Shock Effects on Cometary-Dust Simulants

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While comets are perhaps best known for their ability to put on spectacular celestial light shows, they are much more than that. Composed of an assortment of frozen gases mixed with a collection of dust and minerals, comets are considered to be very primitive bodies and, as such, they are thought to hold key information about the earliest chapters in the history of the solar system. (The dust and mineral grains are usually called the "refractory" component, indicating that they can survive much higher temperatures than the ices.) It has long been thought, and spacecraft photography has confirmed (figure 1), that comets suffer the effects of impacts along with every other solar system body. Comets spend most of their lifetimes in the Kuiper Belt, a region of the solar system between 30 and 50 times the average distance of the Earth from the Sun, or the Oort Cloud, which extends to ~1 light year from the Sun. Those distances are so far from the Sun that water ice is the equivalent of rock, melting or vaporizing only through the action of strong, impact-generated shock waves.

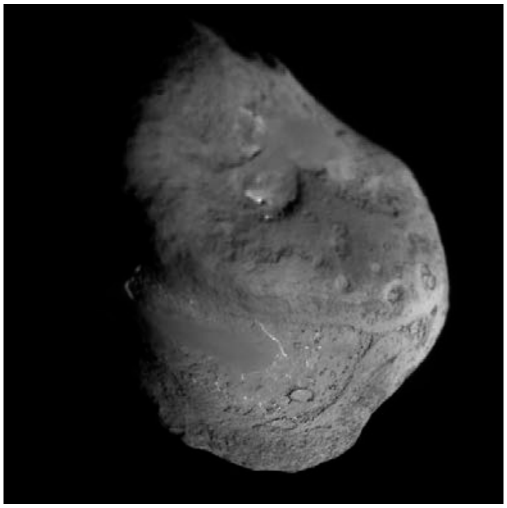

Figure 1.– The nucleus of Comet Tempel 1, which was the target of the Deep Impact mission in 2005. Craters, presumably of impact origin, are visible in a wide range of preservation states. Each of the two crisp, similar-sized craters on the bottom half of this picture has a diameter very similar to that of the Astrodome, around 220 m.

High-velocity impacts not only create craters such as those in figure 1, but the shock waves they generate also affect the refractory components of the comets' nuclei and, by inference, those of any other ice-rock body in the Kuiper Belt or Oort Cloud. With typical impact speeds of "only" around 3 km/s (~2 mi/s), the overall effects on the refractory components are not completely clear. It is known, however, that infrared (IR) spectra of dust in comets' tails are similar to IR spectra of various well-studied silicates, such as olivines and pyroxenes, but the matches are far from perfect. Furthermore, dust samples from Comet Wild 2 (figure 2) show damage to crystal structures that can be explained easily by impact-generated shock. Seeing macroscopic evidence of impact in the photography and microscopic evidence of impact in the samples, it is only natural to question what other effects impact can have on comets and their constituent materials. Characterizing the effects that relatively low-velocity impacts can have on some of the more common refractory components of comets, which is one way to attack this question, is the focus of this research.

With this in mind, scientists within the ARES Directorate are midway through a 4-year grant to investigate these effects, addressing the fundamental quest NASA has to understand planetary geophysical processes on solar system bodies. Using the vertical gun in the ARES Experimental Impact Laboratory, scientists launch 3.2-mm ceramic spheres at olivine and pyroxene crystals (figure 3), and the resulting fragments are recovered and analyzed with a Fourier-transform IR spectrometer and a transmission electron microscope (TEM).

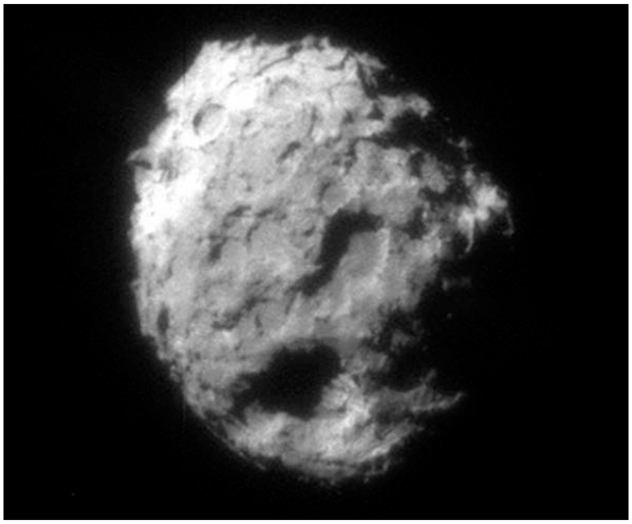

Figure 2.– The nucleus of Comet Wild 2 (about 5 km in diameter) as photographed by the Stardust spacecraft, which collected dust particles as it flew past the comet.

Aluminum-oxide ceramic was chosen as a projectile material because it is similar to rock in its density and shock behavior, and so provides a good simulation of rocky meteorites. While collisions among comets most commonly involve ice-rock mixtures colliding into ice-rock mixtures, these early experiments modeled rock colliding into ice-rock targets because such a combination would result in the greatest likelihood of damage to the rock component. Should effects be observed with the “rocky” projectiles, it would be a simple matter to use lower-density impactors to simulate ice. Pieces of pyroxene and olivine, versions of which have been found in samples from the Stardust mission and are commonly detected in spectra of comet dust, were used as targets. They were placed in a container filled with granular potassium bromide (KBr; see figure 3), which acted to absorb the residual momentum of the projectile after it collided with the target mineral. KBr has the added benefit of being soluble in water, so the shocked material could be collected after the KBr dissolved away in water, leaving the shocked mineral behind.

Figure 3.– An enstatite (a form of pyroxene) crystal before (left) and after (right) being pulverized by a ceramic projectile. The inside diameter of the target container is 34 mm (about 1.5 in.)

In this way, mineral grains were shocked at speeds up to 2.8 km/s, retrieved, and analyzed. Figure 4 shows IR spectra of shocked and unshocked forsterite grains (the gem peridot is high-quality forsterite). Note that the peaks change not only their amplitudes but their maxima, which occur at shorter wavelengths than those of the unshocked sample. Measurements of this sort provide the first indications of why the spectra of dusty comet tails do not match the spectra of pristine minerals. Furthermore, early examination of the shocked forsterite grains with the TEM shows damage to the mineral's crystal structure that is very similar to that observed in Stardust particles. This work is continuing, and will soon involve targets cooled to very low (liquid-nitrogen) temperatures, further increasing the fidelity of the experiments.

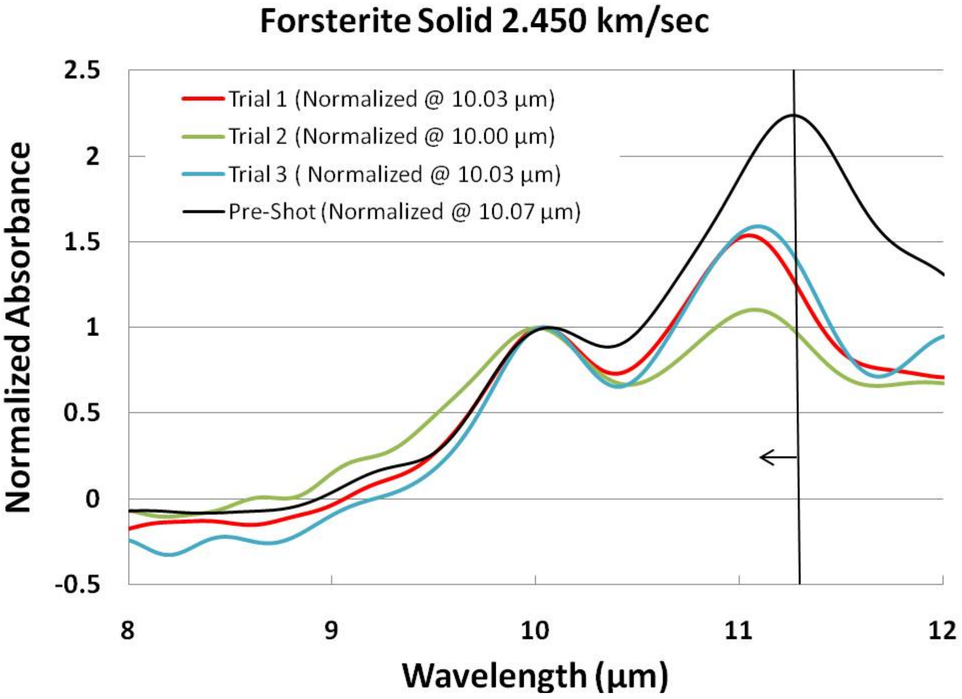

Figure 4.– Comparison of IR spectra from unshocked (black) forsterite and three samples of forsterite shocked in an impact at 2.45 km s^{-1}. The spectra of the shocked samples differ because the fragments were probably not subjected to the same shock level – a spherical projectile generates the highest shock pressure at the point of contact; the shock felt by the target at any other point depends on its location relative to the impact point.

Mars Habitability, Biosignature Preservation, and Mission Support

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Our work has elucidated a new analog for the formation of giant polygons on Mars, involving fluid expulsion in a subaqueous environment. That work is based on three-dimensional (3D) seismic data on Earth that illustrate the mud volcanoes and giant polygons that result from sediment compaction in offshore settings. The description of this process has been published in the journal *Icarus*, where it will be part of a special volume on Martian analogs. These ideas have been carried further to suggest that giant polygons in the Martian lowlands may be the signature of an ancient ocean and, as such, could mark a region of enhanced habitability. A paper describing this hypothesis has been published in the journal *Astrobiology*.