MINERALOGY OF STARDUST TRACK 80: EVIDENCES FOR AQUEOUS ALTERATION AND IGNEOUS PROCESS J. Stodolna, D. Jacob and H. Leroux, Unité Matériaux et Transformations, Université de Lille 1, 59655 Villeneuve d'Ascq, France, julien.stodolna@ed.univ-lille1.fr.

Introduction: Wild 2 samples brought to Earth by the Stardust mission provide a unique opportunity to understand the nature and origins of the cometary material. Until now, most of the studies have concerned coarse grain terminal particles found at the end of the aerogel deceleration tracks [1]. Synchrotron X-rays fluorescence spectroscopy has also showed that Wild2 particles were made of poorly cohesive assemblages that have been broken and scattered along the track during the capture [2]. Two types of particles are distinguishable: large terminal grains, which could have served to nucleate the cometary particles at the earliest stage of accretion, and abundant fine-grained material, which was probably stick around large grains. The fine-grained components are found deposited along the track walls and represent the largest part of the collected material [2]. Yet it appears that this material experienced a high increase of temperature associated to the capture. Part of the grains was thermally modified up to melting and mixing with melted aerogel [3-4]. Here we focus on the mineralogy and petrology of grains present in the walls of track 80. More than one hundred of crystalline grains have been characterized by transmission electron microscopy (TEM).

Samples and experimental procedures: The allocated samples consist of four slices from the same wall part of the track 80 bulb. The samples have been prepared for TEM characterization at the University of Washington by the acrylic embedding method [5]. The aerogel has been compressed between two glass slides, embedded in acrylic resin, ultramicrotomed and then washed with chloroform to dissolve acrylic. This preparation avoids the biased optical selection of particles and preserves the aerogel medium in which Wild2 particles are encased. It allows the study of small particles which are hardly optically detectable. The compression of aerogel allows also to concentrate the particles in a small volume and thus to have a high quantity of material in a single slice. TEM results have been obtained using a Philips CM30 and a FEI Tecnai G2-20 both equipped with Energy Dispersive X-ray Spectroscopy (EDX) (see [3] for a full description of the analytical procedure).

Results and discussion: The samples are composed of crystalline and thermally modified amorphous material (Fig.1). The crystalline fraction is about 50%. The amorphous components result from the rapid cooling of a high temperature mixture of melted aerogel and cometary material. This glassy matrix displays Fe-Ni-S nano-beads resulting from the reduction of FeO initially present into the silicates and the volatilization-condensation of iron-sulfide [4]. The average composition of this samples is close to the CI composition including S [6].

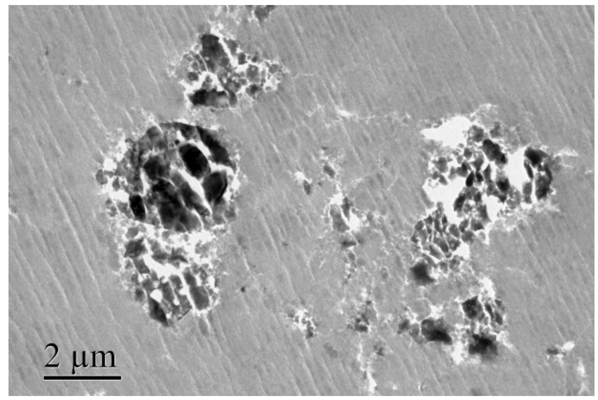

Fig1: TEM bright image of a rounded olivine grain surrounded by thermally modified material. The rounded shape could be the result of abrasion during the interaction with the aerogel at high velocity.

The crystalline material displays two main morphologies: well rounded grains with a diameter larger than one micrometer and sub-micrometer small angular grains which probably are residual fragments of largest grains. Olivine and pyroxenes are dominant, in proportion respectively 50 and 35% of the total amount of crystalline material. The melting temperature of pyroxenes is approximately 400°C lower than olivine. For this reason, the pyroxenes were probably preferentially melted compared to olivine. The ratio olivine/pyroxene is thus likely larger in the Stardust samples than in the original Wild2 comet material. In some cases the crystalline grains are partially melted. They present a dense glassy rim enriched in silica without bubbles nor Fe-Ni-S nanophases. The rim thickness is typically 300 nm for olivine grains and 500 nm for pyroxene, which is consistent with the lower melting temperature of pyroxenes. Nevetheless, this value is highly variable from grain to grain, probably due to the break down of particles during the slowing down.

Olivine grains size extends up to ~2.5µm in diameter. The grains have a wide range of composition, from Fo_{100} to Fo_{40}, with most of the compositions between Fo_{100} and Fo_{75}. This composition range is similar to that of most of the carbonaceous chondrites like Orgueil (CI), Murchison (CM2) or ALH77307 (CO) and to primitive ordinary chondrites like Sharps (H) and Semarkona (L) for example.

For pyroxenes, we have found crystals up to 1 µm width. Both low- and high-calcium pyroxenes are present. Compositions range is from Wo_0 to Wo_{45} and from En_{98} to En_{50} with most of the compositions close to En_{95-85}. The complete enstatite composition range is comparable to composition variations found in anhydrous IDPs and larger to that observed in primitive ordinary and carbonaceous chondrites. Some grains display a high aluminium concentration, up to 10 at.%.

Several iron oxide grains (magnetite) have been identified by electron diffraction and micro-analysis, with a size up to 1.5 µm in diameter. They represent approximately 10% of the total crystalline material. The grains have very low minor elements contents (<0.2 wt% for Al_2O_3, MgO and MnO). Magnetite is frequently found in matrix of ordinary and carbonaceous chondrites, in hydrous IDPs and micrometeorites.

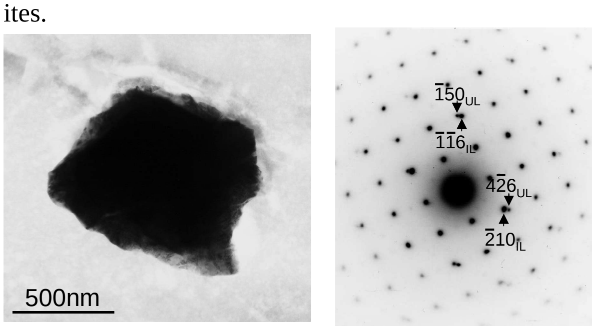

Fig2: TEM bright field image of the ilmenite-ulvospinel grain. The associated electron diffraction pattern shows the superimposition of a trigonal pattern in the [241] zone axis (ilmenite) and a cubic pattern (ulvöspinel) phase in the zone axis orientation [51-3].

An ulvöspinel/ilmenite (iron titanium oxide) assemblage has been identified. Micro-analysis reveals a bulk titanium content close to 10 wt. %. The diffraction patterns consist of a superimposition of a predominant trigonal phase corresponding to ilmenite and a cubic phase corresponding to ulvöspinel (Fig.2). This configuration could be associated to an exsolution process between the two phases. Nevertheless, exsolution lamellae have not been clearly detected on TEM images, may be due to inadequate orientation of the sample. Subsolidus oxidation of ulvöspinel to ilmenite intergrowth can take place during cooling of igneous and some metamorphic rocks.

Brownmillerite $Ca_2(Fe,Al)_2O_5$ grains have been also identified. This phase is observed in thermally metamorphosed limestone blocks included in volcanic rocks as well as in high-temperature thermally metamorphosed impure limestones [7]. Other minor phases have been detected such as cristobalite, Fe-sulfides, fluorapatite, Cr-Al-Mg spinels, Mg-Fe-Al spinels.

Conclusion: We have characterized about one hundred Stardust crystalline grains located in the walls of track 80 bulb. The acrylic embedding preparation method allowed the preservation of all the grains, including the smallest ones. The sample shows a high variability of minerals, from highly reduced silicates (forsterite and enstatite) to oxidized material such as Fe-rich olivine, ulvöspinel and magnetite.

The presence of magnetite in Wild 2 suggests that some cometary material suffered from aqueous alteration, probably prior to the accretion on the comet nucleus. Nevertheless there is still no evidence for phyllosilicates in the Wild 2 material.

The identification of additional igneous phases (Al rich pyroxenes, ilmenite/ulvöspinel, brownmillerite) is in accordance with other studies [8-9]. Several causes can be invoked for melt formation in the solar system including chondrule formation and volcanic activity at asteroid or planetoid surfaces.

We characterized in a single incident particle a high variability of minerals which clearly originated from various formation conditions. This suggests that minerals have been formed at different distances from the sun in the protoplaneray disk and were redistributed in region of comet formation. Radial transport, as possible origin of mixing in the protoplanetary disk, has been already mentioned in many studies [e.g., 10]. Nevertheless the initial small diameter of the particle (estimated inferior to 100µm [11]), in association with the mineralogy diversity, suggests a higher efficiency mixing than expected untill now.

Acknowledgements: The authors thank G. Matrajt and D.E. Brownlee for the preparation of the samples. They also thank the CNES (Centre National d'Etudes Spatiales) for their support.

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