MINERALOGY OF WILD 2 RESIDUES IN MICRON-SIZED CRATERS FROM THE STARDUST Al-FOILS.
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Introduction: The NASA Stardust spacecraft collected cometary grains in aerogel blocks, and on aluminum foils which were wrapped on the collector frame between the aerogel tiles. During the preliminary examination period, the aluminium foils proved particularly useful in determining the cumulative flux and size distribution for smaller sized particles (typically micron-sized) [1]. This work was performed mainly using scanning electron microscopy (SEM) for counting and size measurement. A large number of small craters were found, but the corresponding dust particles represent a small proportion of the total mass of Wild 2 cometary material [2]. Their shape suggests that the small craters were formed by dust composed of a relatively low number of individual components. Thus their study presents a good opportunity to infer the size and composition of the discrete fundamental components, and thereby understand the formation of cometary aggregates. In this study, eight micro-crater cross sections were prepared by focused ion beam (FIB) sectioning, and studied by transmission electron microscopy (TEM) for chemical nano-analysis and microstructural characterization.

Experimental procedures: The studied microcraters were first selected by SEM (Fig 1). Their diameters range from 0.7 to 3.7 µm. According to a recent calibration for small craters [3], the corresponding particle size range from 0.4 to 2.3 µm as a first estimate. From these craters, we prepared electron transparent sections using FIB technique on a FEI Strata DB 235. The TEM work was performed using a FEI Tecnai G2-20 and a Philips CM30, each equipped with a LaB_6 gun and energy dispersive spectrometer (EDX) for micro-analysis (See [4] for details)

Results: In the FIB sections, comparison of the measured crater depths to their diameters [2] shows that the density of most impacting particles was relatively high. The craters frequently show irregular profiles suggesting that they were formed by several components which were not closely appressed together (Fig. 1 & 2). This morphology suggests that the small-sized Wild 2 dust was made by weakly bound aggregates. The residues are mainly located on the bottom of craters but are sometimes on the lateral walls near the external lips. Usually the residue is highly irregular in thickness (up to 200 nm) and composition (Fig. 3). Frequently the layer is discontinuous and thus consists of isolated pockets of glassy or crystalline material (~ 60 nm or greater size). Amorphous components are dominante and the plating of residue across the aluminum crater floor suggests that most of the grains were melted and quenched as a glass or have been amorphized and strongly deformed during the impact.

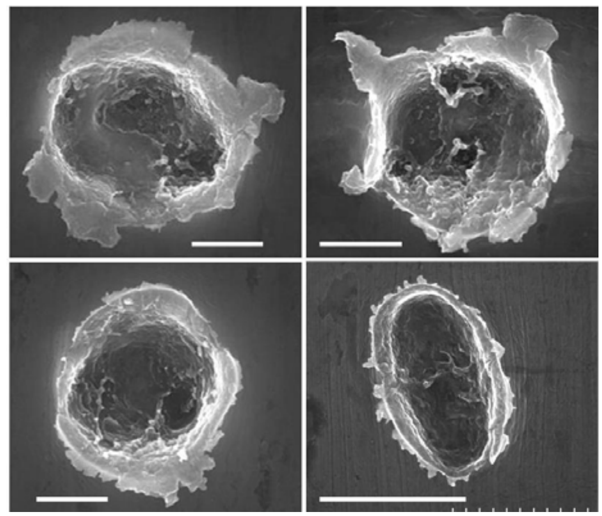

Figure 1: SEM images of four studied micro-craters before FIB preparation. All show an irregular shape implying aggregate impactors. The scale bar is 1 µm.

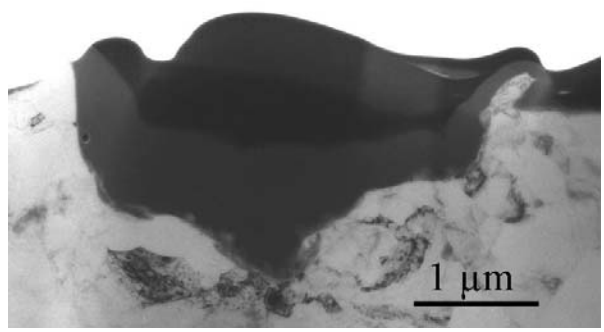

Figure 2: FIB section of a crater viewed in the TEM (bright field image). Note the irregular shape of the crater floor.

Microanalysis shows that the local composition of amorphous material is often comparable to the stoichiometry of minerals such as olivine and pyroxenes, with a significant fraction close to the pyroxene formula. Figure 4 shows a composition frequency diagram for the (Fe+Mg)/Si ratio measured in the residue layers. The diagram displays two peaks, at (Mg+Fe)/Si close to 1 (pyroxene composition) and close to 2 (olivine composition). Most of the composition close to olivine is related to crystalline grains for which the crystallographic structure is confirmed by electron diffraction. This diagram suggests that most of the components were crystalline (pyroxene and olivine, relative ratio ~ 1:1) before the impact on the Al foils. The apparent better robustness of olivine may be due to the differential melting point of olivine and pyroxene (~1980 °C for forsterite and ~1550 °C for enstatite). The Mg/(Fe+Mg) ratio of the Mg-Fe-silicates is highy variable but displays a strong peak close to Fo_{100} and En_{100}. One glass with composition comparable to that of Ca-rich pyroxene, and three pure SiO_2 amorphous areas were also detected. Iron sulfides are found as elongate trains of crystalline grains, parallel to the crater floor, again indicating strong deformation during the impact or recrystallization after impact melting. Residue composition for the eight studied craters is summarized in Table 1

Conclusion: The residues in the small impact craters are present mainly as patches. They are revealed by X-ray maps to be of differing compositions, suggesting the overall impactors were multicomponent aggregates. From the local composition measurements in the residues, it appears that most of these components have stoichiometries close to those of olivine and pyroxene, suggesting that the dust aggregates were mainly composed of crystalline material. Mg-rich olivine and Mg-rich pyroxene are the dominant phases (ratio ~ 1/1), mixed together with iron-sulfide and minor, but significant SiO_2.

Crater	Mineralogy
# 1	Two glassy areas like En_{100}, four Fe-sulfides
# 2	Largely dominated by a homogeneous glassy material with composition close to En_{100}. Minor iron-sulfide dots.
# 3	Three largely separated pockets: two olivine (Fo_{56} and Fo_{91}) and one pure amorphous SiO_2.
# 4	Three separated olivine grains Fo_{75} (crystalline), a mixture of silicate glass with various composition, Fe-Sulfides.
# 5	Discrete pockets of olivine (Fo_{90}), pyroxene (including one Ca-rich grains), glass between Ol and Px composition. Small Fe-sulfides.
# 6	Discrete pockets of silicates: olivine Fo_{90} and glassy areas close to En_{90}.
# 7	Crystalline forsterite Fo_{98} and SiO_2.
# 8	Two discrete pockets of pure SiO_2, forsterite, numerous small Fe-sulfides.

Table 1:Summary of residues in the studied craters.

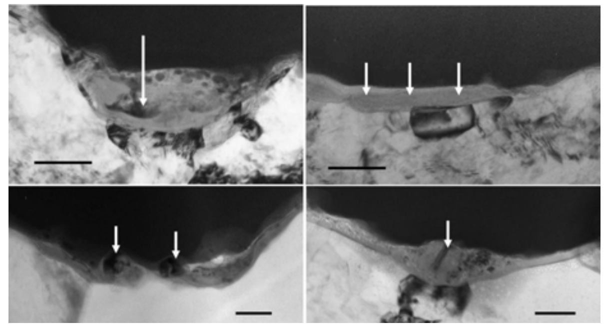

Figure 3: Selected bright field images showing part of the residue layer in four craters. (a) Partly crystalline grain with pyroxene composition En_{98} (arrowed) in contact with an amorphous area containing Fe-Ni-S inclusions (b) Continuous layer of an amorphous silicate with composition En_{100} (arrowed) (c) 2 crystalline grains of olivine Fo_{75} (arrowed) and Fe-sulfide mixed with amorphous silicates of a composition between pyroxene and SiO_2. (d) Large grain of forsterite (arrowed) within an amorphous residue layer SiO_2-rich.

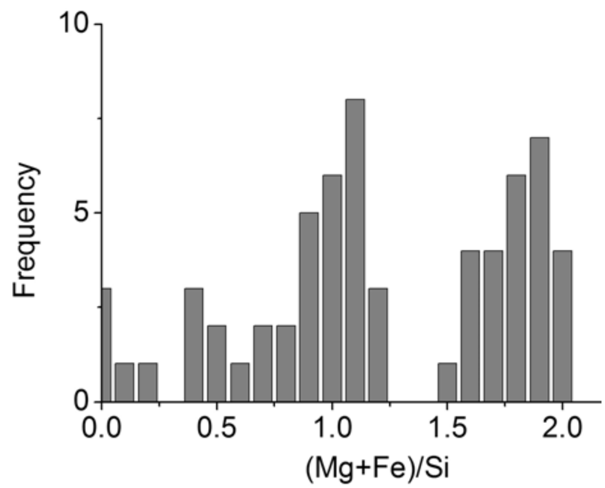

Figure 4: (Mg+Fe)/Si frequency diagram for silicate residues, mainly isolated patches on the crater floor.

References: [1] Hörz F. et al. (2006) *Science, 314,* 1716–1719. [2] Kearsley A. T. et al. (2008) *Meteoritics & Planet. Sci., 43,* 41-74. [3] Price M. C. et al. (2009) *LPSC, XXXX,* Abstract # 1564 [4] Leroux H. et al. (2008) *Meteoritics & Planet. Sci., 43,* 143-160.

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