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The Density, Porosity, and Structure of *Very* Small Bodies

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Abstract

Most asteroids, with the exception of the very large and, possibly, the very small, appear to be pervasively fractured, often piles of rubble held together by self gravity and other forces. These rubble piles have large porosities, which gives them substantial resistance to further disruption and produces unique cratering morphologies. In the case of small NEAs, non-gravitational forces can give rubble piles surprising strength.

1. Introduction

As shown in Figure 1, asteroids in general appear to divide into three major groups. The three largest asteroids, 1 Ceres, 2 Pallas, and 4 Vesta have bulk densities similar to their analogue meteorites, indicating essentially zero macroporosity. These objects appear to have survived the age of the solar system with their primordial structure intact and have not been disrupted by impacts. Interestingly they are also large enough to be classified as Dwarf Planets. Asteroids with between 15-25% macroporosity appear to have been heavily fractured by impacts but remain coherent. Asteroid 433 Eros and 243 Ida are examples of this group. The third group are objects that have greater than 30% macroporosity and probably represent bodies that have been shattered in collisions, disrupted, and re-accreted by self gravity. An example is 253 Mathilde shown in Figure 2. These are likely to be gravitationally-bound rubble piles. While these general groups are useful for describing the physical processes, the macroporosity of asteroids is really a continuum with no strong natural breaks and thus grades smoothly from fractured to rubblized. The same continuum is seen in the distribution of Near Earth Asteroids (NEAs)

2. Discussion

If very small (i.e. diameters < 100 meters) bodies are often rubblized, how can they hold together with very small gravities against high rotation rates and tidal forces from the inner planets? Part of the answer is that they don't. At high rotation rates, probably induced by YORP spin-up, small bodies will shed their larger surface boulders (like the large boulder at the end of asteroid 25143 Itokawa shown in Figure 3) to form binary systems (Scheeres, 2007). The shedding of mass also sheds the YORP-induced angular momentum and spins-down the asteroid.

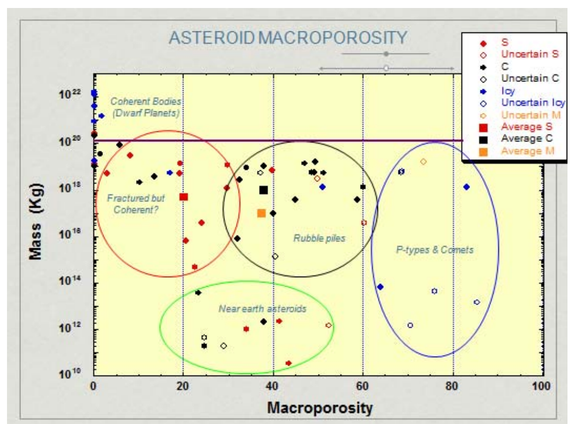

Figure 1: The Macroporosity of asteroids and comets.

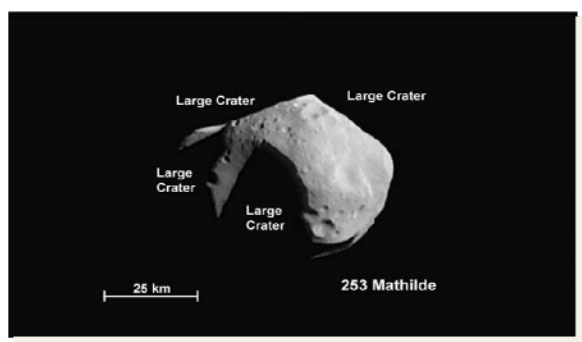

Figure 2: Asteroid 253 Mathilde from the Galileo spacecraft. Note the numerous large craters that were formed without disrupting the asteroid or deforming the adjacent craters (NASA/JPL).

Close approaches to terrestrial planets has been suggested to induce shape distortions in low-strength small bodies (Richardson et al., 1998) and evidence of this effect has been reported by Binzel et al. (2010) by showing that the freshest-appearing small bodies were also subject to recent planetary close encounters. The suggestion is that tidal forces distorting the shape of the asteroid tend to overturn of space-weathered surface material, exposing fresher, less-altered material.

While it is clear that small bodies can have high porosity, and they can fission and distort, what does this mean for the coherent strength of these objects? Scheeres et al. (2010) investigated the forces acting on particles of small bodies. These include not only gravity but also electrostatic forces, solar radiation pressure, and van der Waals cohesion. Van der Waals cohesion is probably the most important of the last three. Scaling the extensive terrestrial experience with dry powders to the microgravity of small asteroids suggests that particles of millimetre to centimetre size probably have substantial van der Waals cohesion. Scheeres et al. (2010) estimates that for a 10 meter asteroid will have positive 1 milliG acceleration for rotation periods of less than a minute but that van der Waals cohesion will balance this acceleration for particles smaller 4 centimetres diameter.

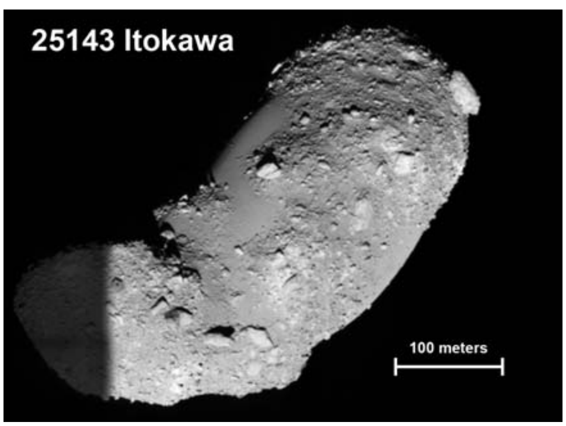

Figure 3: The NEA 25143 Itokawa (ISAS/JAXA).

This non-gravitational force balancing poses some interesting implications for the structure of very small bodies. Rapidly rotating small bodies on the order of 10 meters may not be coherent boulders after all, but rather lumpy sand bars. The outer layers of the body would be composed of smaller sand and gravel-sized material held in place by electrostatics and van der Waals forces. The interior could contain larger blocks and cobbles that are contained by interparticle friction. The entire assemblage could have very large porosity, but still retain enough coherent strength to be a rapid rotator because of these non-gravitational forces.

Another factor to consider is the behavior of cratering on very porous bodies. Recent experiments (Housen and Holsapple, 2010) have shown that instead of producing large amounts of high speed ejecta impacts in porous bodies spend the impact energy in compaction and produce very little ejecta. The net effect may be to minimize the erosive properties of impacts, particularly micro-meteorite impacts, on small bodies allowing them to retain granular regoliths.

Acknowledgements

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