WHEN IMPACT CRATERING GOES GLOBAL ON ASTEROIDS. E. Asphaug, Department of Earth and Planetary Sciences, University of California, 1156 High St., Santa Cruz, CA, USA, easphaug@ucsc.edu

Introduction: Through missions [1], ground based observations [2], and laboratory studies and models [3], we are beginning to understand the geophysics of small planetary bodies [4]. Investigations now focus upon near-Earth asteroids, both for science and for pragmatic reasons – the development of near-Earth space as a resource, and the deflection of potentially hazardous objects [5]. Although detailed studies of interior mechanical properties will require orbiters, penetrators and landers, much about their interior characteristics may possibly be derived from much simpler image-based investigations of their crater populations.

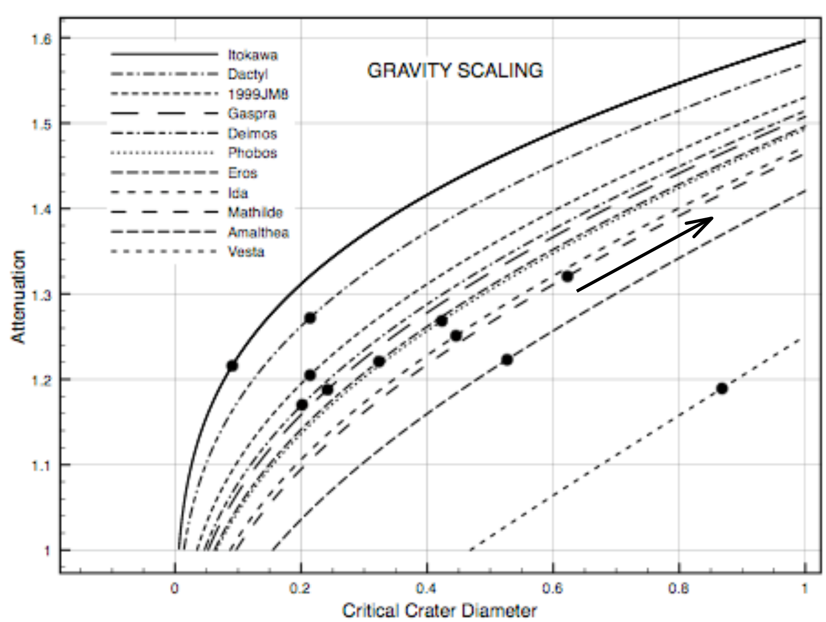
This idea is motivated by studies linking impact-generated stress energy to cratering and topographic degradation ([6,7,8,9]). One approach [10] considers the largest crater to form on an asteroid, recognizing the curious observation that larger asteroids (e.g. Mathilde, Phobos) appear to have hemisphere-spanning craters, whereas smaller asteroids (e.g. Itokawa, Dactyl) lack any undegraded craters larger than a fraction of the global radius.

The approach developed in [10, in press] is to use crater scaling relations and power-law approximations for stress wave particle velocity attenuation with radial distance to compute the *critical crater diameter*, the threshold at which cratering "goes global". D_{crit} is the smallest crater which degrades all of an asteroid's previous topography to a scale D_{crit} or smaller. The attenuation α is the exponent at which peak particle velocity decays with radial distance $v_p(r)=v_i(r/r_i)^{-\alpha}$, where v_i and r_i are velocity at some initial radius.

In shocks this exponent α is near 2, a value adopted by analytical models of asteroid disruption [11]. But for global studies a smaller attenuation is required. Because asteroids can undergo ground upheaval and disassembly at very low particle velocities – escape velocity is of order 1 m/s per km of radius – the attenuation is expected to be closer to seismic values, which are typically around ~1.2 for ground motions in the cm/s to m/s range. This bears out in the modeling.

Upon formation, a crater of D_{crit} forms as a solitary large crater on an asteroid. Craters $D_L>D_{crit}$ also form on a "clean slate", erasing prior structures even larger than themselves, but these are less common than $D_L=D_{crit}$ and thus likely to be degraded by more frequent events. The most reliable indication that an asteroid has attained critical crater equilibrium – that is, possesses a crater D_{crit} or larger – is that it possesses one large solitary crater. Because D_{crit} it is a function of the stress wave attenuation, an asteroid with an obvious largest undegraded crater bears a record of its interior mechanical properties, especially the nature of its global-scale attenuation of impact energy.

New Results: Presented here is an extension of the approach in [10], in which the two or three largest undegraded craters (not just the largest) is utilized to assess whether critical crater equilibrium has been attained. As an example we can compare Phobos (mean diameter D=22 km) and Mathilde (D=53 km), both with craters about equal to their global diameter. The difference is that Phobos has a single largest crater (D_L=9.4 km) with no rivals, whereas Mathilde has five of six craters around 30 km diameter, with Karoo at D_L=33 km being the largest [1]. It can be argued that Phobos has achieved its critical crater, whereas Mathilde has not, as indicated by the arrow in Figure 1. From this one can deduce that Phobos is a relatively competent propagator of stress energy (smaller D_{crit}, thus lower attenuation α=1.27, see below), congruent with modeling [12, 13], whereas Mathilde is not, also congruent with modeling [14, 15]. Because it is highly porous and attenuative, Mathilde's critical crater diameter may be larger than Mathilde.



By using the largest undegraded craters on an asteroid to indicate how they attenuate stress energy, important questions can perhaps be addressed through low-cost spacecraft or high-fidelity ground-based radar such as at Arecibo [2]. If gravity scaling applies to the formation of global-scale craters on asteroids [e.g. 12] then the following conclusions can be derived:

• For a given attenuation α, the normalized critical crater diameter $\chi=D_{crit}/D$ increases with asteroid diameter D, which may be why small asteroids have no global craters while large asteroids have huge ones.

• If gravity scaling applies to global cratering, then stress wave particle velocities attenuate globally with about the 1.2-1.3 power of distance for most asteroids; attenuation appears to be greater (α>~1.3-1.4) for asteroids regarded as highly porous.

• For Mathilde-sized (~50 km) asteroids with attenuation α=1.45 or higher, D_{crit} exceeds the diameter of the target, and all craters are "local"; if impact governs their large-scale topography, such bodies become saturated with hemisphere-spanning craters.

Figure 1 is adapted from [10] and shows the attenuation α as a function of $\chi=D_{crit}/D$, derived from gravity regime crater scaling relations [3]. Plotted along each asteroid's curve is a solid circle that indicates the largest imaged undegraded crater χ_{obs}, from Table 1. If χ_{obs}~χ this solves for velocity attenuation α in each asteroid. The derived attenuations are close to seismic values (~1.2-1.3) for most asteroids.

Asteroids in Figure 1 are labeled in order of size. Small asteroids have curves to the upper left, and large asteroids are to the lower right. Because this is gravity scaling, Ida and Mathilde plot near one another, Ida being twice as dense but half as large. Asteroids of low density, or otherwise suspected of being highly porous, appear to have higher attenuation. But because it is likely that χ_{obs}~χ for asteroids with one solitary large crater, while $\chi_{obs}<\chi$ for asteroids with several craters that are almost equally large, the attenuation derived for Mathilde is a lower limit, as indicated by the arrow.

Because χ increases with asteroid diameter for a given α, large asteroids of the same material will have giant craters, compared to small asteroids that can have no global-scale undegraded craters. This means e.g. that Itokawa is globally reset, to scales of ~30 m, by an impact crater ~30 m diameter (χ~0.1).

The requirements for this approach to apply are that (1) gravity scaling applies to the largest craters to form on an asteroid, (2) stress wave attenuation is realistically represented by a single power law, and (3) that the evolution of an asteroid's largest-scale topography is governed by impacts, not endogenic processes. While these are testable and well-undersood caveats, it is likely that benchmarking experiments on small asteroids need to take place in order to address them.

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Table 1. The mean diameters (D, km), densities (ρ, g/cm^3), largest distinct crater diameters (D_L, km) and normalized largest craters $\chi_{obs}=D_L/D$ on several well-studied asteroids and asteroid-like bodies. This is based upon [1]; see [10] for other sources. It excludes highly degraded craters, so that e.g. D_L on Deimos is not the ~10 km feature [1] but the next-largest crater, which retains rim topography. Vesta and Amalthea are included for comparison, although any body whose largest-scale topography is the result of endogenic activity (e.g. relaxation) is not applicable, as the calculation for D_{crit} assumes that an asteroid's largest scale topography (and degradation thereof) is the result of cratering.

	D	ρ	D_L	χ_{obs}
Itokawa	0.33	1.9	~0.03	0.1
Dactyl	1.4	~2 (?)	0.3	0.2
1999 JM8	~7	~2 (?)	1.5	0.2
Deimos	12.4	1.8±0.3	2.5	0.20
Gaspra	12.4	2.7 (?)	3.0	0.24
Eros	17	2.7	5.5	0.32
Phobos	22.2	1.9±0.1	9.4	0.45
Ida	31.4	2.6±0.5	14	0.44
Mathilde	53.0	1.3±0.1	33	0.62
Amalthea	167	0.86±0.1	88	0.52
Vesta	530	3.5±0.4	460	0.85