Morphology of Impact Features in Space Exposed Aerogel, R.P. Bernhard[1], T.H.See[1] and F. Horz[2] [1]Lockheed-Martin Space Mission Systems & Services, C23, Houston, TX 77058; [2]NASA Johnson Space Center, SN2, Houston, TX 77058

Introduction: The Orbital Debris Collection Experiment [ODC] exposed ~ 0.7 m^2 of aerogel for 18 months to the man-made and natural hypervelocity particle environment on board Mir [1]. The SiO_2-based aerogel had a density of 0.02 g/cm^3 and was composed of 72 individual monoliths, each 10 cm square and ~ 12 mm thick. Even first-order inspection of these collectors with the unaided eye revealed a wide variety of impact features, ranging from slender and deep penetration "tracks" to relatively shallow, hemispherical "pits". The latter have no experimental equivalent [2, 3, 4]. We note that such pits were observed on earlier aerogel collectors exposed on EURECA [Brownlee, pers. comm.], as well as Shuttle [Westphal, pers. comm.], yet they remained largely undocumented. Tracks in the ODC collectors display typical aspect ratios of L/D > 20, with the length (L) measured from aerogel surface to track tip, and depth (D) is maximum track diameter at any depth below the surface. Pits, on the other hand, exhibit an L/D < 2. Features of 2 > L/D < 20 are present as well, suggesting that they may be transitional between the slender track and the shallow pit. In this report, we suggest that a morphologic continuum exists among all features, and thus, an evolutionary sequence that is largely controlled by impact velocity.

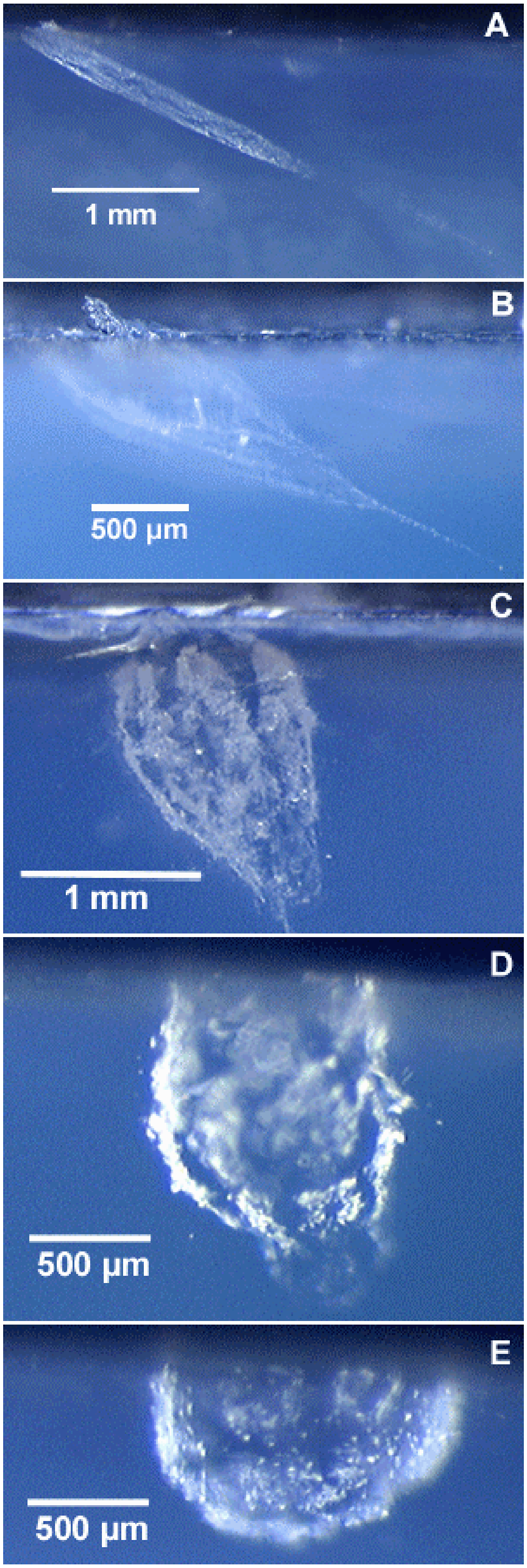
Observations: Cross sections of the diverse impact features observed in ODC aerogel are illustrated in Figures A – E, arranged with decreasing L/D. Figure A illustrates a slender, needle track. Typical tracks may either have contiguously tapering, relatively straight walls, or more cylindrical cavity portions, in which case they taper more rapidly at depth. The feature in Figure B has curved walls, giving it a slightly bulbous appearance. For descriptive purposes we distinguish between a "main cavity" and a "stylus". The main cavity resides near the surface, although it may well occupy half of the track length; the stylus composes the remainder of the track. The latter is a needle like feature that has feathery, micro-fractured edges and that terminates in a rather distinctive style of deformation, resembling cone-in-cone structures. With the stylus being relatively invariant, most of the morphologic characteristics relate to the main cavity. Tracks resembling Figures A and B are the most common. In contrast, features like C are rare. It's main cavity is stubby and truly bulb-shaped, and it has only a small stylus. The latter is obviously a minor feature, caused by a small chance fragment that penetrated somewhat deeper than most of the projectile. Case C is a transitional stage between B and D, the latter a relatively deep pit without a stylus. Figure E represents the typical, shallow pit with an almost hemispherical shape. We consider these morphologies to represent a continuum with the slender track and the shallow pit constituting the endmembers.

The transitional nature between deep tracks and shallow pits is also manifested by subtle changes in the appearance of the cavity walls. The interior cavity walls vary from a feathered, micro-fractured and somewhat "dull" appearance, to highly translucent, as if glazed, the latter suggestive of melting. Most long cavities assume the feathered look at depth. The majority of pits have the highly transparent, glazed interiors and no feathering. Some of the larger pits, however, may develop substantial, spike-like, concentric fractures, and is the reason Westphal [pers. comm.] refers to such features as "hedgehogs".

The terminus of most stylii reveal optically detectable projectile residues; none of the pits contains any optically visible remnants. This applies to Figure D: the stylus contains a remnant, yet no projectile traces are seen on the walls or at the bottom of such features. These microscope observations are confirmed by detailed SEM analyses; most pits do not reveal obvious projectile remnants using SEM/EDS methods. Brownlee [pers. com.] made similar observations in aerogel pits from EURECA. The inability to detect impactor residues in these pits by SEM-EDS methods implies either impact by projectiles of low Z-number, such as water ice, or that typical silicates and man-made materials completely vaporized.

Interpretation: We consider the diversity of impact features in space-exposed aerogel to be largely the product of impact velocity, rather than of projectile physical properties, such as density or compressive strength. This hypothesis rests on a number of arguments:

(1) The shallow pits are not low-velocity features. We recognize low-velocity impacts by co-orbiting human-waste particles on ODC. Such particles produce pervasive and characteristic micro-fracturing and crushing of aerogel; the resulting depressions also contain copious amounts of "projectile".



(2) The shallow pits are not caused by low-density projectiles. We have extensive experience with low-density, “fluffy” impactors from experiments employing compressed cocoa powder at 3 to 7 km/s. Such impactors result in shallow depressions, but the latter contain numerous, parasitic tracks; their interiors are not glazed, and they contain copious amounts of projectile.

(3) The molten interiors of pits require high velocities. While we cannot specify the velocity, the molten interiors argue for higher velocities compared to unmolten, fractured and “feathery” cavity walls.

(4) The pits contain no impactor residue. We have analyzed numerous impact features produced by waste-water and all contain measurable K, Na, and Cl, as a minimum, and pure water-ice seems unreasonable. This leaves high velocity and associated vaporization of the impactor as the most plausible cause.

(5) The ODC pits have no experimental analog, despite considerable variability of experimental impact conditions in aerogel [2, 3, 4]. Typical, non-porous silicate or metal projectiles make deep tracks, akin to A and B, at 3 – 7 km/s.

Conclusions: The above observations and arguments strongly suggest that the pits are the result of very high-velocity impacts and that the morphologic continuum of impact features in space-exposed aerogel is largely a function of impact velocity. The pits are essentially the equivalent of space-produced micro-craters that do not contain projectile residues. As a consequence, we conclude that there is a velocity dependent limit in the utility of aerogel to soft-capture hypervelocity particles.

References: [1] Hörz, F. *et al.* (1998), *LPSC XXIX*, 1777, [2] Tsou, P. (1995) *J. Noncrystalline Solids*, 186, 415-427, [3] Burchell, M.J. and Thompson, R. [1996] *Shock Compression of Condensed Matter, AIP Conf.* 1155-1158, [4] Hörz, F. *et al.* (1998), *NASA Tech. Mem. TM-98-201792*.