Small-Scale Impact Processes on Stony Asteroids

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Asteroids are a very diverse group of small objects (when compared to the much larger planets) orbiting the Sun. Most known asteroids are located between the orbits of Mars and Jupiter (in the “asteroid belt”), but large numbers are in orbits that cross that of the Earth. While scientific curiosity historically has driven investigations of asteroids, it is becoming intensely apparent that detailed information about asteroids could someday be critical in dealing with a potentially disastrous impact. Some asteroid types are believed to be sources of one of the most common types of meteorite, the “ordinary chondrites.” In fact, the large meteoroid that exploded over Chelyabinsk in Russia in February 2013 was an ordinary chondrite, and evidence suggests that ordinary-chondrite asteroids constitute a large fraction of the “Earth crossers.”

Earth-based astronomical observations have long implied and recent spacecraft missions have shown that even small asteroids (figure 1) are covered with unconsolidated debris (as is the Moon), which is generically termed “regolith.” The regolith on any typical airless body in the solar system is generated primarily through the breaking up (or “comminution”) of surface rock by impacting meteoroids. This is a process that, while it cannot be duplicated exactly on Earth for a variety of reasons, is amenable to simulation in the laboratory. All that is needed is an accelerator that can launch projectiles accurately at speeds of at least 2 km/s, a vacuum chamber, a piece of ordinary chondrite, a container to keep it confined, and people obsessed enough to shoot it 59 separate times, sieving it after every few shots and removing samples for later analysis. Amazingly, all of those requirements can be met in one place: the Experimental Impact Laboratory. (Actually, the ordinary chondrite is a piece from a larger meteorite that was found in Antarctica in 1985, brought to Houston, and kept in the Antarctic meteorite curatorial facility until it was allocated to us for the experiments.)

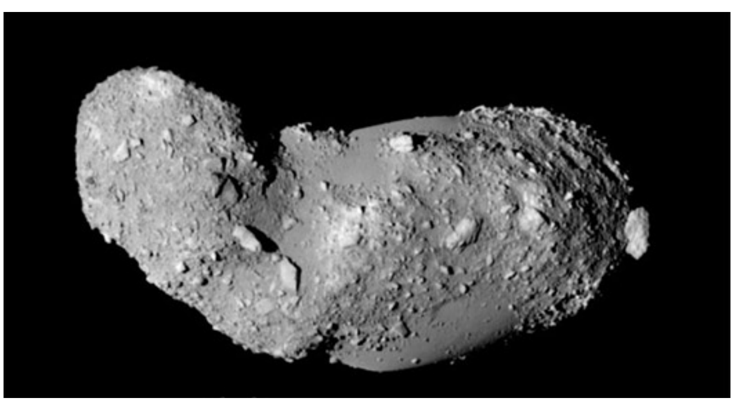

Figure 1.– The asteroid Itokawa, as photographed by the Japan Aerospace Exploration Agency’s Hayabusa spacecraft in 2005. The maximum dimension of the asteroid in this view is about 535 m (about a third of a mile). This asteroid is almost pathological in its regolith configuration, with textures ranging from patches of fine material to enormous blocks, such as the 50-m example at the extreme right, named Yoshinodai.

The 464-g (just over 1 lb) meteorite was subjected to 2 km/s impacts with 3.2-mm (1/8-in.) ceramic spheres. The largest fragment remaining after each shot was used as the target for the next impact, until the biggest surviving fragment was less than half the weight of the impacted piece. The meteorite required nine separate shots before it met that criterion, which means that it was a surprisingly tough rock. By comparison, similar experiments using terrestrial gabbro targets (a coarse-grained, strong, igneous rock fairly common on Earth and the Moon) required only about half of that energy to reach the same level of destruction. Given this, it is possible that, had the Chelyabinsk meteoroid been a large block of gabbro instead of ordinary chondrite, it might well have broken up at a higher altitude, doing less damage on the ground.

All of the debris from those nine shots was collected, put in a container, and impacted repeatedly. Regular breaks were taken to sieve the results, which allowed us to follow the "evolution" of this artificial regolith. Identical experiments using gabbro and basalt (a very fine-grained equivalent of the gabbro) were also performed, but they stopped at 25 shots, by which time enough information was in hand for comparison (figure 2). The larger pieces of the chondrite, again surprisingly, disrupted sooner than those of the gabbro and basalt, and when the pieces of the chondrite broke apart, they did so more thoroughly. It is entirely possible that, when the meteorite was disrupted initially, it suffered more internal fracturing than was apparent.

Work is underway to investigate possible chemical and mineralogical effects that might have occurred when the meteorite changed from rock to "regolith." It is already obvious, however, that the formation of regoliths on asteroids could be very different in detail from the equivalent process on a larger body like the Moon.

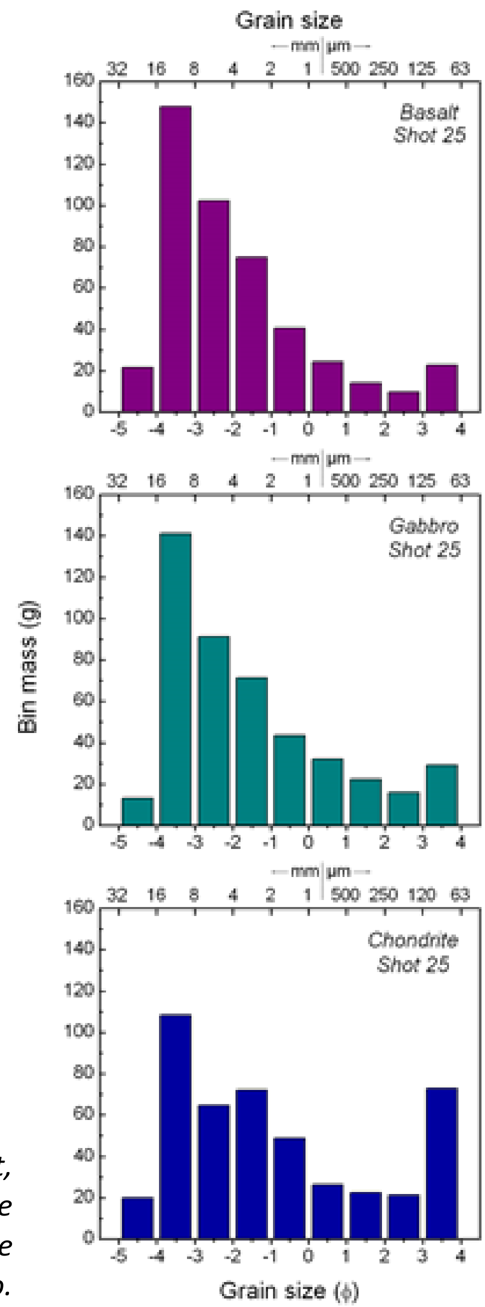

Figure 2.– Comparison between size distributions of basalt, gabbro, and chondrite after 25 impacts each. Note the similarity between the two terrestrial rocks and the difference between them and the gabbro.