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Possible equatorial-polar differences in crater densities on the dwarf planet Ceres

Andrew J. Dombard, Wesley S. Tucker, Saeida Ahmadi, and Roy E. Plotnick
Earth & Environmental Sciences, University of Illinois at Chicago, Chicago, Illinois, USA (adombard@uic.edu)

Abstract

The spatial statistics of the crater populations on Ceres may reveal a disparity between crater densities in equatorial and polar regions, which could be tied to processes that preferentially erased Ceres' larger craters that are linked to solar insolation (topographic relaxation or sublimation).

1. Introduction

Though seemingly a standard, heavily cratered body, the crater population on the dwarf planet Ceres is weird. Using imagery from NASA's Dawn spacecraft, Marchi et al. [2] found that Ceres is deficient in large craters above 100 km in diameter, and that craters > 20 km in diameter appear to show spatial variability, with the highest density in the northern hemisphere. As reviewed in this article, these authors noted topographic relaxation as one potential mechanism to remove preferentially large craters; however, the retention of large amplitude topography would argue against this process. In addition, sublimation of a more ice-rich surface would likely have occurred before erasure of the largest craters. Last, cryovolcanic processes could erase craters, yet evidence of widespread cryovolcanic features are not apparent.

Thus, the process that rendered Ceres' craters weird is unknown. Relaxation or sublimation, if they occurred, might show a global variability because of lower temperatures in polar regions, resulting in a polar-equatorial disparity in crater densities. Conversely, cryovolcanism could have led to erasure that was more regional in nature, resulting in clusters of more heavily cratered regions for those craters that, on average, formed faster than the rate of resurfacing.

Thus, clustering of craters could be leveraged to determine the manner in which large craters were erased from the record. The existing work [2] only noted that there does appear to be some variability, but did not explore why or whether the apparent variability is simply the product of stochastic variability in a random population. Here, we explore the spatial statistics of Ceres' crater population.

2. Methods

We explore the statistics using 2 methods applied to a database of Ceres' craters complete down to 1 km [1]. First, we consider the multi-lacunarity [3, 5] of the crater population. Lacunarity is a statistical method that looks for gappiness (or conversely, clumping) of data at different spatial scales. In this method, a map is uniformly sampled using a window of a fixed size. This procedure results in a distribution of looks (here, number of windows with x number of craters). Lacunarity is then a measure of a dimensionless variance of this distribution (all windows look the same equates to low variance and low lacunarity), while multi-lacunarity refers to looking at higher order moments of the distribution (i.e., skew and kurtosis). This sampling is repeated for windows of different sizes. We have recently adapted lacunarity to a sphere [4] in order to explore global distributions.

We use multi-lacunarity to test for randomness by comparing the data against 10,000 test cases of random crater locations on a sphere for populations of equal numbers. Multi-lacunarity curves that sit within the envelope of these 10,000 cases means that there would be less than a 1 in 10,000 that the craters are distinguishable from a random population.

Next, we use ArcGIS to create kernel densities of the crater population, which similarly samples a globe to quantify where craters are more populous.

3. Results and Discussion

A map of craters > 100 km in diameter does show they are concentrated in the southern hemisphere (Fig. 1), but the multi-lacunarity reveals that these 20 craters are indistinguishable from a random population. This finding is a direct by-product of the statistics of small numbers. Twenty craters could be randomly placed on a sphere and yet be concentrated in one hemisphere; there simply are not enough members to smooth out apparent clustering due to the stochastic nature of randomness.

Conversely, the population of craters 20-70 km in diameter is distinguishable from a random population for window radii greater than ~10° (windows ~160 km across), suggesting structure at large scales. In addition, a kernel density map of this size range of craters shows a higher density in the north (Fig. 1). A direct conclusion of clustering of craters due to the resurfacing of Ceres at this stage is unwarranted, however.

Maps of the full population reveal that the largest craters on Ceres (those with diameters greater than ~ 100 km) have erased smaller craters. Obvious gaps associated with Dantu, Occator, and Urvara are readily apparent. These gaps are less obvious for craters 20-70 km across, but they would likely still exist. It is notable that the scale of clustering seen in the lacunarity (~160 km and greater) is roughly coincident with the zone that would be affected by the emplacement of a 100 km crater and its ejecta.

Fortunately, these largest craters are not everywhere, being more strongly concentrated in the southern hemisphere (though indistinguishable from a random population). Using ArcGIS, we create a mask of regions covered by the emplacement of craters > 100 km in diameter (plus ejecta) and overlay it on the kernel density of craters 20-70 km in diameter (Fig. 1). Reading through the holes in this mask, there is still visible clustering of the data. Notably, the craters are preferentially located in the northern hemisphere, with fewer generally seen closer to the equator.

The preliminary conclusion is thus that whatever process is responsible for the removal of Ceres' larger craters was more efficient closer to the equator. This finding is more consistent with topographic relaxation or deep sublimation driven by solar insolation, and less consistent with regional resurfacing from cryovolcanism.

The effect of the erasure of smaller craters by the emplacement of larger craters renders this conclusion equivocal, however. Thus, we will continue to parse the crater population into different size ranges to explore their spatial statistics, in order to confirm that there is a disparity in crater density between equatorial and polar regions on Ceres.

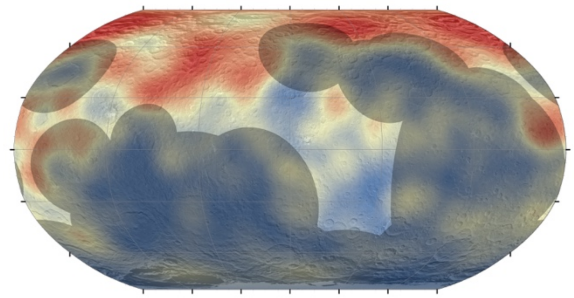

Figure 1: Global map of kernel density (warmer colors: higher density) of craters 20-70 km in diameter, overlain by a mask of 1.6x the diameter of craters > 100 km on Ceres. Reading through the mask, there may be a disparity in the number of mid-sized craters between equatorial and polar regions.

Acknowledgements

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