dozen of the particles extracted were placed between two round microscope cover slips that were taped together. These samples were used for Raman analysis. Additional particles were attached to one microscope cover slip with a very thin layer of silicone sealant. These were used for X-ray fluorescence analysis, as well as Raman analysis when possible.

Results and Discussion: The results from the Raman spectroscopy are summarized in Table 1. Raman peaks have been found to be characteristic of the compositions of olivines and pyroxenes [3,4]. The values given as Experimental Peaks and Sample Standard Peaks are average values for many samples, except for fayalite/knebelite where only two spectra were obtained. In general, the peaks from the pre-impact samples (Sample Standard Peaks) were found at wavenumbers slightly lower than the values given in the RUFF Database. The Experimental Peaks, i.e.,

the peaks from the captured and extracted samples, were the same for forsterite, monticellite and augite AV as the corresponding Standard Samples peaks, i.e., those of the unshot particles. Harris, et al., found that for forsterite a minimum shock pressure of 65 – 86GPa was required to permanently change the Raman spectra [5]. Since capture in aerogel does not result in such high shock pressures, a change in the Raman spectra would not be expected. The rest of the mineral samples had one or more peaks that varied by several wave numbers. In each case, the Experimental values were less than the Standard values. There is no observed correlation between the size of the captured and extracted particles (range 7 to 100 microns) and the Raman spectra obtained.

The results from the XRF measurements are shown in Figures 1 and 2. The black filled circles are the Sample Standard compositions, while the unfilled circles are the values for the

capture samples. The overall conclusion to be drawn from these results is that the forsterite, monticellite and the fayalite/knebelite samples typically lost a few percent of their magnesium relative to the amounts of iron and calcium. Since hedenbergite contains very small quantities of magnesium, this alteration was not observed for these mineral samples. The pyroxene samples captured in aerogel showed a similar decrease in magnesium. Overall, the samples captured in aerogel at velocities of between 5 and 6 km/s were altered very little by the hypervelocity process as determined by Raman and XRF analysis.

References: 1. Brownlee, D., et al., *Science* 314, 2006, 1711-1716, 2. Zolensky, M. E., et al., *Science*, 314 (2006) 1735-1739. 3. Kuebler, K. E., et al., *Geochim. Cosmochim. Acta*, 70 (2006) 6201-6222. 4. Foster, N. F., et al., *Geochim. Cosmochim. Acta*, 121 (2013) 1-14. 5. Harris, K., Burchell, M. J., *Meteor. Planet. Sci.*, 51(7) (2016) 1289-1300.

Table 1 – Raman Spectroscopy Summary

Mineral	Experimental Peaks (Average, cm ⁻¹)	Sample Standard Peaks (Average, cm ⁻¹)	RUFF Database Peaks (Average, cm ⁻¹)	Peak Resolution
Forsterite	817, 850	817, 850	822, 855	Good
Fayalite/Knebelite	809, 840	815, 841	815, 841	Poor
Monticellite	817, 849	818, 850	817, 850	Fair
Diopside	661, 1006	664.5, 1011	666, 1012	Poor
Enstatite	330, 662, 678, 1006	339.5, 661.5, 682, 1009	340, 662, 682, 1007	Good
Augite (XLS)	664, 1005	672.5	215, 667, 1010	Fair
Augite (AV)	671	672	215, 667, 1010	Good
Augite (SV)	221, 668	222, 673, 1028	215, 667, 1010	Good
Hedenbergite	649, 1003	650, 1007	660, 1012	Good

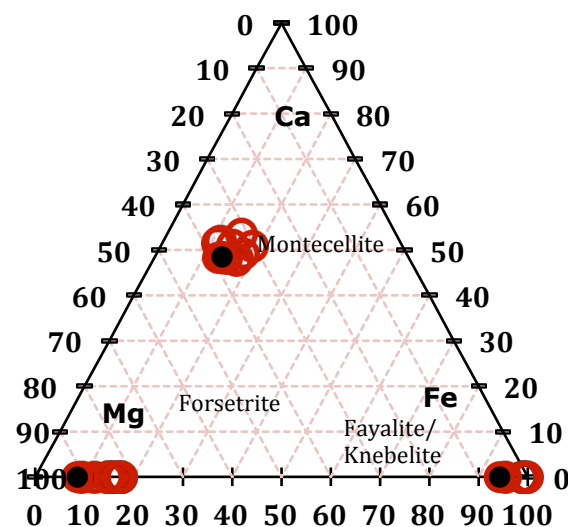


Figure 1 – Ternary phase diagram for olivines.

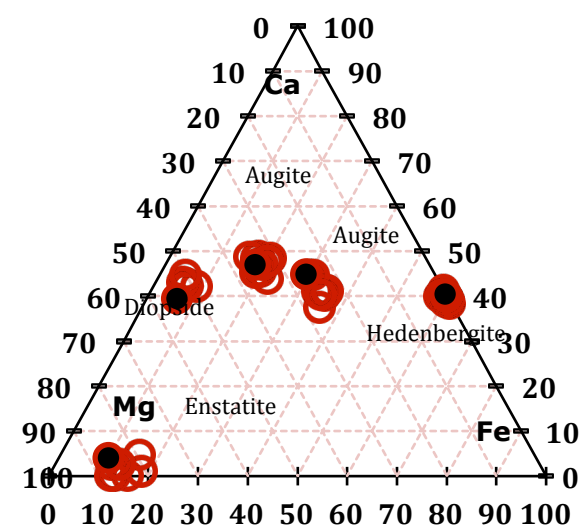


Figure 2 – Ternary phase diagram for pyroxenes.