

**TRACE ELEMENTS IN ‘CLEAN’ STARDUST GLASS: AN AEROGEL BACKGROUND OR COMET WILD 2 SIGNATURES?** F. J. M. Rietmeijer and E. Dobrică, Department of Earth & Planetary Sciences, MSC03 2040, 1 University of New Mexico, Albuquerque, NM 87131-0001, USA, fransjmr@unm.edu

**Introduction:** It begins with the underdense, density-graded silica aerogel tiles made to capture ejected dust from 81P/comet Wild 2. This aerogel contained ppm-levels of the rock-forming elements, Mg, Fe, S, Ca, Al, Na and K [1]. It was thought that hypervelocity (6.1 km/s) capture would concentrate these elements in “clean”, *i.e.* inclusion-free, SiO<sub>2</sub> glass that would give rise to a false chemical signal of the true chemical abundances of Wild 2. Accepting that silica glass was contaminated by concentrated elements from pre-flight silica aerogel, two different approaches were taken to address the issue: (1) ignoring SiO<sub>2</sub> glass >99.5 mole% or discarding areas [in aerogel] with “less than 1% of non-SiO<sub>2</sub> [oxides] from further consideration [2,3] and (2) analytically establishing a chemical background for each Stardust allocation using inclusion-free silica glass [4,5]. There is new evidence that gold nanograins in aerogel may not be concentrated into measurable energy dispersive (EDS) abundances in silica glass [6]. Is it possible then that comet chemistry survived intact mixed into the purest silica glass or as tiny particles in almost pure silica glass? The tiny Fe,Ni particles in the almost pure silica glass are visible (Fe,Ni) or (Fe,Ni,S) remnants of Wild 2 sulfides but the silicate-elements from melted comet grains leave only “chemical ghost signatures” in silica glass [7]. What was considered a chemical background of concentrated aerogel-elements is in fact comet material. Rare “ghost-grains” embedded in silica glass with the characteristic, electron-opaque Fe-Ni-S nanograins are somewhat of enigma. They can have Mg-Al-[Si] [8] and Mg-Al-Ca-K-[Si] compositions [7]. They might form (1) quenched droplets of melted Wild 2 silicates or (2) quenched-liquid shells on surviving Wild 2 grains.

**Objective:** Using the Transmission Electron Microscope (TEM) sections in the previously analyzed allocation FC6,0,10,0,26 (track 10) that was probed in a point-by-point EDS mode [7], this work will compare the results of element mapping of the same sections to address the question: “*is there a gradual transition from “ghost grains” to surviving chemical traces of Wild 2 dust in almost pure silica glass?*” *The answer addresses the question whether aerogel-contaminant element concentrations might be sufficiently concentrated to cause [EDS] measurable comet Wild 2 signatures preserved after to dust fragmentation and/or melting during hypervelocity dust capture [6,7,9].*

**Method:** Dark-field TEM and element mapping were obtained using high-angle annular dark-field annular scanning transmission electron microscopy (HAADF-STEM). All imaging and analysis was carried out at 200kV on a JEOL 2010F FEGTEM/Scanning TEM equipped with a GATAN GIF 2000 system. In situ EDS X-ray analyses and maps were obtained using an Oxford Instruments Aztec EDS system equipped with an Oxford X-Max<sup>N</sup> 80T EDS detector. The Cliff-Lorimer thin film approximation was used for quantification of EDS data using theoretically determined *k*-factors. The EDS data were collected using raster analysis over specific areas in STEM mode.

**Results:** In a single discrete area of silica glass in this allocation three ~25-nm core-ring sulfide grains [7] are surrounded by a high concentration of electron-opaque spheres ranging from ~15 nm to ~1 nm. The core-ring grains have low-Cr, low-S, Fe(Ni)-Cr-S compositions. While the smaller grains may show similar compositions, they are mostly low-S eutectic [7] Fe,S and stoichiometric FeS grains with or without small amounts of chromium. Their measured compositions are quenched daubréelite (Cr<sub>2</sub>FeS<sub>4</sub>)/sub-S FeS melts, and quenched chromite (Cr<sub>2</sub>FeO<sub>4</sub>)/FeS melts. These sulfides are a common Wild 2 feature [10]. Chromite and daubréelite are comet Wild 2 dust. This scenario predicts a uniform Cr composition in the immediate surrounding silica glass and possibly beyond. Element mapping showed a uniform Cr distribution of up to 0.5 wt. % Cr (or 0.2 at. % Cr) in magnesian silica glass. In this petrographic context the uniform Cr background is clearly a Wild 2 rather than a silica aerogel background signature that would be dismissed from further consideration.

This allocation contains a large (660 nm x 550 nm) grain of conjoined plagioclase and leucite crystals. Plagioclase developed chemical disorder during hypervelocity-capture flash-heating [7] (Fig. 2a). Chemical disorder is expressed as random domains with compositions consistent with Ca,Al loss. A (Mg-Al-Ca-K)-silica globule also present in this allocation shows that both plagioclase and leucite experienced flash-heating [7]. No sodium was associated with this globule. The spot-analyses showed a trace of sodium in the silica glass closest to the plagioclase grain.

The Na,Ca,Al elemental map (Fig. 2b) shows sodium associated with plagioclase but also across the magnesiosilica silica glass with embedded Fe-Ni-S grains and containing small amounts of Ca and Al.

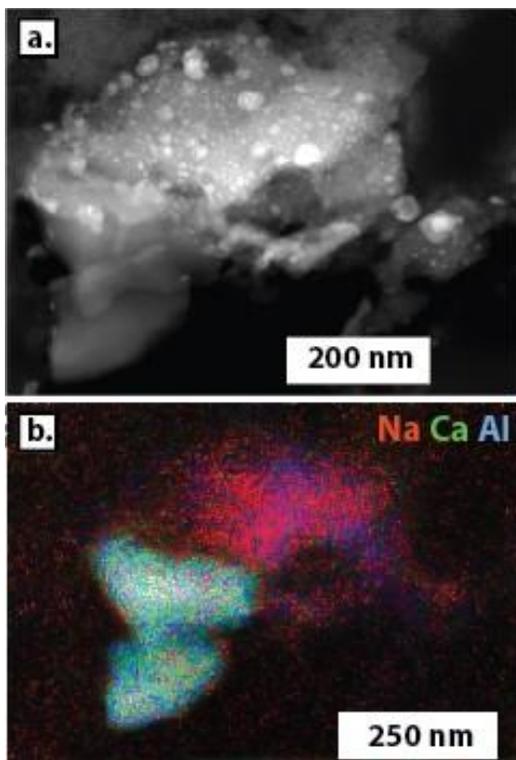


Figure 2: (a) Dark-field scanning TEM image of magnesiosilica glass matrix with embedded Fe,Ni,S nanograins (bright) in allocation FC6,0,10,0,26 with a shark-tooth-shaped thermally modified plagioclase grain, and [7] (b) the Na,Ca,Al map in an ultramicrotome section of allocation FC6,0,10,0,26.

The Na,Ca,Al map (Fig. 2b) shows a lower Na signature across the thermally-affected plagioclase grain than across the rest of the sample that is dominated by typical Mg-bearing silica glass with embedded Fe-Ni-S nanograins. The Na abundance across this large area of the Mg-bearing silica glass is 0.5 wt. % (or 0.4 at. %). No measurable amounts of sodium were found elsewhere in the sections of this allocation.

We suggest that this original Wild 2 plagioclase grain was not 100% pure  $\text{CaAl}_2\text{Si}_2\text{O}_8$  but contained a small amount of Na. Flash-heating during hypervelocity capture not only caused Ca-Al domain formation and (Al,Ca) loss. It also released sodium at temperatures below the Na-K feldspar melting temperature at  $\sim 1100^\circ\text{C}$ . This Na-cloud appears to be a local feature. Whatever the correct interpretation of this feature maybe the correct one within the context of the entire track, it shows that very low abundances of hyper-

velocity-induced melts (vapors?) of Wild 2 matter can be redistribution throughout silica glass. While the Na distribution may turn out to be a localized phenomenon across the magnesiosilica matrix, the Al/(Al+Ca) ratios (at.) varied across this matrix also showed random, localized, variations.

The ideal plagioclase Al/(Al+Ca) (at.) ratio is 0.67 but this ratio in the chemical domains of the thermally modified plagioclase [7; Fig. 2] cluster at Al/(Al+Ca) = 40 and  $\sim 80$ . Across the silica glass matrix in this allocation these measured Al/(Al+Ca) ratios are  $\sim 0.8$  and  $\sim 0.9$ . It has to be kept in mind that in these silica glass sections the actually measured element abundances are very low, viz. (1) Al = 1.0 wt.% (or 0.7 at.%) and Ca = 0.24 wt.% (or 0.1 at. %). A single,  $\sim 80$  nm in diameter, Al-“hot spot” is an aluminosilica “ghost grain” (8.7 wt. % (or, 6.6 at. %)). It has no obvious connection to the thermally-modified plagioclase that was flash-heated during hypervelocity that initiated several different chemical responses that affected different locations within this small volume of Stardust glass. Albeit in an oblique way, with the EDS detection limits and the causal link to the Wild 2 plagioclase in mind, these preliminary results show that refractory element impurities in the pre-flight silica aerogel may not reach EDS-detectible abundances.

**Discussion:** These preliminary results show causal links between Wild 2 particles and very-low element chemical signatures in Mg-bearing silica glass can be are linked to “local” sources. They cause both localized and allocation-wide chemical signatures in Mg-bearing glass. We find no evidence that the very low chemical abundances represent concentrated chemical contaminants from the pre-flight silica aerogel. In this allocation, there was no chemical silica aerogel background that needed to be removed from the silica glass composition. Further studies may show that the Stardust aerogel performed very well indeed.

**References:** [1] Tsou P. et al. (2003) *JGR*, 108, E8113. [2] Stodolna J. et al. (2009) *Meteoritics & Planet. Sci.*, 44, 1511-1518. [3] Stodolna J. et al. (2012) *GCA*, 87, 35-50. [4] Rietmeijer F. J. M. (2009) *Meteoritics & Planet. Sci.*, 44, 1121-1132. [5] Rietmeijer F. J. M. (2015) *Meteoritics & Planet. Sci.*, 50, 1767-11789. [6] Rietmeijer F. J. M. (2016) *Meteoritics & Planet. Sci.*, 51, 574-583. [7] Rietmeijer F. J. M. (2016) *Meteoritics & Planet. Sci.*, 51, 1871-1885. [8] Leroux H. et al. (2008) *Meteoritics & Planet. Sci.*, 43, 97-120. [9] Ishii H. A. et al. (2008) *Science*, 319, 447-450. [10] Zolensky M. E. et al. (2006) *Science*, 314, 1735-1939. This work was supported by NASA Grant NNX14AF21G