THE NATURE OF MODERATELY FRAGMENTING COMET DUST: CASE STUDIES OF TRACKS 25 (INTI) AND TRACK 77.

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Introduction: The comet particles captured by the Stardust mission produced aerogel capture tracks that ranged from wide bulbous shapes to thinly tapered nearly cylindrical shapes. It appears that the strongest most competent materials did not fragment during capture and produced the narrow carrot-shaped tracks classified as type A tracks by Burchell et al. [1]. At the other extreme, a few comet particles severely fragmented and produced wide bulbous type C tracks where only a minor fraction of the impacting mass remained intact and reached the track terminus. In most cases the tracks have intermediate shapes (type B) [2]. They contain major "terminal particles, they are moderately bulbous and they often contain abundant side or multiple main tracks produced by fragments that are a appreciable fraction of the total impactor mass. Burchell et al. found that all of the tracks shorter than 100µm were type A while tracks >1mm were split 50:50 between types A and B.

We have done detailed TEM studies of several moderately fragmenting particles that produced type B tracks. This work was done with microtome sections and potted butts of dozens of individual 1-10µm fragments. The results of this study provide important information on the true nature of particles that produce bulbous tracks and insight into why some particles break and others do not. An important issue with these tracks is to determine if the impacting particle was primarily a single component in the comet, such as a chondrule, CAI or AOA, or if was an agglomeration of random sub-compoments. This is a significant issue both for scientific reasons and the practical aspects of planning the best way to examine type B Stardust tracks. A prime example is Track 25 (Inti) a rare track whose terminal particle is a CAI [3]. This track contains hundreds of >µm fragments along the track in addition to the CAI at the terminous. If all of the fragments are from the CAI then they can be used to provide a more complete understanding of the original impactor than just the few major fragments at the end.

We have conducted detailed TEM observations of 18 fragments each in tracks 25 and 77. In the case of track 25 (Inti), all but a few of the smaller grains are clearly CAI materials showing that the impacting particle was nearly pure CAI with only minor adhering material. We found three micron-size fragments that did not appear to be CAI materials and we assume that these were small "matrix" grains attached to the main impactor. Two of these small grains were Fo_{100} and Fo_{76} olivine and the third was a pendlandite grain. No olivine or sulfide was found internal to the CAI fragments supporting the interpretation that they were adhering surface materials.

Most of the Inti fragments are remarkable rocks composed of similar fine-grained assemblages dominated by diopside, fassaite, spinel and anorthite with minor amounts of other phases including perovskite, gehlenite, osbornite, and very rare refractory metal inclusions. Even though most fragments are only a few microns across they are polymineralic and contain four or more of the above phases. This suggests that the bulk of the particle that produced T25 was a reasonably uniform mix of micron and submicron grains of these refractory minerals. Most of the fragments larger than a few microns have diopside rims indicating the original Inti particle was basically a collection of ~3µm nodules all surrounded by ~ 0.5 µm diopside rims. Many of the fragments broke along the diopside rims. Enclosure in compressed aerogel beautifully preserved these rims even though they are less than a micron thick. Most importantly, the detailed investigation of all the 18 fragments did not reveal the presence of secondary phases seen in altered CAIs [4]. We did not see nepheline, sodalite, oligoclase, high concentrations of FeO or ZnO in spinel or other indications of alteration.

In contrast to track 25, whose fragments are poly mineralic and dominated by micron and smaller grains, most of the track 77 fragments are dominated by single minerals with grain sizes ranging up to 10 microns. Most of the mass of the impacting particle was Fe-rich olivine with nearly equilibrated compositions ranging from Fo_{55} to Fo_{68}. Minor components also include Fe poor olivines not in equilibrium with the dominant Fe rich olivine. These include Fo_{97}-Fo_{100} and several cases of LIME olivine where Mn>Fe. Fragment 5 is a non-porous complex polymineralic material composed of olivine, Na,Cr rich augite, glass and sulfides and is quite different from most of the other fragments.

Methods: Mounting and microtoming large numbers of individual transparent fragments of these type B tracks is a daunting task. As described in [5], entire tracks were flattened by a factor of ~50 and then embedded to form ~100µm thick slabs of acryic. This process provides ideal conditions for locating comet grains and distinguishing them from aerogel or melted aerogel. The refractive index match between acrylic and silica renders aerogel-dominated materials essentially invisible. Individual components were optically mapped with a high numerical aperature 100X objective and then cut from the slabs using ultrathin rasor blades while the slab was observed in an inverted compound microscope. Removed samples in acrylic were then glued onto stubs and microtomed.

Figure captions: BSE images of potted butts of individual fragments. *Track 77* - 77,1 is the terminal particle largely composed of Fo_{62-67} olivine. 77,2 is Fo_{60} olivine with a 1μm central kamacite bead that contains small schreiberite inclusions. 77,3 is Fo_{52} olivine with a small chromite inclusion and 77,5 is a complex polyphase fragment containing Fo_{65-69} olivine, Na,Cr rich (kosmochlor) augite, albite, pendlandite, pyrrhotite and possible glass. *Track 25 (Inti)* – The terminal particle 25,1 is composed of diopside rimed fine-grained assemblages of diopside, fassaite, anorthite and other CAI refractory phases. The upper region is connected to bottom region out of section-plane. 25,2 , 25,3 and 25,9 all have 0.5μm diopside rims enclosing phase assemblages similar to those found in 25,1.

Conclusions: The ram pressure during 6.1 km/s capture in 0.01 g cm^{-3} aerogel is ~400 MPa (4 kilobars), is enough to break concrete but not enough to fracture silicate and sulfide mineral grains. In the case of Inti, most of the track fragments are CAI materials and it appears that this CAI was a loosely bound porous aggregation of ~3μm polymineralic refractory particles bounded by 0.5μm diopside rims. In some cases the rims grew into each other. This particle mainly fragmented along rim-contact boundaries. In Track 77 the impacting particle was coarse-grained with a composition that is generally consistent with a type II chondrule. The presence of nearly pure forsterite and a fine-grained polymineralic component that contains kosmochloric augite complicate this origin. The T77 particle probably fragmented along pre-existing fractures.

The detailed study of the these two tracks show that the most of the track fragments are mineralogically related to each other in significant ways. These particles were not "dirt balls", clumps of random unrelated components. Both tracks did contain very minor amounts of unrelated materials that are presumably analogous to matrix in chondrites. The comet emission process appears to have ejected relatively clean grains of components such as CAIs and chondrules. The release of clean grains from a sublimating comet is consistent with meteor and comet observations that suggest that comet dust is loosely aggregated uncompacted material.

References: [1] Burchell, M.J. et al. (2008) MAPS 43, 23. [2] Trigo-Rodriguez, J. M. et al. (2008) MAPS 43, 75. [3] Simon, S. B et al. (2008) MAPS 43, 1861. [4] Rout, S. S. and Bishoff, A. (2009) MAPS 43. 1439. [5] Matrajt, G and Brownlee, D. E. (2006) MAPS 41, 1715.