CONSTRAINING THE EFFECT OF CAPTURE-HEATING ON COMETARY SILICATES AND SULFIDES UNDER STARDUST ENCOUNTER CONDITIONS.

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Introduction: The aluminium foils on the STARDUST spacecraft had the primary function of securing the aerogels in place, however they also provided an extra surface totaling $153 cm^2$ [1] upon which cometary materials may be examined, in the form of impact residues. The return of the STARDUST cargo and the ensuing examination by the Preliminary Examination Team (PET) revealed the successful capture of many particles in both aerogel and foil [2]. These cometary materials are now available for analysis. Fully exploiting this unique opportunity requires that we understand the impact process occurring on foils and in aerogel; and in particular, whether it is possible to distinguish the most important minerals expected within cometary materials and to establish how their compositions may have been modified during capture. The success of mineral interpretation for terminal particles [3] shows that larger grains pose no great problems. However, the admixture of aerogel and fine particle remnants [3] along aerogel tracks suggests that it may be useful to determine the composition of smaller grains in-situ in aluminium foil craters. Our preliminary work aimed to determine whether Scanning electron microscopy (SEM) and energy dispersive X-ray microanalysis (EDX) analyses of crater residues (illustrated in Figure 1) from laboratory experiments could be interpreted to determine the initial projectile composition (See Figure 2).

For our initial study, a range of magnesium silicates (Mg-rich olivine (Fo_{89}), enstatite, diopside and lizardite) were chosen as representative of minerals likely to be contained within comets [4]. The Mineralogy & Petrology PET paper [3] has reported the common occurrence of magnesium silicates, namely olivines and (mostly low-Ca) pyroxenes and also Fe-Ni sulphides. The observation that Wild 2 olivines cover a wide range of compositions prompted us to extend our study to cover a suite of olivines spanning the Fo-Fa range (Fo_{100}, Fo_{80}, Fo_{60}, Fo_{40}, Fo_{20} and Fo_{0}).

Iron-sulphides found so far in STARDUST samples are very informative minerals, with the apparent lack of intermediate phases between iron sulphides and iron-nickel sulphides implying that they condensed as crystalline rather than amorphous grains (which might have then annealed), and the rare occurrence of pentlandite being the only suggestion of low temperature metamorphism under oxidizing conditions or aqueous alteration [3]. During the PET it was also suspected that capture in aerogel had significantly modified initial sulfide compositions, with progressive loss of S [3, 5] and therefore it is important to assess the extent to which these minerals have been modified. Any modification of primary sulfide compositions is also significant for understanding the bulk composition of Wild 2, since loss of S may imply loss of other volatiles including trace elements that are chalcophile in nature. We are currently analysing the effects of impact on iron sulphides - pentlandite and pyrrhotite.
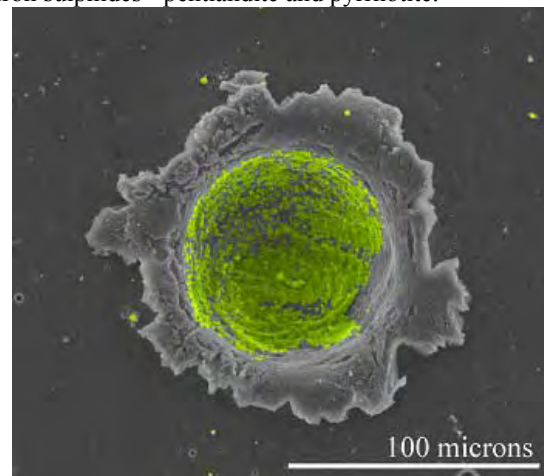

Figure 1: A laboratory crater imaged using an SEM showing the extent of residue preserved after impact (Fe X-ray map shows pyrrhotite residue in yellow).

Experimental methodology: The magnesium silicates: olivine (Fo_{89}), enstatite, diopside and lizardite (along with the pyrrhotite) are from NHM collections. Finding homogeneous, natural samples of olivines with compositions lying in tight groups across the range of Fo-Fa is near impossible, therefore synthetic olivines commissioned from Richard Brooker, Dept. of Earth Sciences, University of Bristol, for use as standards in the XRD laboratory of the NHM were employed. Available museum samples of pentlandite were generally very small, pure crystals incorporated in larger masses of pyrrhotite, chalcopyrite and pyrite and therefore proved very difficult to isolate. A sample of pentlandite from Sudbury (Ontario), containing a pure crystal large enough to extract was eventually purchased and characterized for projectile use.

For this study, a series of light gas gun shots at ca. 6kms^{-1} were conducted at the University of Kent using STARDUST foil targets. The projectiles were all single-phase grains; being taken from either well characterized natural or synthetic sources, and were fired as a buckshot [6] and therefore required crushing and sieving prior to firing. Whilst most cometary particles appear to be polymineralic aggregates of small grains [2,3,7], in order to understand the behaviour of these particles it is clearly a prerequisite that we understand the behaviour of individual phases. In addition, single-phase grains of each of these minerals are commonly observed in the STARDUST sample suite [2,3,7].

A large array of analytical tools are available for residue analysis (e.g. [8]), which may cause varying degrees of damage to the sample. Defining composition as early in the investigation process as possible is therefore vital. SEM and EDX were the chosen methods of analysis, as they are largely non destructive, relatively fast, and allow data to be gathered from inside craters. Residues from at least 5 large (>50μm) craters for each of these minerals were analysed using SEM EDX at the NHM. As the residue thickness and geometry (a thin sheet on a sloping interior crater wall) differ from the form of conventional microanalysis standards, creating a relatively short matrix absorption pathway, it was not considered appropriate to use the matrix correction routines used for normal quantative electron microprobe analyses. The raw count data for these residue analyses were therefore compared against those for their precursor projectiles.

For the initial work on magnesium-rich silicates, only Mg and Si were chosen for comparison as they provide an effective means of distinguishing between these important cometary dust components. The diversity of STARDUST mafic silicate compositions requires any effective plot to employ a wide suite of element determinations, including Ca and Fe. To this end we are now testing other styles of data presentation. Our work on sulfides is at an early stage, although we have some hundreds of craters, we await their preparation for minor and trace elements analyses.

Results and Discussion: The impact programme was successful, generating a large number of craters to analyse. In the results for the initial analyses of the magnesium silicates olivine (Fo$_{89}$), enstatite, diopside and lizardite [9], we saw that the minerals remain distinct from one another in both projectile and residue compositions, Figure 1, although a small but systematic increase in Mg counts relative to Si is seen for all residues when compared to projectile compositions. Our interpretation of both sets of silicate results is that the main difference between projectile and residue

compositions is due to the analysis procedure. Sulfide results are preliminary and further work is ongoing.
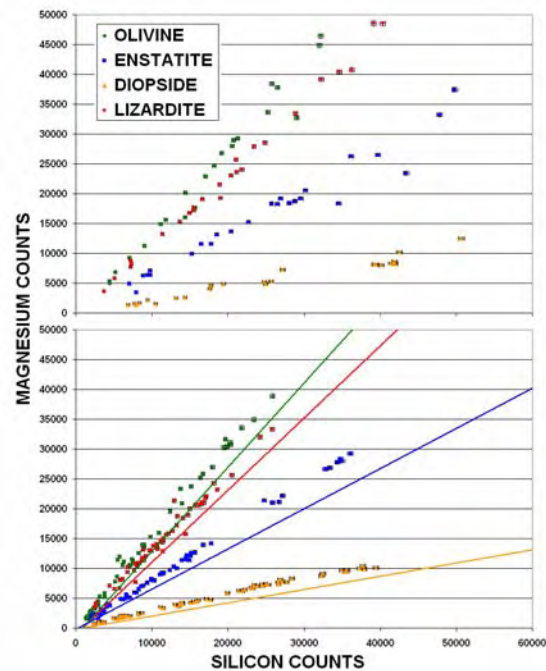

Figure 2: (Top) Apparent composition of projectile materials, shown as raw magnesium and silicon counts, based upon EDX spectra of rough mineral powders. (Bottom) Impact residue compositions, compared to a linear fit to the projectile compositions.

Conclusions: We now have a near-complete dataset of projectile and residue for the main mineral components (silicates, sulfide and metal) present in the STARDUST collection, and are extending our analysis to cover aerogel as well as foil capture. It is our ambition to constrain the effect of capture heating on the complete suite of STARDUST materials, potentially allowing us to re-calculate primary composition from residue composition, and (for instance) overcome the problem of volatile-loss from sulfide (e.g. [3]).

References: [1] Tsou P., Brownlee D. E., Sandford S. A., Hörz F., Zolensky M. E. (2003) *Journal of Geophysical Research (Planets)* 108(E10): 8113, 10.1029/2003JE002109 [2] Brownlee D. E. et al. (2006) *Science* Vol. 314. pp.1711-1716. [3] Zolensky M. E. et al. (2006) *Science* Vol 314. pp.1735-1739. [4] Hanner M. S. (2003) In: Henning T. (ed.) *Astromineralogy.* pp.171-188. [5] Flynn G. et al. (2006) *Science* Vol. 314. pp.1731-1735. [6] Burchell M. J. (1999) *Meas. Sci. Technol.* 10. pp.41-50. [7] Hörz F. et al. (2006) *Science* Vol 314. pp.1716-1719. [8] Zolensky M. E. et al. (2000). *Meteoritics & Planetary Science* 35. pp.9-29. [9] Wozniakiewicz P. et al. (2006) MetSoc 69 Abstract#5076.