TEM INVESTIGATION OF PYROXENES MICROSTRUCTURE IN COMET 81P/WILD2 TERMINAL PARTICLES. D. Jacob[1], J. Stodolna[1], H. leroux[1], [1] Laboratoire de Structure et Propriétés de l'Etat Solide - UMR CNRS 8008, Université des Sciences et Technologies de Lille – Bât. C6, 59655 Villeneuve d'Ascq Cedex, France. damien.jacob@univ-lille1.fr

Introduction: Samples of three pyroxene-rich particles collected from the Wild2 comet during the Stardust mission have been investigated by transmission electron microscopy (TEM). These pyroxene grains correspond to three terminal particles from tracks 32 and 69. They are coarse-grained Ca-poor pyroxenes with compositions and structures ranging from orthorhombic enstatite to monoclinic pigeonite.

Samples and experimental procedures: The TEM utramicrotomed samples, namely *C2027,2,69,1,1*, *C2027,2,69,2,2* and *C2027,3,32,2,3* originate from terminal particles of neighboring tracks. Details about extraction, manipulation and preparation for TEM by ultramicrotomy can by found in [1]. Results were acquired using LaB_6 filaments Philips CM30 (300 keV) and FEI Tecnai G2-20 twin (200 kV) microscopes, equipped with Thermo-Noran and EDAX Si-detectors respectively for Energy Dispersive X-ray Spectroscopy (EDX) (see [2] for a full description of the analytical procedure).

Results:

C2027,2,69,2,2 and C2027,3,32,2,3. The ultramicrotomed samples consist of elongated crystalline shards. A thin and discontinuous rim of dense amorphous SiO_2-rich material surrounds the particle slices. The shard-like aspect is likely due to the ultramicrotomy preparation. Despite this aspect, the crystallites present very close orientation, as deduced from diffraction patterns. They probably originate from an initial single grain prior to the sample preparation. Both samples exhibit very similar and homogeneous compositions and microstructures. The compositions correspond to enstatite within the range $En_{94\text{-}97}Wo_{2\text{-}5}Fs_{2\text{-}5}$. Selected area electron diffraction patterns reveal an orthorhombic *Pbca* space group. In most of the shards, some planar faults parallel to (100) are observed. Lattice fringe images (figure 1) reveal that the planar faults consist in the insertion of one or more clinoenstatite lamellae (fringe spacing ~ 9 Å) in the orthoenstatite matrix (fringe spacing ~ 18 Å). Strain contrast is observed at the termination of the faults, suggesting the presence of dislocations at the end of the clinoenstatite lamellae. Free dislocations lying in the (100) planes are also present. They appear as long segments elongated in the [100] direction or small segments normal to it. Diffraction contrast examinations including some extinction conditions suggest a Burgers vector compatible with [010].

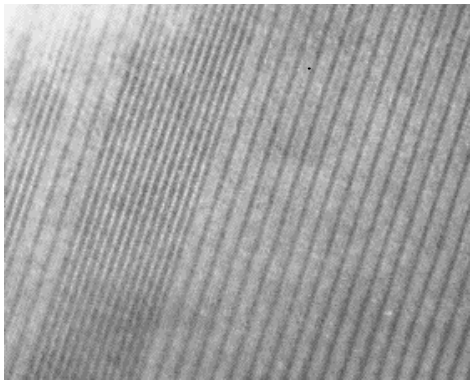

Figure 1: *TEM bright-field image of enstatite in C2027,2,69,2,2. The clinoenstatite lamellae parallel to (100) are clearly visible by the 9 Å lattice spacing, whereas the 18 Å lattice spacing corresponds to orthoenstatite.*

C2027,2,69,1,1. The general aspect is quite similar to that of the previous samples, with a central part having a shard-like aspect surrounded by a rim of amorphous material. Nevertheless, the rim is broader than in the previous cases. Compressed aerogel is also found at the margin. Pyroxene composition is in the range $En_{73\text{-}78}Wo_{3\text{-}6}Fs_{18\text{-}23}$. Diffraction patterns indicate a pigeonite monoclinic $P12_1/c1$ space group. The dominant microstructure consists in a high density of (100) lamellae (figure 2), clearly visible when they are orientated edge on regarding the electron beam direction. Their width ranges between 5 and 50 nm. Electron diffraction patterns (figure 3) show that these lamellae are associated with twinned domains. Indeed, the pattern in figure 3 corresponds to the superposition of two $P12_1/c1$ [010] zone axes, related by a reflection mirror along (100). Electron diffraction patterns taken along other directions ([011] and [012]) fully confirm the (100) twinning. In general, the (100) twinned domains are roughly aligned with respect to each others from one shard to another, suggesting a common parent grain prior to the TEM preparation. Dislocations lying in the (100) planes are found in the largest fragments. Diffraction contrast analyses suggest that they have a Burgers vector [001]. A few chromite exsolutions were detected, in topotactic relationship to the host pigeonite. The sample contains also small olivine grains (Fa_{21}) in inclusion within the pyroxene matrix. Some of the olivine grains contain [001] screw dislocations.

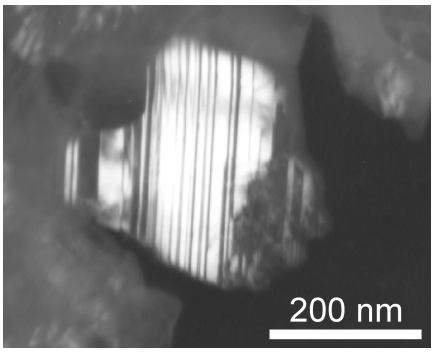

Figure 2: *TEM dark-field image showing the (100) twins in pigeonite, sample C2027,2,69,1,1.*

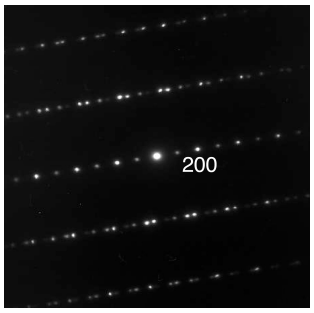

Figure 3: *Diffraction pattern associated with figure 2. The pattern corresponds to the superposition of the* $P12_1/c1$ *[010] and* $[0\bar{1}0]$ *zone axes.*

Damaged areas. In the three samples, some highly disordered crystalline areas are observed. These areas consist of laths along (100) planes, misoriented one to each other (figure 4). Their mean orientation is nevertheless close to that of the surrounding undamaged grains, as revealed by the electron diffraction patterns. No significant composition differences are detected with respect to that of the surrounding undamaged fragments.

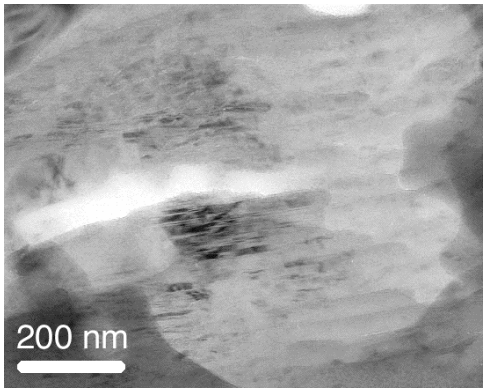

Figure 4: *TEM bright-field image showing one of the highly disordered areas that consist of laths misoriented one to each other along (100) planes. Sample C2027, 2,69,1,1.*

Discussion: The three studied terminal particles are coarse-grained pyroxene which survived to strong heating. They appear relatively undamaged in comparison to the thermally modified grains frequently found in samples extracted from the wall tracks [1,2]. They are single crystal particles several micrometers in diameter with a homogeneous microstructure.

The dominant microstructure in the two orthopyroxene samples is the presence of planar clinopyroxene intergrowths. This microstructure can be formed during cooling from the high temperature protopyroxene stability field [3]. On the other hand, clino-lamellae are also known to occur under shear deformation, possibly due to a shock event (see [4] for a review on shock deformation in minerals). Since free dislocations in glide configuration are also present, we favor a shock deformation process.

Pigeonite in sample C2027,2,69,1,1 contains a high density of (100) twins. Twinning in clinopyroxene can be either obtained by rapid cooling from the protopyroxene stability field (e.g., [5]) as well as by shock deformation [e.g. 4]. Dislocations in olivine clearly evidence a shock deformation event but none of them are found in the twin walls of pigeonite as it might be the case for a shock deformation origin.

The highly disordered areas, present in all the studied samples, are likely due to shock deformation rather than a heating effect. Planar elements on (100) are typical for strong shock level. The co-existence of undamaged areas in contact with highly disordered areas might be due to shock heterogeneity at the submicron-scale.

Conclusion: The microstructure of the studied samples may have been formed by shock deformation, probably prior to the capture into aerogel. Nevertheless the exceptional physical conditions of the collect include a possible intense thermal pulse. A thermal shock as responsible for the observed microstructure cannot be ruled out.

References: [1] Zolensly M. E. et al. (2006) *Science, 314,* 1735-1739. [2] Leroux H. et al. (2008) *Meteoritics & Planet. Sci., in press.* [3] Smyth J. R. (1974) *Amer. Mineral., 59,* 345-352. [4] Leroux H. (2001) *Eur. J. Mineral., 13*, 353-372. [5] Shimobayashi N. and Kitamura M. (1991) *Phys. Chem. Mineral., 18,* 153-160.

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