N86-30592

HYPERVELOCITY PARTICLE CAPTURE: SOME CONSIDERATIONS REGARDING SUITABLE TARGET MEDIA

Friedrich Horz, Mark J. Cintala, NASA Johnson Space Center, and Thomas H. See, Lockheed EMSCO, all Houston, TX 77058

INTRODUCTION:

Hypervelocity particles colliding with passive capture media will be traversed by shock waves; depending on the stress amplitude, the particle may remain solid or it may melt or vaporize. Any capture mechanism considered for cosmic dust collection in low Earth-orbit must be designed such that sample alteration and hence loss of scientific information is minimized. Capture of pristine particles is fundamentally difficult, because the specific heat of melting and even vaporization is exceeded upon impact at typical, geocentric encounter velocities (e.g., Ahrens and O'Keefe, 1977).

The phase relations of a number of representative geologic solids subjected to shock stresses typical of hypervelocity impacts are illustrated in Figure 1, calculated by Cintala (1984); similar results were reported by others (e.g., Ahrens and O'Keefe, 1972, Orphal et al, 1980). The calculations are in part based on measured equation of state (EOS) data and on their extrapolation to high pressure states based on (model dependent) thermodynamic assumptions. In contrast, Figure 2 illustrates some typical experimental results: basalt targets were traversed by shock stresses of well known amplitude and the recovered specimen were analyzed by petrographic means (Schaal et al, 1979; such recovery experiments are limited to < 100 GPa stresses and thus to solid/liquid phase transitions). While some discrepancies exist between calculated and observed melting behaviors, the differences are subtle for the purposes of the present discussion. Typical, dense rocks and silicates melt at > 40-50 GPa. The introduction of porosity causes multiple shock reverberations at the free surfaces and lowers the equilibrium stress for shock induced melting (e.g., Kieffer, 1971, Cole and Ahrens, 1974, and Cintala, 1984). Although incipent melting is observed in porous media at pressures as low as 8 GPa, these melts are extremely localized and essentially confined to grain boundary melting. Most porous targets, however, are noticeably compacted and thus texturally altered even at 5 GPa; pore-space is decreased and component minerals may be mechanically disaggregated, exhibiting distinct mosaicism under the petrographic microscope.

We conclude that shock stresses in excess of 50 GPA should be avoided during hypervelocity particle capture on board Space Station and that stresses < 20 GPa, even at 15 km/s collision velocities, should constitute desirable instrument design goals. In the following we will identify some principal characteristics of the capture medium that may satisfy these requirements.

CAPTURE MEDIUM: MATERIAL PROPERTIES

The stress amplitude generated upon impact is controlled by the EOS of both target and impactor. Pertinent data for many materials were determined experimentally (see, for example, the compilation by Marsh, 1980) and include geological solids as well as prospective media for Space Station collectors. Hugoniot curves for some representative materials are illustrated in Figure 3; the particle velocity (u_p) and peak stress (P) plane was selected because, for a one dimensional case

$$V_i = u_{pt} \text{ (Target)} + u_{pp} \text{ (Projectile)} \qquad \text{(eq. 1)}$$

Note that the peak stresses (Fig. 3) at any given u_p may vary significantly, depending on a material's compressibility, which in turn depends partially on initial specific volume and thus density. Notice also the dramatic differences between metals and rocks (Figure 3A) versus low density, porous media (Fig. 3B). In accordance with eq. 1, the so called "impedance match" method (Duvall, 1962) may be used to calculate u_p and hence P for any target/impactor combination and impact velocity. Using graphical extrapolations of the measured EOS, we have solved eq. 1 for three representative projectile materials (dunite, sintered quartz-glass, and highly porous tuff), which impact potential capture "targets" at velocities as high as 15 km/s. Note that capture media of ultra-low densities result in peak stresses < 20 GPa, even at typical heliocentric particle velocities. Low-density materials are therefore the preferred, if not required, media for the capture of hypervelocity particles.

CAPTURE MEDIUM: MEMBRANE THICKNESS

In general, only highly porous media have suitably low bulk densities. The impactor will sense them as "low density" materials only, if their typical pore dimensions are substantially smaller than the impactor dimensions, (D); especially the pore septa or fibers, i.e., the "solids" in a porous substance must have thicknesses << D. This thickness (L) controls the shock pulse duration (t), because t = 2L/U, where U is the shock wave velocity. According to Ahrens and O'Keefe (1977) the attenuation of a shock wave strongly depends on the quantity L (or t) and may be scaled dimensionally. If L << D, part of the impactor may not be shocked to high pressure states. Fragmentation, however, may not readily be avoided, because much of the impactor may still be engulfed by isobars in excess of the particle's tensile strength (<0.2 GPa for dense, crystalline rocks; Cohn and Ahrens, 1979). Upon impact with a porous target, a series of compressive and tensile waves will result in the impactor, all of small (t) and thus of small spatial extent relative to D; compressive and tensile waves may overtake and cancel each other, as multiple free surfaces will set up multiple rarefactions (e.g., Gehring, 1970 or Swift et al, 1982). The one dimensional analysis of Ahrens and O'Keefe (1977) suggests L / D approximately 1/20 or smaller.

CONCLUDING REMARKS:

Survival of unmelted impactor fragments at relatively high collision velocities was demonstrated in the laboratory (Tsou et al, 1986) and on Solar Max thermal blankets (McKay et al, 1986, Blanford et al, 1986). It thus appears possible to collect relatively unaltered hypervelocity particles in Earth orbit. Additional impact experiments are necessary to evaluate materials of ultra-low densities that satisfy the above considerations. Ultimately a stack of very thin foils, rather than some foam material, may also be considered and may be tailored (= L) for capture of specific impactor masses. Operationally, recovery of projectile fragments from such materials becomes a concern, because penetration paths may be tens of projectile diameters in length. Target media that may be dissolved quantitatively without adverse effects on the contemplated microanalyses appear desireable for expedient recovery of particle fragments.

REFERENCES:

1) Ahrens, T.J. and O'Keefe, J.D. (1972) Shock melting and vaporization of lunar rocks and minerals. The Moon, 4, p. 214-249.

2) Ahrens, T.J. and Cole, D.M. (1974) Shock compression and adiabatic release of lunar fines from Apollo 17, Proc. Lunar Sci. Conf. 5th., p. 2333-2345

3) Ahrens, T.J. and O'Keefe, J.D. (1977) Equations of state and impact-induced shock wave attenuation on the Moon. In "Impact and Explosion Cratering," D.J. Roddy et al, eds., Pergamon Press, Elmsford, N.Y. p. 639-656.

4) Blanford, G.E. et al, (1986) Extraterrestrial olivines brought back from Space, Lunar Planet. Sci. Conf. 17th, Abstracts.

5) Cintala, M.J. (1984) A Method for Evaluating Shock Propagation and its thermal effects during Impact Events. Lunar Planet Sci. Conf. 15th, Abstracts, p. 154-155.

6) Cohn, S.M. and Ahrens, T.J. (1979) Dynamic tensile strength of analogs to lunar rocks, Lunar Planet. Sci. Conf. 10th, Abstracts, p. 180-182.

7) Duvall, G.E. (1962) Concepts of shock wave propagation. Bull, Seismol. Soc. Am., 52, no. 4, p. 869-893.

8) Gehring, J.W. (1970) Theory of impact on thin targets and shields and correlation with experiment, in "High Velocity Impact Phenomena." Kinslow, R., ed., Academic Press, New York, p. 105-157.

9) Kieffer, S.W. (1971) Shock metamorphism of the Coconino sandstone at Meteor Crater, Arizona, J. Geophys. Res. 71, p. 5449-5473.

10) Marsh, S.P. ed. (1980) LASL Shock Hugoniot Data. Univ. of California Press, Berkeley, 1980, 658p.

11) McKay, D.S. et al, (1986), this volume.

12) Orphal, D.L. et al. (1980) Impact melt generation and transport, Proc. Lunar Planet. Sci. Conf. 11th, p. 2309-2323.

13 Schaal, R.B. et al, (1979) Shock metamoprphism of granulated lunar basalt, Proc. Lunar Planet. Sci. Conf. 10th, 2547-2571.

14 Tsou, P. et al. (1986) this volume.

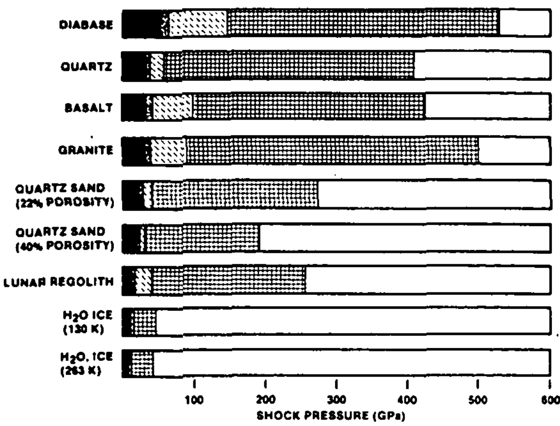

FIG.1

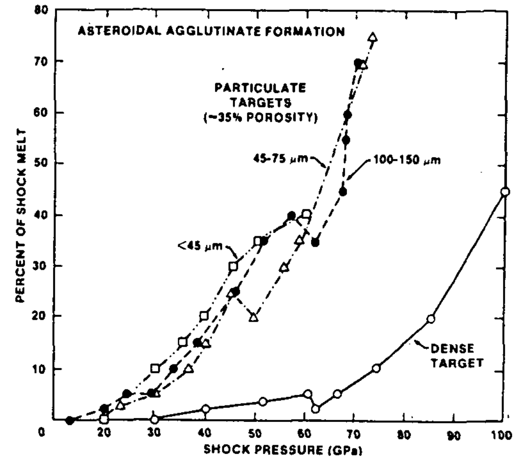

FIG.2

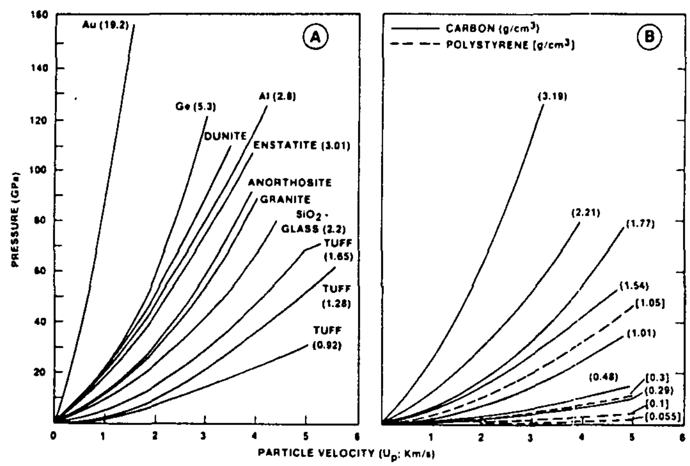

FIG.3

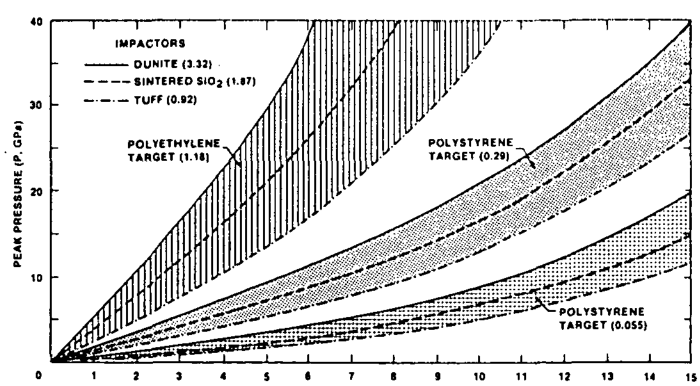

FIG.4

FIGURE CAPTIONS:

Fig. 1: Phase relations of representative geologic targets (or impactors) subjected to shock stresses typical of those encountered during collisions at cosmic velocities (after Cintala, 1986).

Fig. 2: Experimentally determined melting behavior of dense and porous basalt. (Schaal et al, 1980).

Fig. 3: Typical Hugoniot curves for a variety of materials of generic significance for Space Station cosmic dust instruments.

Fig. 4: Peak-pressures as a function of impact velocity encountered by a variety of projectiles colliding with targets of 3 different bulk densities.