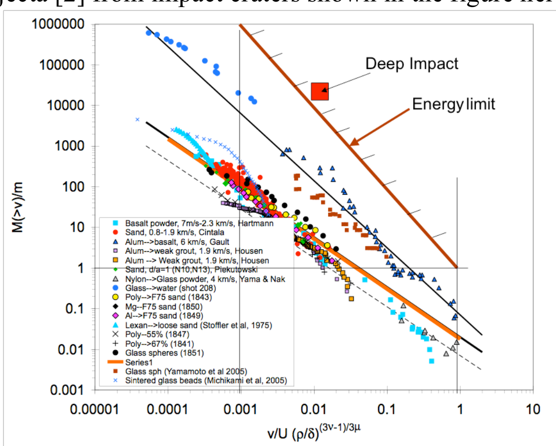
DEEP IMPACT: AN OUTBURST TRIGGERED BY AN IMPACT? K. A. Holsapple[1] and K. R. Housen[2]
[1]University of Washington 352400, Seattle, WA 98195, and Planetary Science Institute, Tucson, AZ; holsapple@aa.washington.edu; [2]Applied Physics, The Boeing Co., MS 2T-50, P.O. Box 3999, Seattle WA 98124. kevin.r.housen@boeing.com.

Introduction: The Deep Impact (DI) mission impact into the comet Tempel 1 produced very unusual outcomes compared to current wisdom about "conventional" impact cratering; although both prior to and subsequent to the event, many researchers including ourselves [1] tried to fit the observations into the conventional cratering wisdom. Prior to DI little was known about cratering into the highly porous materials characteristic of Temple 1, which has an estimated density of only 0.4 g/cm^3. As a result of the DI observations, Shultz et al. [2] recently report extensive laboratory experiments in very porous materials which qualitatively reproduce many of the observed features.

It is the quanitative features that remain puzzling if they are compared to "conventional" cratering. Specifically, the total mass thrown out is extremely large: many observations concluded that there was on the order of 10^7 kg or greater of material ejected at velocities on the order of 100 m/s. Those admittedly rough figures are compared to the known database for the ejecta [2] from impact craters shown in the figure here:



The ejecta masses measured for cratering for the most porous solids are along the lowest dotted line in this figure, and the DI point is 3-4 orders of magnitude above that line. In fact, the value is almost a factor of 100 above the ejecta for cratering in water. And those results imply a momentum imparted to the comet that is about 50 times the momentum of the impactor. (As an aside that would be a useful outcome for deflecting Earth-threatening bodies).

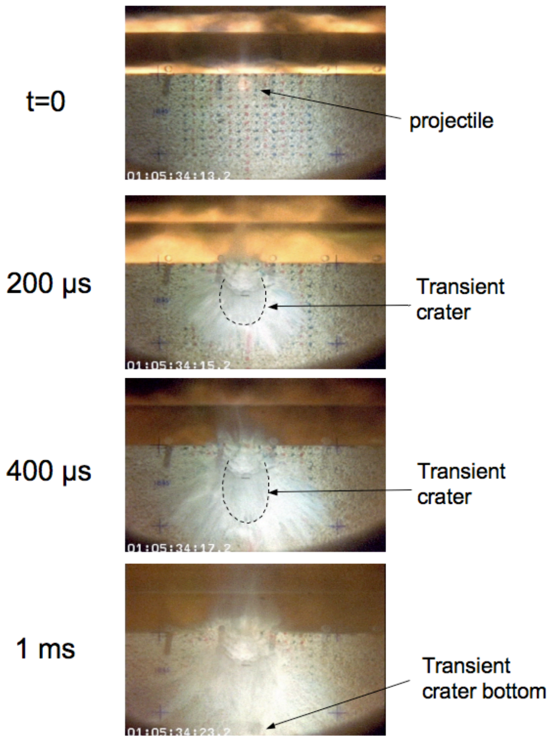
And an even more basic comparison is significant. The estimated 10^7 kg of material at 100 m/s would have several times the kinetic energy of the impactor, above the energy limit line depicted in the figure. (This line assumes all the mass at the same velocity, not a distribution.) In excavation cratering only a very small part of the impactor energy is present in the kinetic energy of the ejecta. In non-porous materials it is on the order of 10-30%, whilce in dry powders it is only a few percent. If indeed DI had that much ejecta, it must have relied on an energy source in addition to the kinetic energy of the impactor. That could be internal energy stored in the comet as pressure, or solar energy absorbed by the expanding ejecta cloud, or perhaps energy liberated in phase changes due to the impact.

So why was there so much ejecta? Where did the energy come from? Why was the duration of the evolving ejecta much longer than for cratering? Are we wrong to compare the event to our concepts of cratering by excavation? Instead is it the highly porous and volatile nature of the material that sets the outcome? We are gathering very interesting evidence and preliminary concepts suggesting that an interpretation of the Deep Impact event as a conventional excavation cratering event is likely to be wrong and misleading.

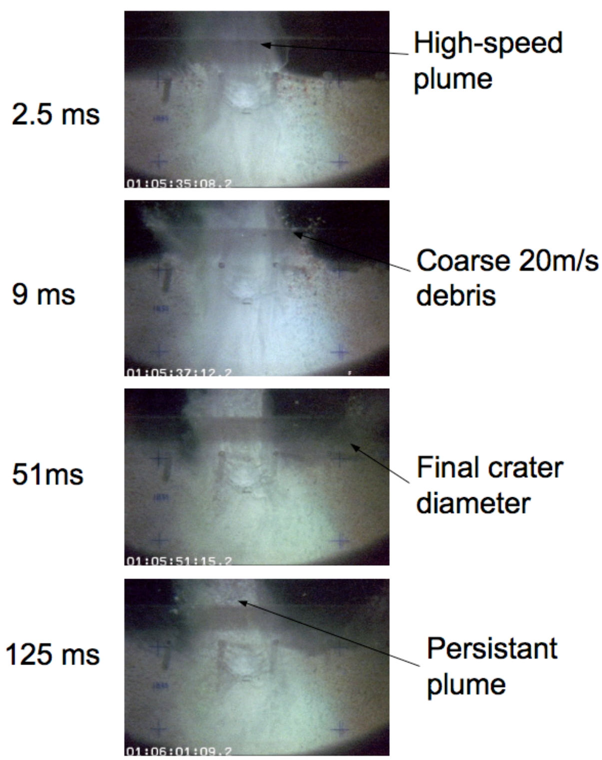
Experiments: Impacts were performed in a quarter space fixture into a highly porous silicate target material consisting of a mixture of fine quartz sand, water and perlite, a naturally occurring siliceous volcanic rock. The bulk density of the target was 0.34 gm/cm^3, with a corresponding porosity of 87%, similar to the estimates for DI. The projectile impacted normally to the target surface near the interface between the target material and the front window. A high-speed camera was positioned to view normally to the front window. Running at 10^4 pictures/sec, the camera recorded a cross-sectional view of the crater growth and the evolution of the ejecta plume.

In order to facilitate visualization of the material flow, colored particles of perlite were emplaced at the target/window interface in a rectangular array. The figure below shows the completed target with the array of colored marker particles. The projectile in this test was a polyethylene cylinder 12.1mm in diameter and height, with a mass of 1.328 gm. It was launched to a speed of 1.8 km/s. The target chamber was evacuated to a pressure of ~20 mm Hg.

At 200μs after the impact the transient crater was considerably deeper than wide. Fine white material, presumably severely crushed perlite, was seen moving radially along the target window interface. Subsequent images showed the transient crater continuing to grow with a depth much greater than its diameter.



The next figure shows a later series of images from the same impact. For impacts into a moderately porous material, like dry sand, the ejecta curtain is well known to form a sheet that moves out along the target



surface closely attached to the rim of the transient crater. In contrast, the upper image in this figure shows a high-speed vertical plume of fine ejecta. Later on, after several ms, coarser material appeared in the vertical plume and another plume formed, at approximately 45°, which is reminiscent of dry sand. This plume tended to follow the crater rim, which formed at a time of roughly 50 ms. Surprisingly, the vertical plume continued to evolve and lasted for more than twice the crater formation time. Although the ejection speeds in the vertical plume decreased with time, its persistence and direction appear to be a unique aspect of cratering in highly porous materials. Given its long duration, the plume cannot be the result of the usual material flow field established during passage of the impact generated shock but instead seems to be related to the impact heating of a highly porous material.

This behavior is strikingly similar to the observations of the DI event. What is the physical reason? It may be the so-called "anomalous behavior" of highly porous materials subjected to shock waves [3]. That strange behavior occurs when very porous material is heated so much in the shock that, although the pressure is in compression, the density actually <u>decreases</u> because of the extensive heat production and resulting thermal expansion. When it is rapidly pressurized the volume gets bigger! Such a mechanism might be further enhanced in a highly volatile target or by other phase changes. This may be the significant feature for the interpretation of the DI event, and we intend to study it, both theoretically and experimentally in much more detail. It has not been previously identified nor studied in the planetary community and may be a very significant factor in plume outbursts triggered by an impact.

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References:

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