SUBSTRATE EFFECTS FROM OBLIQUE HYPERVELOCITY IMPACTS INTO LAYERED TARGETS.

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Introduction: Many planetary surfaces have a layer of low-impedance material at the surface, such as sedimentary sequences, ice sheets or thick regolith layers. The presence of such a layer affects subsurface and surficial damage induced by hypervelocity oblique impacts.

Recent modeling studies [i.e., 1-2] show that layered surfaces, with differing strength for the layers, affect crater size and structure. Further, experiments [3] and simulations [2, 4-7] reveal that low-impedance surface layers also affect the final crater size, structure and peak pressures at the layer interface and in the competent substrate [1, 6]. The limiting variables controlling these processes are not fully understood, however, and previous studies have largely examined these processes for nominal-angle (45°) or vertical impacts or with the layer much thicker (or thinner) than the projectile diameter.

Impacts into surface sedimentary or ice layers on Mars or the Earth may leave little to no record. If the impactor does not penetrate into the competent substrate (i.e., involves only into the upper layer), the record of impact may be completely erased once the sediments are eroded or the ice melts [i.e., 5, 8-10]. Here, we focus on oblique impacts (≤30° from horizontal) into layers with thicknesses comparable to the projectile diameter. Small-scale laboratory experiments compared with numerical models increase our understanding of how impact damage is expressed in the substrate.

Experimental Approach: The combination of experimental data and numerical models provides a more complete understanding of impact processes than either method alone. Further, it allows those processes to be scaled to planetary-sclaed impacts with greater confidence. Previously, a 1:1 comparison between experiments performed at the NASA Ames Vertical Gun Range (AVGR) at the Ames Research Center with 3-dimensional CTH models documented the conditions and process of failure in a sequence of laboratory impacts into planar polymethylmethacrylate (PMMA) targets [11-12].

For this study, we used the AVGR facility to impact a low-impedance layer at an oblique angle (0.635-cm Pyrex and aluminum spheres, with speeds of ~5.6 km/s and an angle of 30° from horizontal). The layered target was a 15 x 15 x 6-cm PMMA block overlain by a layer of plasticine with varying thicknesses. These were compared with impacts directly into 15 x 15 x 6-cm PMMA blocks without the presence of a low-impedance layer. Three-dimensional CTH models allowed computing identical conditions. The calculations used a Mie-Grüneisen equation of state (EOS) for Pyrex [13] and PMMA and SESAME tables for aluminum. A modified Mie-Grüneisen EOS for C4 was used to model the plasticine [14-15] and the Johnson-Cook fracture model was used to assess subsurface damage due to shear failure. Plastic failure occurs when specified values of plastic strain are experienced by the material after the material reaches the compressive yield strength. This value can be adjusted for specific materials and situations. Extensional failure is examined separately and occurs when extensional stresses exceed the tensile strength of the material.

Large-scale, 3D simulations were also computed, including 1-km diameter dunite projectiles impacting at 15 km/s and 30° above horizontal into 1-km thick sediment or ice layers above bedrock. The layered targets were compared with impacts directly into the bedrock. Ice layers were modeled using the ANEOS EOS and a geological yield failure model. The modified Mie-Grüneisen for plasticine was also used as a proxy for a low-density (or porous) sediment/regolith layer with a geological yield surface.

Results and Discussion: High-speed imaging (250,000 frames per second) captures the sequence, location and evolution of failure within the target that was then compared to results from computational models. The final, surface expression is retained in the competent targets.

The presence of a low-impedance layer significantly reduces the amount of damage caused by a hypervelocity impact [3-5]. Further, the extent of the damage expression on the substrate surface is reduced. (Fig. 1), and, in some cases, a crater is not visible on the surface. Laboratory experiments record a significant reduction in both subsurface damage and surficial disruption. Numerical models verify this observation at the laboratory scale and demonstrate that the same phenomenon occurs at much larger scales as well (Figure 2).

Varying the thickness of the low-impedance layer affects the amount of damage seen within the target and on the surface for our assumed 30° impact angle. Much of the energy is absorbed/scattered within the low-impedance layer [1,3,6] and, therefore, thicker layers provide a larger buffer and consequently less damage is seen in the competent substrate.

Implications: Impacts into low-impedance layers overlying bedrock could drastically reduce expression of damage in the substrate. Once the layer is removed, the expression in the bedrock will be significantly reduced or even non-existent. This has implications for identifyng relict impacts (including shock effects) on Earth and Mars [3] surfaces after removal of the overlying layer.

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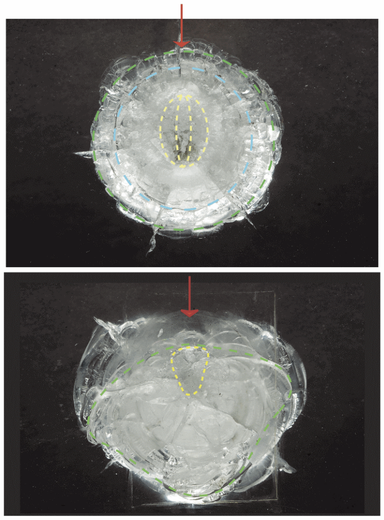

Figure 1. Top view of the final 'crater' in laboratory experiments. The dashed yellow lines show the approximate crater limits. The dashed green lines show the approximate damage extent on the upper surface. (top) 0.635-cm Pyrex sphere into PMMA target at 5.2 km/s and 30 degrees. The projectile trajectory follows the red arrow. (bottom) 0.635-cm Pyrex sphere into 0.635-cm plasticine layer atop PMMA target at 5.6 km/s and 30 degrees. The projectile trajectory follows the red arrow. The plasticine layer suppresses crater formation, and the total damage volume is much less. The subsurface damage appears slightly broader from above, but it is much shallower following an impact into plasticine.

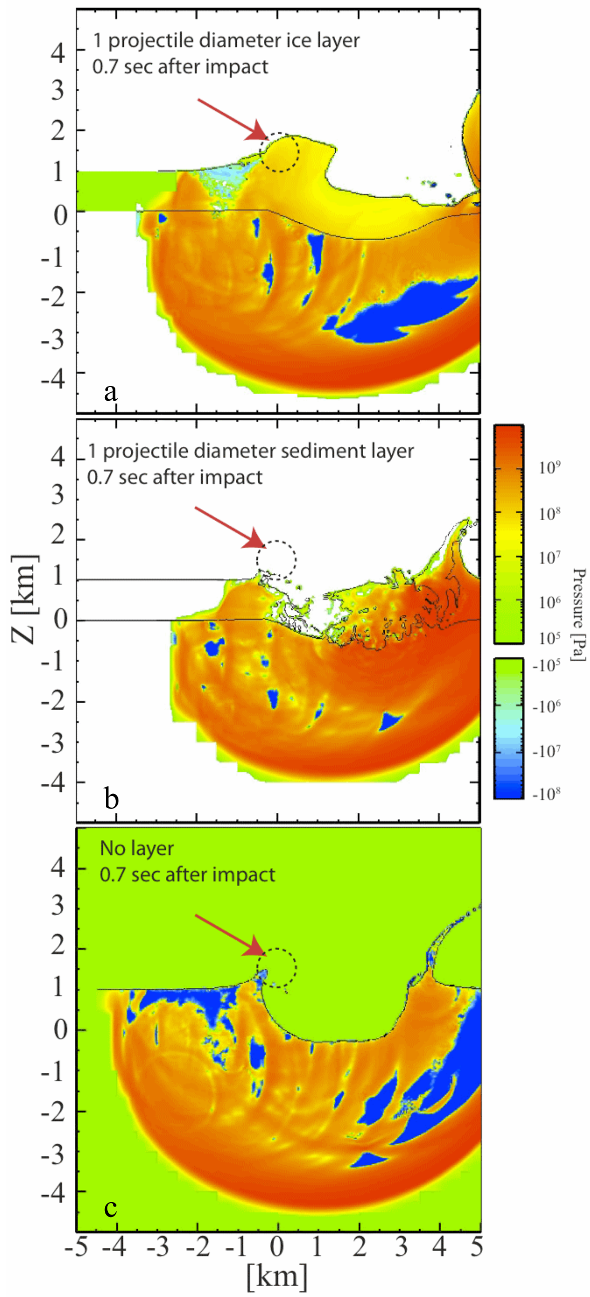

Figure 2. Pressure fields after 0.7 seconds for three different geometries representing low impedance layers over bedrock. View is at y=0, parallel to the impact trajectory for a 1-km projectile impacting at 15 km/s and 30° above horizontal: a) 1 projectile diameter thick (1-km) ice layer over bedrock; b) 1-km thick "sediment" layer over bedrock (represents 1 projectile diameter low impedance layer; plasticine is used as a proxy for sedimentary deposits); c) No low-impedance layer, impact directly into bedrock. The presence of a low-impedance layer results in a significantly shallower crater in the bedrock and damage in the basalt is reduced.