MINERALOGY OF TRACK 77 (PUKI): TOWARD THE UNDERSTANDING OF THE FINE-GRAINED COMPONENTS OF WILD 2.
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Introduction: Particles from comet Wild 2 were collected by the Stardust spacecraft [1]. The cometary grains have been trapped into a silica aerogel medium at an encounter speed of 6.1 km/s. During the collision the impact produced deep penetration tracks in the aerogel [2,3]. Track morphologies suggest the frequent occurrence of particles composed by loosely bound aggregates. It is also illustrated by synchrotron X-rays fluorescence spectroscopy studies which show that material is dispersed along the track cavities for number of impacts [4,5]. In contrast to the coarse components which penetrate deeply, the fine-grained material decelerate rapidly and is found more thermally modified by the heating associated to the capture process. This material is often mixed with molten aerogel, rendering its study difficult. Its typical microstructure consists of a vesicular, silica-rich glassy matrix containing a high density of Fe-Ni-S nanophases [6]. Their composition is frequently very close to the chondritic CI composition.

Here we present a transmission electron microscope (TEM) study of microtomed slices of track 77 (also called "Puki"). Track 77 is a type B track, with a bulbous cavity from which several slender tracks emerge (Fig. 1). The objective of the study is to document the mineralogy and petrology of this track, including the fine-grained components.

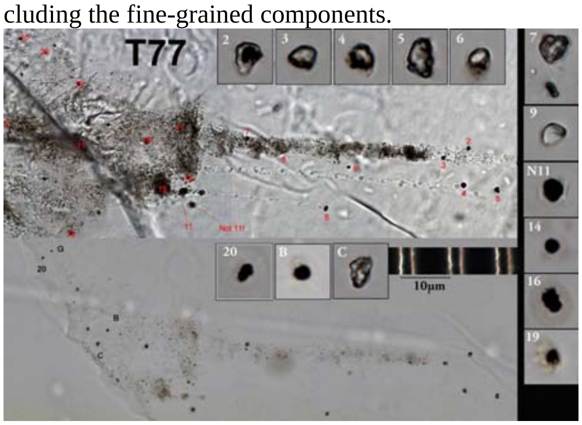

Figure 1: track 77 – micrograph by D. Brownlee, University of Washington.

Samples and procedure: Four samples from track 77 have been studied. The track was first keystoned [7] and then prepared for TEM investigation at the University of Washington [8]. In summary, the track has been flattened between two glass slides, embedded into acrylic resin and then sliced by ultramicrotomy. Since acrylic is soluble it has been removed after ultramicrotomy. The main advantage of this preparation method is that it preserves all pieces of collected samples in the aerogel medium (see [8] for a full description of the method and discussion about the potential applications). Four ultra-thin slices have been studied using a TEM FEI Tecnai G2-20 twin equipped with Energy Dispersive X-ray Spectroscopy (EDX) (see [6] for a full description of the analytical procedure).

Results: Cometary material is found largely dispersed within the compressed aerogel medium. Part of this material consists of a large range of minerals which include olivine, low-Ca pyroxene, diopside, tridymite, anorthite and spinel. These crystalline phases are usually rounded micron-sized fragments, as single crystals or polycrystalline assemblages. The compositions of olivine and pyroxenes are largely variable showing that the cometary particle that created track 77 was composed of a suite of non-equilibrated minerals. The internal microstructure is almost free of crystal defects suggesting that the minerals did not suffered from shock metamorphism. Al-rich glass, in association with olivine or pyroxene, has been also detected.

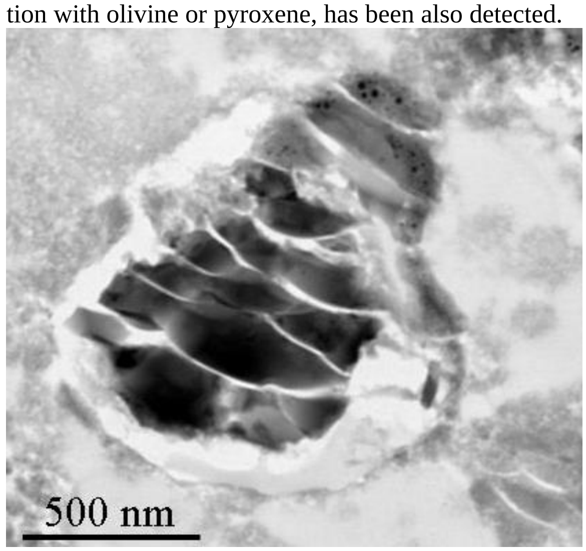

Figure 2: STEM bright field image showing an olivine grain (Fo55) in the compressed aerogel. Note the presence of a glassy material containing number of Fe-Ni-S nanophases (upper right of the micrograph).

The compressed aerogel also contains more or less extended glassy patches (Fig. 2). The glass is SiO_2-rich and frequently embedded Fe-Ni-S nanophases and vesicles. The composition of the glassy material is locally highly variable but average of micron-sized areas show compositions frequently close to the CI-composition for the major elements. These compositions are plotted in a ternary diagram Fe-Mg-S on figure 3, for 500 x 500 µm square areas of several SiO_2-rich glassy patches.

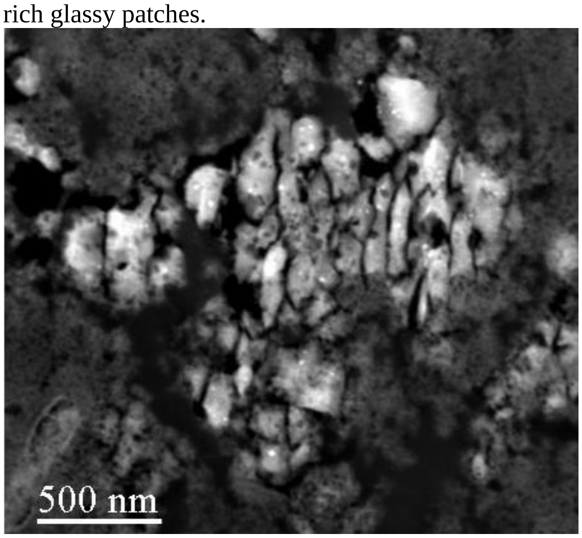

Figure 3: STEM dark field image showing a SiO_2-rich glassy area. The glassy matrix contains a high number of Fe-Ni-S nanophases and its average composition is close to the chondritic CI composition.

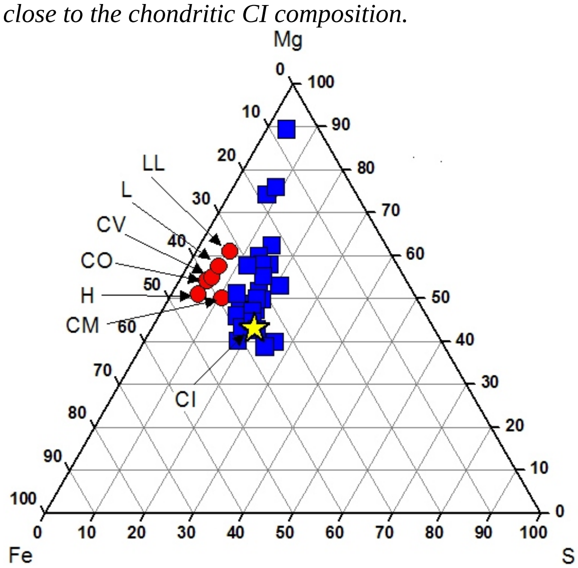

Figure 4: Fe-Mg-S ternary diagram showing the composition of 500 x 500 nm square areas analyses from three glassy patches (solid square, in blue). These compositions are compared with those of chondritic meteorites (solid circles, in red - data from [9,10]). For the Stardust samples, which frequenty display silica admixture from aerogel, Fe-Mg-S ternary diagram is an useful tool on which ferromagnesian silicates, sulfides and metal can be represented and potentially compared with any other extraterrestrial material (see [11] for details). Here most of the compositions of the glassy matrix are close to the one of the CI chondrites (yellow star).

Discussion and conclusion: Track 77 displays a mixture of crystalline silicates and amorphous material. The crystalline silicates represent the "coarse-grained" components (typically higher than 300 nm in diameter) and appear to have survived to the thermal processing of the capture process. They are chemically disequilibrated showing that the impacting dust was an aggregate of minerals of various origins. In contrast, the glassy material shows clear evidence for thermal modification and mixing with molten aerogel, as described in details by [6,11]. The elemental distributions within the glassy patches suggest that these areas originate from a fine-grained material (typically below 300 nm), probably very close to the matrix of aggregate IDPs. The Wild 2 dust responsible for the formation of track 77 was thus a mixture of "coarse-grained" crystalline silicates cemented by an ultrafine matrix, CI-like in composition.

An estimate of the relative proportion of the crystalline and amorphous components has been calculated from several TEM slices. The crystalline coarse-grained fraction represents about 60 % of the cometary material. In the glassy patches, some crystalline precursors were probably also present (but now melted and quenched as a glass), showing that the crystalline fraction in the Wild 2 particle which created the track 77 was even higher than 60%.

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References: [1] Brownlee D.E. et al. (2006) *Science 314*, 1716-1716. [2] Hörz F. et al. (2006) *Science 314*, 1711-1719. [3] Burchell et al. (2008) *Meteoritics & Planet. Sci., 43*, 23-40. [4] Lanzirotti A. et al. (2008) *Meteoritics & Planet. Sci., 43*, 187-213. [5] Ishii H.A. et al. (2008) *Meteoritics & Planet. Sci., 43*, 215-231. [6] Leroux H. et al. (2008) *Meteoritics & Planet. Sci., 43*, 97-120. [7] Westphal et al. (2004) *Meteoritics & Planet. Sci., 39*, 1375-1386. [8] Matrajt G. and Brownlee D.E. (2006) *Meteoritics & Planet. Sci., 41*, 1715-1720. [9] Anders E. and Ebihara M. (1982) *Geochim. Cosmochim. Acta 46*, 2363-2380. [10] Wasson J.T. and Kallemeyn G.W. (1988) *Phil. Trans. Roy. Soc. A325*, 535-544 [11] Leroux et al. (2009) *Geochim. Cosmochim. Acta* (in press).