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The Role of Ejecta in the Small Crater Populations on the Mid-Sized Saturnian Satellites

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Abstract

We find evidence that crater ejecta play an important role in the small crater (less than a few km) populations on the Saturnian satellites, and more broadly, on cratered surfaces throughout the Solar System. We measure crater populations in Cassini images of Enceladus, Rhea, and Mimas, focusing on image data with scales less than 500 m/pixel. We use recent updates to crater scaling laws and their constants [5] to estimate the amount of mass ejected in three different velocity ranges: (i) greater than escape velocity, (ii) less than escape velocity and faster than the minimum velocity required to make a secondary crater ($v_{\min}$), and (iii), velocities less than $v_{\min}$. Although the vast majority of mass on each satellite is ejected at speeds less than $v_{\min}$, our calculations demonstrate that the differences in mass available in the other two categories should lead to observable differences in the small crater populations; the predictions are borne out by the measurements we have made to date. In particular, Rhea, Tethys, and Dione have sufficient surface gravities to retain ejecta moving fast enough to make secondary crater populations. The smaller satellites, such as Enceladus but especially Mimas, are expected to have little or no traditional secondary populations because their escape velocities are near the threshold velocity necessary to make a secondary crater. Our work clarifies why the Galilean satellites have extensive secondary crater populations relative to the Saturnian satellites. The presence, extent, and sizes of sesquinary craters (craters formed by ejecta that escape into temporary orbits around Saturn before re-impacting the surface [3, 1, 8] is not yet well understood. Finally, our work provides further evidence for a “shallow" size-frequency distribution (slope index of ~ 2 for a differential power-law) for comets a few km diameter and smaller.

1. Introduction

To derive accurate ages using impact craters, one must first determine the sources of impactors that make craters. Impact craters can be primary, secondary or sesquinary. In the outer Solar System, most primary craters are thought to be made by direct impact of cometary nuclei. Secondary craters are the result of essentially ballistic trajectories of ejecta from the primary crater to some distance away. For typical impact speeds of heliocentric comets onto Saturnian satellites of several to 30 km/s [7, 4], ejecta can be launched at speeds from a few hundred m/s to several km/s. When an ejectum is launched at a speed faster than the escape velocity of a moon, it can go into orbit about the planet. For almost all of Saturn’s satellites, most escaped ejecta are eventually swept up by the source moon, but the orbits of some escaped ejecta can be sufficiently perturbed, or the original ejection velocity so high, that the ejecta will impact another satellite [7, 4]. In either case, craters formed by ejecta that initially escape their parent object are called sesquinary (“$1\frac{1}{2}$-ary") craters [3, 8]. Because secondary and sesquinary craters are products of primary craters, and because the larger (and therefore generally older) primary craters create the most ejecta, older terrains will have the greatest number of craters of all types. This introduces uncertainty in the number of primary craters, which is the only kind to be trusted chronometrically [6].

2. The Role of Ejecta as Impactors

Using ejecta velocity distributions and scaling laws from [5], we have divided Saturn’s mid-sized satellites and Jupiter’s Galilean satellites into groups based on the expected masses of ejecta available to form secondary and sesquinary craters. For example, Mimas and Enceladus have weak surface gravities and large cometary impact velocities, resulting in more ejecta to form sesquinary craters than secondaries. Tethys, Dione, and Rhea have stronger surface gravities and smaller impact speeds, and should have more ejecta to form secondaries than sesquinaries.

3. Crater Size Distributions

We have measured the crater size-frequency distributions (SFDs) on terrains on Enceladus, Mimas, and Rhea. The Enceladus young terrain crater SFD has a slope near -2 (differential), similar to that found on the Galilean satellites. These observations provide evidence for a present-day shallow primary impactor population (presumably comets) for diameters in the range from < 100 m to several km. We have found no clear evidence so far for the expected sesquinary craters. A possible explanation is that ejecta break into pieces too small to make observable craters during their decades or centuries in orbit.

4. Summary and Conclusions

The bulk of the crater SFDs across the Saturnian satellites *may* be explained by a single impacting population. The variation in impact velocity and surface gravities among the moons means that a single impacting population will generate different primary crater SFDs on each satellite. For a given sized impactor, the variation in primary crater size is followed by variation in ejecta mass and ejecta speeds available to make secondary and (probably) sesquinary craters. For example, on Iapetus a 1 km comet makes an approximately 8 km transient crater with $\sim 2 \times 10^{11}$ kg available to make secondaries, while the same impactor makes a 17 km transient crater on Mimas, with no mass available to make secondaries. The mass available to make secondaries will travel different distances across the moons. The superposition of the varying primary crater, and resulting secondary (and sesquinary) crater distributions may explain the crater SFDs seen on the satellites. We propose an update to the Voyager-era interpretation of the Saturnian cratering record: Population I is likely dominated by heliocentric comets, and appears on all regular Saturnian satellites as the main source of craters above several km diameter; Population II is a result of secondary (and perhaps sesquinary) craters, with significantly varying signatures between the satellites, due to differences in primary impact velocities, surface gravities, and escape speeds. For details of our work, see [2].

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