UNCOVERING THE SATURNIAN IMPACTOR POPULATION VIA SMALL SATELLITE CRATERING RECORDS. J. E. Richardson and P. C. Thomas, Center for Radiophysics and Space Research, 310 Space Sciences Building, Cornell University, Ithaca, NY 14853, richardson@astro.cornell.edu.

Introduction: Cratered terrain on the solid surface of a solar-system body provides us with a valuable record of that surface's bombardment history, material properties, weathering mechanisms and rates, and other endogenic processes. On 'old' surfaces with very low weathering rates or other crater erasure mechanisms, the density of impact craters can reach equilibrium conditions (called crater saturation), where for each new crater formed, a crater of roughly the same size is erased, and crater counts (in a given size range) level off as a function of time and further bombardment.

Recent advances in computing technology and our understanding of the processes involved in crater production, ejecta production, and crater erasure have permitted us to develop a Cratered Terrain Evolution Model (CTEM) which can be used to investigate a variety of questions in the study of cratered landscapes. In a previous study [1], we investigated the manner in which crater densities attain equilibrium conditions, and discovered the following:

(1) Crater density equilibrium generally occurs near observed crater densities of about 0.1-0.3 on a relative-density (R) plot, or about 2-10% geometric saturation [2]. However, this may vary significantly, depending upon the parent impactor population's size distribution.

(2) If the impactor population has a cumulative power-law slope of less than -2, then small-crater 'sandblasting' dominates the crater erasure process and crater density equilibrium values tend to follow classic Gault [2] behavior: with crater densities leveling off at roughly 5-10% geometric saturation, with a cumulative power-law slope of about -2.

(3) If the impactor population has a cumulative power-law slope of greater than -2, then large-crater 'cookie-cutting' dominates the crater erasure process and crater density equilibrium values will continue to reflect, or follow the shape of the impactor population, as large regions are continuously 'reset' and then repopulated with small craters again.

(4) If the impactor population has a variable cumulative power-law slope, then a mixture of 'sandblasting' and 'cookie-cutting' will occur, depending upon the size-range of craters involved, and crater density equilibrium values will continue to follow the shape of the impactor population. This behavior thus allows the shape of an impactor population to be determined for a particular surface, even after that surface has reached crater density equilibrium.

Our previous study [1] went on to show that the heavily-cratered regions of the Lunar surface (such as the Lunar Highlands) represent a crater population which is in crater density equilibrium, but which also continues to follow the shape of the impactor population which produced it. Specifically, the size-frequency distribution of the impactor population which best reproduces the crater density curve for heavily-cratered regions of the Lunar surface is nearly identical to that of the current Main Asteroid Belt (MAB), as suggested by Strom et al. [3], and points to the MAB as the primary source for impactors in the inner solar-system.

Saturnian Satellite Study: The next phase of this work is to investigate the impactor population for the outer solar-system, beginning with the small Saturnian satellites. These bodies share the unique characteristics of: (1) having been imaged at high-resolution by the Cassini ISS; (2) are small enough such that impact cratering is the dominant geologic process, with extremely low surface weathering rates and few crater-erasing endogenic processes; and (3) have very low escape velocities (< 170 m/s) such that secondary cratering is negligible on these bodies -- all circular (hyper-velocity) impact craters can be assumed to originate from objects either in heliocentric orbit or plane-to-centric orbit around Saturn. So far, adequate crater count statistics have been assembled for satellites Phoebe (~220 km diameter), Hyperion (~270 km diameter) and Mimas (396 km diameter): see Fig. 1.

Fig 1: R-plot of crater counts for Phoebe (open symbols) & Hyperion (closed symbols). Mimas not shown.
Modeling Synopsis: Utilizing our CTEM, initial model surfaces are established which have the same mean radius, surface area, and gravity as each satellite under study, with estimates for their material properties assigned to each. A series of model runs are then performed, searching for convergence upon a common, synthetic impactor population which will recreate the cratering record for each satellite. In addition to varying the shape of the impactor population, impact velocities can also be varied, from low (2-8 km/s) planetocentric to high (12-18 km/s) heliocentric speeds [4]. Over the course of a given model run, the CTEM maintains a 3D terrain model of crater production and erosion, which includes regolith generation, downslope regolith migration, and automatic crater counting. The model is briefly summarized below:

Impact Cratering Scaling-Laws: The impact cratering scaling relationships are used to relate the size of an impactor to the size of a resulting crater on a particular surface, given several impact parameters (including target gravity, density, and strength). Previously, most applications of these relationships dealt strictly in either the gravity- or strength-dominated cratering regime. However, cratering on a small target body falls into neither regime; gravity and target strength are both important to the size of the final crater. We have therefore adopted the general solution to the transient crater volume scaling relationships [5], which includes both gravity and strength terms. The application of a general solution to the crater volume scaling-law permits us to also include a general solution to the ejecta velocity scaling relationships [6]. These ejecta velocity scaling-laws permit us to compute ejecta blanket thickness as a function of distance from a given crater rim.

Downslope Regolith Migration: Downslope regolith migration can be triggered either by slope instability or by the seismic motion generated by nearby impacts. This regolith motion is computed in finite-differencing fashion following each impact, using the slope degradation theory described in [7].

Crater Superpositioning and Erasure: In general, impact craters on airless bodies are erased by three mechanisms: subsequent impacts, which erode and modify the underlying crater; coverage by the ejecta thrown up by other, nearby impacts; and the downslope movement of regolith due to slope instabilities and impact-induced seismic shaking. If a portion of a crater's rim is either excavated by a subsequent impact or eroded by downslope regolith motion to less than 25% of its original vertical relief, or if the crater's rim or bowl is covered over by regolith to a depth equal to 75% of its current vertical relief, then that small portion of the crater is considered to be "erased" and is no longer included. When the crater has 'lost' over 2/3 of it's original surface area, it is considered to be no longer countable.

Preliminary Results: Fig. 2 shows the cumulative size-frequency distribution for a common, heliocentric impactor population which is capable of reproducing the crater count data for Phoebe and Hyperion (Mimas modeling is ongoing), as compared to the cumulative size-frequency distribution for the Main Belt asteroids [8,9]. Note that the vertical position of the (bold) curve is currently arbitrary and will be constrained with further modeling. In addition to this single-source curve, a dual impactor source, consisting of larger, heliocentric impactors and smaller, planetocentric impactors is also possible, and will be investigated. It is important to note, however, that all attempts to utilize the MAB as the common impactor source for all three satellites have failed, regardless of assumed impact speed. This points strongly to a unique outer solar-system (probably Kuiper Belt) impactor source for the Saturnian satellite system. Further results will be forthcoming.


Fig. 2: (bold) the impactor population which best recreates the crater distributions on the small Saturnian satellites, compared to (thin) two MAB models [8,9].