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Fantastic Craters and Where to Count Them: Analysis of Crater Size-Frequency Distributions on Tethys and Dione

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Abstract

Impact cratering is a geologic process that dominates planetary surfaces across the solar system. Due to its prevalence, impact cratering has been used to date planetary surfaces. Based on crater counts on Saturn's moons, the moons' ages are estimated as ~4.5 Gyr, i.e., contemporaneous with Saturn's formation. Recent dynamical models suggest the moons could be as young as 100 Myr or range in age from 4.5 Gyr to ~ 1 Gyr. We utilize high-resolution imagery from the *Cassini* spacecraft to analyze the impact crater size-frequency distributions (CSFDs) on Tethys and Dione, to investigate any potential change in impactor populations over the histories of these satellites. We find that the oldest region on Tethys has an enhanced population of small ($D < 4$ km) craters compared to the other regions. Our counts on Dione show slopes consistent with previous studies on the moon, that potentially indicate a planetocentric origin of the impactors.

1. Introduction

An outstanding question at the end of the *Cassini-Huygens* mission is "How old are Saturn's moons?" Recent studies [1,2] have suggested, based on various orbital dynamic and geodynamical perspectives, that the inner satellites (Mimas, Enceladus, Tethys, Dione, Rhea) might be as young as 100 Myr, or middle- aged at ~ 1 Gyr; only Rhea might have formed along with Saturn 4.5 Gyr ago [2]. Depending on when it formed, a satellite might currently have an ocean underneath the ice or may have had one in its recent past. Constraining the ages of Saturn's moons is key to understanding the prevalence and workings of ocean worlds in the solar system.

We investigate the surface ages of the moons through analysis of their CSFDs: a heavily cratered surface has been exposed to impacts for a much longer duration than a surface relatively free of impacts. We analyze the impact crater populations of Tethys and Dione in particular to investigate the source populations of impactors onto these moons. Previous studies of these moons [3,4] have analyzed the crater distributions on a more global scale, but our studies focus on high-resolution regional imagery that has not yet been analyzed. Studies by [3,4] concluded the surfaces were primarily impacted by a planetocentric (Saturn-orbiting) impactor population, rather than a heliocentric population. We use regional counts from our mapping to test this conclusion, to help inform moon formation and evolution scenarios, as well as the source impactor population.

2. Methods

We calculated CSFDs in distinct, geographically distributed regions across Tethys and Dione. We mapped five areas on Tethys areas chosen so that we had coverage over different terrain types. Region 1 on Tethys is distinct from the other mapped units due to its location away from Ithaca Chasma, whereas Regions 2,3, and 5 are all located near the canyon system. Region 4 is located at roughly the antipode of Odysseus. We mapped four regions on Dione across different geologic units as defined by [4].

We utilized images from Cassini's Imaging Science Subsystem (ISS) [5]. Images were downloaded from the USGS PILOT website (https://pilot.wr.usgs.gov/) and processed using the Integrated Software for Imagers and Spectrometers [6]. After processing, we brought the images into ArcGIS, where craters were catalogued using the Crater Helper Tools extension for ArcGIS [7], which allowed us to calculate the diameter of the crater independent of the map projection used. Craters were counted if they had a visible depression (indicated by the shadow direction inside the feature), and had a diameter 10 pixels or larger (~150 m/pixel). Craters were counted down to the 5 pixel level, to obtain completeness in the counts at smaller diameters [8,9].

3. Results and discussion

Across both moons we counted a total of 6409 craters: 3117 on Tethys and 3292 on Dione. Within the craters counted we have also measured elliptical craters and polygonal craters. We will present our survey of these crater subtypes.

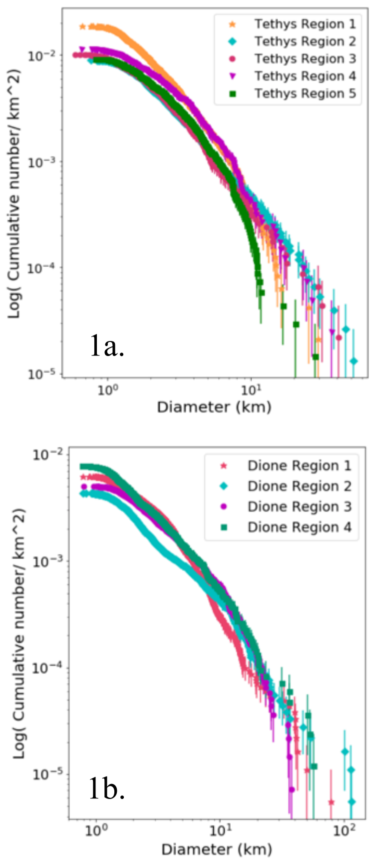

Figure 1. CSFD's of mapped regions

Figure 1a shows our CSFDs for Tethys, Figure 1b for Dione. From these diagrams we see that Tethys Region 1 has an abundance of small craters with diameters D between 1.2 and 4 km, compared to the other regions. These do not appear to be secondary craters from the Odysseus impact basin [10], though it is possible that other basins on Tethys could create secondaries in Region 1. Regions 2, 3, and 4 have similar CSFDs between D = 4 km and 10 km, but vary at larger diameters. Region 5 sees a sharply increased slope at D > 10 km which could be indicative of geologic processes erasing large craters in Ithaca Chasma. We have compared these CSFDs to production functions [11]. Region 1 matches the Case A/ Heliocentric impactor population for craters between 1.5 km and 6 km. Region 2 also follows Case A well up to diameters of 10 km. Regions 3, 4, and 5 match Case B instead, suggesting a planetocentric origin, but lie within error of Case A. We hypothesize there was initially a high flux of heliocentric impactors that hit Tethys (seen in Region 1) and then largely dissipated. That record was then erased in some regions, replaced with a later planetocentric population. The large-scale resurfacing event may have been caused by the freezing of an ocean underneath the ice shell in a manner similar to Vulcan Planum on Charon, with Ithaca Chasma similar to Serenity Chasma.

Most of Dione's regions have similar CSFDs, indicating a common impactor population. Region 2 is located near the "wispy" terrain on the trailing hemisphere of Dione. The lower number of impacts in Region 2 indicates a younger surface age there than in the other three mapped areas. It is possible that small (D < 10 km) craters in Region 2 were preferentially re-surfaced, perhaps by burial by regolith from nearby large impacts. Our mapped terrains on Dione overlap with counts produced by [4]. Our results agree with previous interpretations [4] that these craters were likely formed by planetocentric impactors.

The CSFDs on Tethys and Dione together tell a story about the Saturn system as a whole. On Tethys, the most heavily cratered and oldest Region 1 was hit by heliocentric impactors, but other regions on Tethys appear to have erased this flux, recording more of a later planetocentric population. We find, consistent with previous studies, that Dione records only the later planetocentric population. Dione appears to have been much more geologically active than Tethys. In combination with modeling, these results can constrain the ages of the moons.

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