SPATIAL CLUSTERING OF CHARON'S CRATERS AS A MEANS TO CONSTRAIN CRYOVOLCANISM.

J. L. Noviello[1], K. N. Singer[2], and S. Desch[3], [1]NASA Postdoctoral Management Program Fellow at NASA Goddard Space Flight Center, 8800 Greenbelt Rd, B-34 E119, Greenbelt, MD 20771 (Jessica.Noviello@NASA.gov), [2]Southwest Research Institute, Boulder, CO 80302, [3]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85281.

Introduction: Pluto's moon Charon is a world with a potentially long cryovolcanic history as revealed by the New Horizons mission. The mission's returned data and images now make it possible to investigate cryovolcanism by examining Charon's surface geomorphology. One region, Vulcan Planitia (VP), is covered with relatively smooth material the surface of which shows the spectral signature of water ice and ammonia [1]. This region has been interpreted as a massive cryovolcanic flow that occurred as a subsurface ocean froze and caused global extension, creating tectonic features that may have served as cryovolcanic sources [2–5]. The presence of two large blocks that are tilted and embayed near the border of VP and Oz Terra [4] implies that there was at least one major cryovolcanic flow of significant energy.

Oz Terra (OT), the region north of VP, is elevated relative to VP and is dominated by a polygonally fractured blocky surface with deep (≥1 km) troughs between blocks [2–5]. OT is also more cratered than VP, though both have estimated ages of ~4 Gyr or older [6–9], even after accounting for a possible lack of small impactors in the Kuiper Belt. The errors in this time estimate are ~1 Gyr due to inherent uncertainties in the impactor flux and impactor population near Charon.

The lack of embayed large craters implies that most crater formation happened after the major cryovolcanic event(s). Thus, the freezing of Charon's subsurface ocean, and the subsequent global extension that instigated the cryovolcanic event(s), must have happened before ~4 Gyr ago. However, previous work using a coupled thermal- and geochemical-evolution model found that long-lived radionuclides in Charon's core sufficient to initially melt in Charon's interior and sustain a subsurface liquid water ocean until 1.7–2.5 Gyr ago [7]. Even with cratering error bars as large as 1 Gyr, this still leaves at least a gap of 0.5 Gyr between the possible end of cratering and beginning of ocean freezing on Charon. We must now ask: *how do Charon's cryovolcanic activity and cratering history fit together in a coherent timeline?*

Untangling Charon's cryovolcanic history will require extensive modeling work and a careful re-examination of the moon's geomorphology. We begin this task by studying the spatial clustering of Charon's craters in both VP and OT.

Charon's Craters: Multiple studies [6, 7, 11, 12] have detailed the cratering record on Charon's surface and used these records to estimate its average surface age of 4 Gyr. Some areas in VP appear to be less cratered, at least to the human eye. These areas may represent a late overprint from a cryovolcanic event. Alternatively, they could be a result of random chance from the impactor flux. If these low-density areas are statistically significant, then it is important to figure out their origin and contextualize it with Charon's extended history.

Using the previously published crater dataset described in [6], we will check whether the apparently less-cratered areas of VP are statistically meaningful. If they are significant, then we will use these findings to estimate the volumes of erupted cryolava from the extent of these areas. These estimates would provide constraints for future modeling efforts on Charon's cryovolcanic capacity. Depending on their locations, these areas could be explained by smaller events that occurred after the main emplacement of the smooth material in VP. Finding no statistically significant difference in the crater spacing in VP, especially when compared to OT and its larger craters, would place upper limits to the extent of localized cryovolcanic events and constrain the mode of cryovolcanism.

Proposed Analyses: We have performed some analyses regarding the spacing and clustering of Charon's craters. Figure 1 shows a heat map of overall crater density produced in ArcGIS, and Table 1 shows the number of craters within a certain distance of at least one other crater. In future work we will differentiate between the cratering populations in OT and VP. We also plan to perform a series of k^{th} nearest-neighbor clustering analyses with varying study area sizes [13, 14], as spatial analyses are sensitive to total area sizing. This statistical methodology presents a way to quantitatively analyze the degree of clustering or dispersion as compared to a random population in a two-dimensional space. It has been used previously in the literature on multiple planets and moons excluding Earth. We will do this in both VP and OT, where OT will serve as a control as it does not appear to be resurfaced by cryovolcanism.

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Radial Distance (km)	**Craters within *X* Radial Distance**	**Percent of Craters within Bin**	**Cumulative Total of Craters (out of 952)**
10	242	25.4201681	25.42
20	629	40.6512605	66.07
30	825	20.5882353	86.66
40	892	7.03781513	93.70
50	928	3.78151261	97.48
60	935	0.73529412	98.21
70	942	0.73529412	98.95
80	945	0.31512605	99.26
90	949	0.42016807	99.68
100	951	0.21008403	99.89
110	951	0	99.89
120	952	0.10504202	100.00

Table 1: The number of craters in a combined Vulcan Planitia/Oz Terra population with at least one crater within a specified distance *X*, along with the percentage of craters from the entire population within a size bin and the cumulative crater population within *X* distance of any other crater.

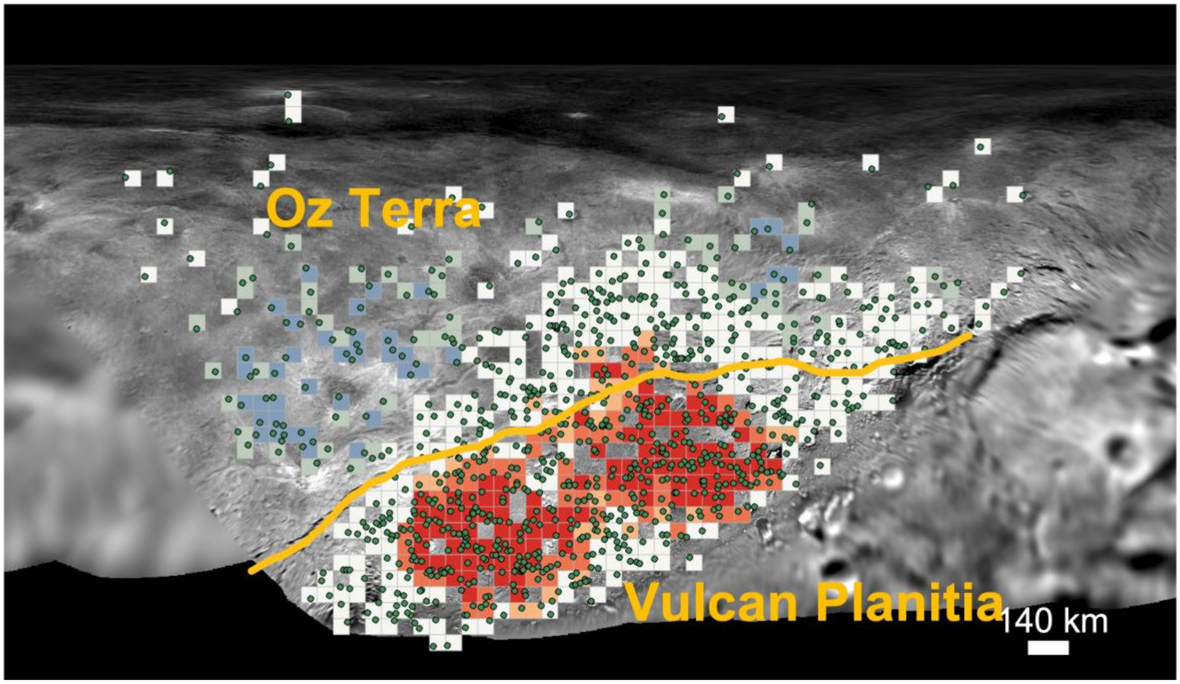

Figure 1: A heat map of Charon’s craters on the imaged hemisphere produced in ArcGIS. The yellow band in the center represents the geomorphologic divide between Oz Terra and Vulcan Planitia. Clustered areas are in red, and dispersed areas are in blue. Areas in white are neither clustered nor dispersed beyond random.