Cratering statistics on asteroids: Methods and perspectives

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Crater size-frequency distributions (SFDs) on the surfaces of solid-surfaced bodies in the solar system have provided valuable insights about planetary surface processes and about impactor populations since the first spacecraft images were obtained in the 1960s. They can be used to determine relative age differences between surficial units, to obtain absolute model ages if the impactor flux and scaling laws are understood, to assess various endogenic planetary or asteroidal processes that degrade craters or resurface units, as well as assess changes in impactor populations across the solar system and/or with time. The first asteroid SFDs were measured from Galileo images of Gaspra and Ida (cf., Chapman 2002). Despite the superficial simplicity of these studies, they are fraught with many difficulties, including confusion by secondary and/or endogenic cratering and poorly understood aspects of varying target properties (including regoliths, ejecta blankets, and nearly-zero-g rubble piles), widely varying attributes of impactors, and a host of methodological problems including recognizability of degraded craters, which is affected by illumination angle and by the "personal equations" of analysts. Indeed, controlled studies (Robbins et al. 2014) demonstrate crater-density differences of a factor of two or more between experienced crater counters.

These inherent difficulties have been especially apparent in divergent results for Vesta from different members of the Dawn Science Team (cf. Russell et al. 2013). Indeed, they have been exacerbated by misuse of a widely available tool (Craterstats: hrscview.fu- berlin.de/craterstats.html), which incorrectly computes error bars for proper interpretation of cumulative SFDs, resulting in derived model ages specified to three significant figures and interpretations of statistically insignificant kinks. They are further exacerbated, and for other small-body crater SFDs analyzed by the Berlin group, by stubbornly adopting certain assumptions about issues that should be left as open questions (e.g., the shapes of impactor SFDs are assumed to be identical throughout the solar system and throughout all epochs, the decay rate of the impactor flux in the asteroid belt is assumed to be the same as in the Earth-Moon system, and all kinks in SFDs are interpreted as "resurfacings" rather than due to layering of targets or due to other kinds of crater creation and degradation processes). In fact, we know that there are different mixes of comets and asteroids in different parts of the solar system, that size distributions differ in different parts of the asteroid belt, that SFDs of asteroid families evolve, that kinks in SFDs can be produced by layering (e.g., on the Moon), and that small-scale crater populations on asteroids like Itokawa and Eros are dramatically affected by processes of lesser importance to large-scale cratering (e.g., because of bouldery substrates, seismic shaking, etc.).

Identification of homogeneous geological units for crater counting is particularly critical. Crater ejecta blankets, which are useful units on planetary-scale bodies, become problematic on smaller bodies where ejecta travel farther and are even ejected at greater than escape velocity resulting in thin, patchy ejecta blankets inappropriate for displaying a useful post-deposition crater population. As we anticipate studying still more cratered small-body surfaces from future spacecraft and even radar imaging of asteroids, comet nuclei, and small satellites, non-specialists and crater-counters alike should be suspicious of crater SFDs obtained through production-line application of black-box routines like Craterstats. Crater SFDs can still be a very useful tool, so long as there is rigorous, statistically robust, open-minded interpretation that takes account of the real unknowns concerning geological and interplanetary contexts.

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References: Chapman, C.R. 2002. Cratering on asteroids from Galileo and NEAR Shoemaker. In "Asteroids III" (ed. W.F. Bottke et al., Univ. Ariz. Press, Tucson), 315–330; Robbins, S.J. et al. 2014. The variability of crater identification among expert and community crater analysts. Icarus 234, 109–131; Russell, C.T. et al. 2013. Dawn completes its mission at 4 Vesta. Meteoritics & Planet. Sci. 48, 2076–2089.