


 INNER WORKINGS

Orbiting experiment may help decode the mysteries of rubble asteroids

Sid Perkins, *Science Writer*

Shake a bowl of mixed nuts and the large ones rise to the surface. This size-sorting phenomenon has been dubbed “the Brazil nut effect” because these large nuts often rise to the top of the mix—or, more accurately, smaller nuts like cashews and peanuts filter down into the gaps between large nuts over time. But the effect, whose physics remain something of a mystery, is more than a barroom curiosity: To ensure consistency, the Brazil nut effect must be considered when mixing granular materials of different sizes and densities to create, for example, powdered metal alloys, pharmaceuticals, and pigments for paints (1).

In recent years, astronomers have suggested the Brazil nut effect isn’t actually restricted to Earth. In fact, it might explain why the surfaces of some asteroids appear unusually riddled with boulders. Consider the asteroid 25143 Itokawa. Data gathered by Japan’s

Hayabusa probe, which visited Itokawa and gathered samples in 2005, suggest that the interior of the 535-m-long asteroid is about 40% open space (2); in essence, scientists propose, it’s a pile of rubble loosely held together by gravity, possibly aided by electrostatic or other cohesive forces between individual bits.

About 80% of the asteroid’s surface is rough terrain sporting boulders from a few meters to 50 m across (3). The smallest objects seen during Hayabusa’s close approaches were centimeter-sized fragments of gravel—but cameras should have been able to see things as small as 6 millimeters across, scientists estimate. So where did all of the small pieces go? Were they bounced into space during past collisions between the asteroid and other objects? [Itokawa’s gravity is estimated to measure between six- and nine-millionths that of Earth (4).] Or, did the vibrations



A shuffling of surface materials on asteroids after they’re struck by meteoroids (artist’s depiction)—something like the Brazil nut effect—may explain why some asteroids have a particularly rubble surface. Image courtesy of NASA/JPL-Caltech.

from such collisions cause small bits to shimmy below the asteroid's surface, à la peanuts and cashews settling beneath a veneer of cosmic Brazil nuts?

Experimenting with Asteroids

Recent simulations of an Itokawa-sized asteroid made solely of 40-m-diameter and 80-m-diameter boulders suggest that the Brazil nut effect may indeed play a role in resurfacing these objects (5). But an experiment now circling Earth on the International Space Station (6) may help provide more definitive answers, says Marc Fries, a planetary scientist at NASA Johnson Space Center in Houston and lead investigator for the study.

The setup, launched into space in March, is rather simple. It includes four transparent tubes filled with materials that will shift and settle as the space station's vibrations rock the experiment. Besides suffering shimmies generated by nearby motors and ventilation systems, the materials will experience stronger jolts when supply ships dock with the station—potential analogs of infrequent cosmic collisions between an asteroid and smaller objects such as meteoroids, says Fries. Cameras will monitor movement of the materials, and images will be downloaded to earthbound scientists once every 3 months or so. After a year or so in orbit, the materials will be locked in place within their tubes and then returned to Earth for more detailed analyses.

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—Richard Binzel

Even though the International Space Station orbits Earth in a free-fall-like state, people and equipment onboard do experience a small amount of our planet's gravitational pull—the "up versus down" gradient needed for the Brazil nut effect to work. Add in the minuscule forces imposed on the station by its gradual rotation and by atmospheric drag, and parts of the station can experience up to three-millionths of the gravitational force measured at sea level on Earth, says Fries.

Having four sets of materials should help researchers tease out differences in how diverse materials actually behave when shaken, says Fries. One tube is filled with three sizes of glass marbles (which can be readily simulated in computer models), and another is filled with similar-sized pieces of shattered, sharp-edged glass. Differences in the motions of these materials should help researchers identify how shape influences their movement. The other tubes are filled with ground fragments of meteorite or minerals chosen to simulate the regolith—fractured rocky material—that could be found on various types of asteroids.

Results of the Strata-1 experiment will do more than satisfy curiosity, says Fries. Understanding the processes that occur on the surfaces of asteroids should help engineers design better anchors for landers used

in future missions. Even further in the future, people will be designing equipment to land on asteroids and extract resources such as precious metals.

In the short term, however, his team's findings will help planetary scientists better interpret the results of sample return missions; that includes a recently launched NASA mission that will arrive at an asteroid in 2018 and, if all goes according to plan, return samples to Earth in 2023. For example, asks Fries, "If you collect material from an asteroid's surface, are you getting a representative sample of the body?" Or, instead, would the probe end up collecting a size-sorted sample that included an unusually high proportion of material from the asteroid's interior?

Although the experiment is only a first cut at understanding how the Brazil nut effect might be influencing asteroid surfaces, "when you know very little, all new information is important," says Richard Binzel, a planetary scientist at the Massachusetts Institute of Technology in Cambridge.

Skimming the Surface

There are strong signs that the surfaces of dozens of asteroids have experienced some sort of large-scale shuffling. Itokawa, besides having an unusually rubbly surface, shows few signs of craters. Perhaps more telling, says Binzel, the mix of wavelengths of light reflecting off a large number of asteroids orbiting through the inner solar system are, on average, slightly but distinctly redder than the spectra reflected from others. Although the surfaces of many asteroids suggest they have been "space-weathered" (exposed to the long-term bombardment of the solar wind and micrometeorites) for a million years or more, the more-reddish hues of these so-called Q-type asteroids suggest their surfaces have been disturbed in the last 500,000 years or so.

The degree of such changes, and what may have caused them, remains a topic of debate, says Binzel. Meteorite impacts may expose fresh material. And the expansion and contraction of rocks as they heat up and cool down over the course of the asteroid's "day" may contribute to a Brazil nut-like shifting of material. Another possible influence is that, over time, the uneven radiation of heat from the irregular surface of an asteroid might drive it to spin faster and faster, triggering a shift in loose material ranging from minor landslides to the mere rolling over of rocks to expose unweathered surfaces.

Although the Strata-1 experiment is still under way, a preliminary analysis reveals that the effects of the strong jolts created by docking of supply ships can be separated from the longer-term, more gradual effects of astronauts turning on and off motors and other equipment as part of their daily routine, says Fries. It's not yet clear, he notes, but final results may be able to help scientists figure out which processes are working to shuffle the surfaces of asteroids, as well as their relative importance if more than one is at play.

But the most intriguing source of an asteroid's surface freshening—one that happens on rare occasions indeed—might be flexing of the asteroid triggered by

variations in gravitational forces due to its close passage to a hefty planet, says Binzel. In 2010, he and his colleagues analyzed the orbits of 95 asteroids that swing through the inner solar system. Of that sample, 75 of them—including all 20 of the Q-type asteroids in the group—may have passed within a few thousand kilometers of Earth at some point in the past 500,000 years (7). In a follow-up analysis, he and another team surmised that seven Q-type asteroids that never orbited near Earth might have, instead, passed within a few thousand kilometers of Mars (8). The conclusions are tentative because of the difficulties in ascertaining an asteroid's position within an orbit over time, says Binzel; it's only possible for astronomers to say that these asteroids might have passed within a certain distance of Earth or Mars in the past.

From remote observations, it's clear that the surface disruption of Q-type asteroids must be widespread, says Binzel. What's not clear, he notes, is the form that disruption takes. Maybe it's as simple as flyby-induced tidal forces causing a large number of rocks or sand grains to

roll over in place. Or maybe, he suggests, it's a more thorough churning of the surface.

Answers could come 13 years hence. On April 13, 2029, the 300-m-wide asteroid 99942 Apophis will pass less than 30,000 kilometers above Earth's surface. (That's less than one-tenth of the Earth–moon distance and slightly inside the orbits of geosynchronous communications satellites.) Currently, Apophis' surface appears well weathered and thus hasn't been significantly disrupted in the past million years or so, he notes. But 2029's flyby may be close enough to cause substantial disturbance on the asteroid.

Of course, astronomers will be watching to see if the asteroid's surface reddens as a result of the close call. But the event will also be an excellent opportunity to send instrument-laden landers to the asteroid to directly measure what forces the asteroid experiences and what seismic activity is triggered as Apophis swoops past the planet, says Binzel. "We'll get to see what happens to an asteroid when it comes very close to Earth," he explains. "Nature will do the experiment for us; all we have to do is watch."

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