APEX-ANTAPEX ASYMMETRY OF IMPACT CRATER DENSITY ON GANYMEDE'S DARK TERRAIN .

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Introduction: Synchronously rotating satellites bombarded by a heliocentric impactor population should have a difference in crater density between their apex and antapex of motion. Predictions by Zahnle et al. [1] indicate the crater density at the apex could be up to ~70x greater than at the antapex. An absence of such a difference could be caused by saturation cratering, periods of nonsynchronous rotation, or impacts by planetocentric debris/secondaries [1].

An apex-antapex crater asymmetry was found by Zahnle et al. [1] on the bright terrain of Ganymede. The difference, however, is much smaller than predicted, with the density at the apex being only 4X greater than at the antapex. From this they concluded that either the distribution was saturated or, perhaps more interestingly, Ganymede rotated nonsynchronously at some point in its history.

The goal of this project is to similarly analyze Ganymede's dark terrain, which is approximately twice the age of the resurfaced, ~2 Gyr old bright terrain [2]. As with bright terrain, a significantly diminished or absent difference in cratering density on Ganymede's dark terrain may indicate some interesting events taking place in the satellite's history.

Methods: Crater diameters and coordinates were measured and recorded from a 1 km/pixel global mosaic. In the case for palimpsests (large, circular bright patches, likely the remains of viscously relaxed craters [e.g., 3]), the formula $D_p = 2.442\ D_c^{0.906}$ [4] was used to calculate the unrelaxed original crater diameter, D_c. D_p is our measurement of the bright patch from edge to edge. From the collected data, relative plots, termed R-plots, were generated. An R-plot ratios the distributions determined here to a standard distribution with a differential slope of -3, with $\sqrt{N}$ error bars [5].

In order to examine the variation in crater density with increasing distance from the apex (0°, 90°), the data was grouped into 10° bins with centers every 5° from the apex. The areas of each slice were calculated in order to obtain the crater density. The crater density per 10^6 km^2 vs. the angular distance from the apex was then plotted on a linear graph to show the variation with $\sqrt{N}$ error bars.

Results: In Figure 1, the crater density vs. apex angle is shown for Perrine, Marius, Nicholson, and Galileo Regio for craters with D > 10 km, as well as for bright terrain. The data for Galileo Regio was collected by Rivera-Valentin et al. [6], labled as R-V07 on the graph. The data for Ganymede's bright terrain is taken from Zahnle et al. [1] and applies to craters with D > 30 km. Without extrapolating beyond the apex angles analyzed, the dark terrain data generally drops by a factor of ~1.5X with increasing distance from the apex. Perrine Regio seems to show an increase, rather than a decrease.

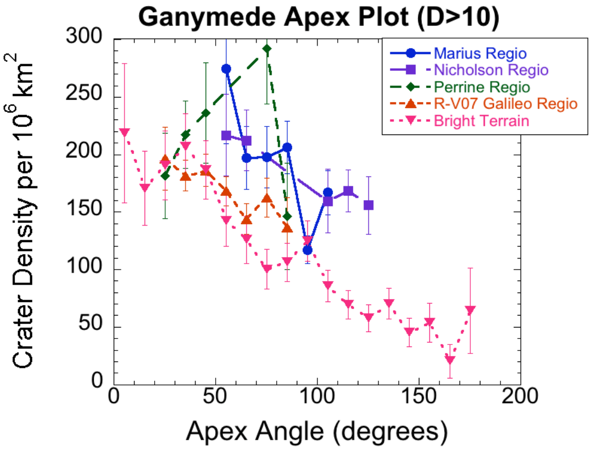

Figure 1. Crater density vs. apex for terrains on Ganymede. Crater densities tend to slightly decrease with increasing distance from apex. R-V07 data provided by Rivera-Valentin et al. [6]. Bright terrain data is reproduced from Zahnle et al. [1].

In Figure 2, we show the data for craters in the dark terrains with D > 30 km to determine if the pattern changes for larger craters. Because there are fewer craters of this size, the error is much larger and the data more scattered. Within all this noise, it still appears that the crater densities in Nicholson, Marius, and Galileo Regio decrease by a factor of ~1.5X from the apex to antapex. Perrine Regio, however, now also shows a decrease, with a value of ~1.9X.

Figure 3 shows an R-plot that includes each of the major regions of dark terrain, along with the general curve for Callisto [2]. Most of the terrains seem to have a flat distribution for craters between 10 and 100 km in diameter. Galileo Regio seems to fall at a lower crater density than the other regions; this is consistent with Murchie et al. [7] and Casacchia and Strom [8]. Our data seems to match well with the data from Rivera-Valentin et al. [6] and Callisto [2].

Discussion: Four probable explanations have been presented for the lack of the predicted apex-antapex crater asymmetry: saturation cratering, periods of nonsynchronous rotation, or impact of planetocentric debris/secondaries [1]. As Zahnle et al. [1] discussed, impacts by planetocentric debris or secondaries is an unlikely cause because craters formed by these

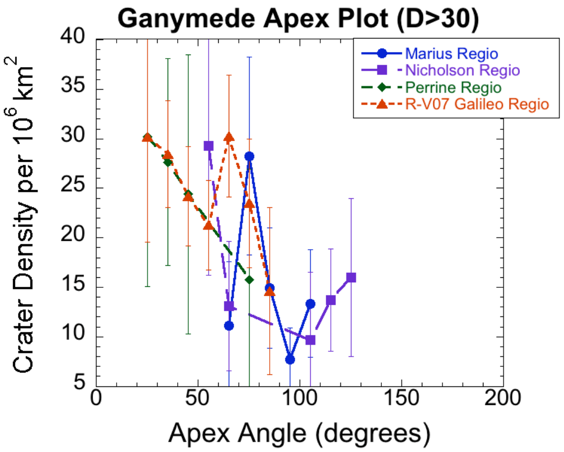

Figure 2. Crater density vs. apex for terrains on Ganymede. Perrine Regio crater density now decreases from the apex along with the other terrains. R-V07 data provided by Rivera-Valentin et al. [6].

impactors are typically thought to be smaller and could not explain the lack of difference for the larger craters.

As on bright terrain [1], both saturation cratering and nonsynchronous rotation are feasible explanations of the diminished apex-antapex asymmetry that the data shows for dark terrain (Figs. 1, 2). Saturation cratering would be a more likely explanation for dark terrain than bright, because dark terrain is much older. Nonsynchronous rotation is also plausible, however, because no sensible reason is proposed to argue that rotation could not have started before bright terrain formation. Our data cannot actually differentiate between saturation cratering and non-synchronous rotation because they both have a similar effect on the data. Non-synchronous rotation is supported by the scattered distribution of crater chains (catena) on Ganymede [1]. Further analysis that might help determine which cause is more likely is using a separate technique to determine if the dark and/or bright terrains are saturated.

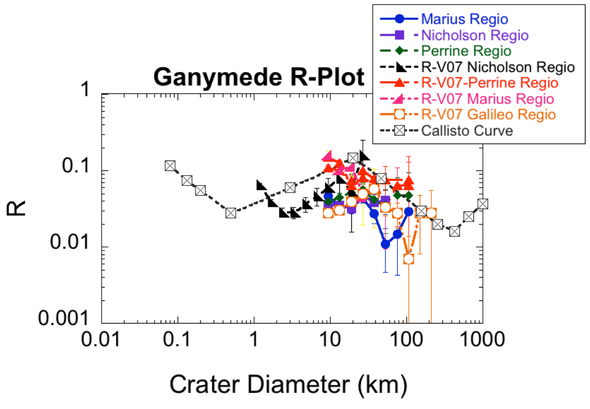

Figure 3. R-Plot for Ganymede, showing the similarity of the cratering patterns to each other and Callisto. R-V07 data provided by Rivera-Valentin et al. [6]. Callisto curve is reproduced from Schenk et al. [2].

For Perrine Regio, our data shows an interesting increase, rather than a decrease, in crater density with increasing distance from the apex for craters with D > 10 km (Fig. 1). For D > 30 km, however, the density decreases with the other dark terrains (Fig. 2). This could imply an extra distribution of craters D = 10-30 km only in Perrine Regio. Equally possible explanations for a locally increased crater density include: a possible ancient field of secondary craters from a basin [9], planetocentric craters that were not efficiently removed from Perrine Regio, random variation, or bias created by the imaging.

Conclusion: Our data exhibits a ~1.5X decrease in crater density over the apex angles analyzed on dark terrain with increasing distance from the apex of motion (Figs. 1, 2). This suggests that Ganymede could have rotated nonsynchronously at some point in its history and/or that the cratering is saturated. Nonsynchronous rotation is further supported by the scattered distribution of crater chains (catena) on Ganymede [1]. Future analysis using a separate technique to determine whether the dark and/or bright terrains are saturated may or may not provide further support for saturation.

Perrine Regio presented an anomalous increase in crater density with increasing distance from the apex for craters with D > 10 km (Fig. 1). When the minimum D was increased to 30 km, however, the density decreased similar to the other dark terrains (Fig. 2). Therefore, we hypothesize that the distribution in Perrine was possibly affected by secondary craters from a nearby basin [9], a planetocentric impactor population that has been more efficiently erased on other terrains, a random variation in the cratering density, or that counts are biased by the imaging. All options seem to be equally plausible, and further analysis on Perrine Regio and the possible nearby basin would be required in order to narrow the possibilities.

The R-Plot (Fig. 3) shows that the patterns of the crater distributions of the regions of dark terrain on Ganymede are very similar within error, even for different crater counters. This implies that we are getting close to determining the actual impact crater distribution for Ganymede's dark terrain. The patterns are also similar to the Callisto curve, implying that Ganymede and Callisto were bombarded by the same impactor population.

References: [1] Zahnle et al. (2001) *Icarus*, 153, 111-129. [2] Schenk et al. (2004) *Jupiter: The Planet, Satellites, and Magnetosphere*, 427-457 [3] Pappalardo et al. (2004) *Jupiter: The Planet, Satellites, and Magnetosphere*, 363-397. [4] P. M. Schenk and F. J. Ridolfi (2002) *Geophysical Research Letters*, 29, 1590. [5] Crater Analysis Techniques Working Group (1979) *Icarus*, 37, 467-474. [6] Rivera-Valentin et al. (2008) *LPSC XXXIX*, 2370. [7] S. L. Murchie et al. (1989) *Icarus*, 81, 271-297. [8] R. Casacchia and R. G. Strom (1984) *JGR*, 89, B419-B428. [9] P. M. Schenk and W. B. McKinnon (1987) *Icarus*, 72, 209-234.