Distribution of Rampart Craters, in Utopia Planitia, Mars.

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Introduction: To help understand the distribution and timing of water in the northern lowlands of Mars we are statistically analyzing all features in the northern lowlands that may be related to water. In this paper we describe the use of a Geographic Information System (GIS) to perform statistical data analysis on rampart crater distribution, one of many putative water-related landforms [1,2,3]. We then compare the distribution of rampart craters to the distribution of all craters.

Rampart craters have ejecta blankets characterized by flow rather then ballistic transport. The ejecta blankets have concentric patterns of hills and grooves that end in a ridge or escarpment, resembling a rampart [1]. The distal edge is commonly lobate [1].

We calculated two descriptive statistics; point density and nearest neighbor index (NNI) for the locations of rampart craters within the study area (15-65N and 75-140E, here called Utopia).

The data source is a crater catalogue [4] of all craters > 5 km in diameter on Mars. The craters located within Utopia were divided into two main populations.

1 *all craters* > 5 km.
2 *rampart craters* > 5 km.

These populations were then subdivided according to the age of the material they impacted [5].*Amazonian all*.

3 *Amazonian rampart*.
4 *Hesperian all*.
5 *Hesperian rampart*.
6 *Hesperian/Noachian all*: in terrain mapped as Hesperian/Noachian [5].
7 *Hesperian/Noachian rampart*: in terrain mapped as Hesperian/Noachian [5].
8 *Noachian all*.
9 *Noachian rampart*.

Point density: A neighborhood is defined by a circle around each crater. The number of craters in a neighborhood is divided by the area of the neighborhood. This is repeated for each crater throughout the study area [6]. The result is a map showing the density distribution of craters within the study area. We used this technique to compare the densities of *rampart craters* with the densities of *all craters* within Utopia.

NNI: NNI [7] determines if a point population is clustered by comparing the distances between points to what would be expected for a random population. The results of the NNI are based on a Poison distribution: an index of 0 indicates maximum clustering, 1 indicates random, and 2.15 indicates uniform [7]. A Z-score is used to determine how significant the difference is between measured distance and expected distance, the higher the number the greater the significance. A macro [8] in the GIS program Arc Map calculated NNI (equation 1), standard deviation (equation 2), and a Z-score (equation 3) for all populations.

the nearest neighbor index

$$NNI = \frac{\bar{d}}{E(\bar{d})} \qquad (1)$$

expected average nearest neighbor distance

$$E(\bar{d}) = 0.5\sqrt{\frac{A}{n}} \qquad (1.1)$$

actual nearest neighbor distance

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n} \qquad (1.2)$$

standard deviation

$$SD = \sqrt{\left(\frac{1}{4\tan^{-1}1} - \frac{1}{4}\right)\frac{A}{n^2}} \qquad (2)$$

standard z-value or how many SDs the actual mean is from the expected mean

$$Z_S = \frac{\bar{d} - E(\bar{d})}{SD} \qquad (3)$$

Where:
A = area,
di = distance from one point to its nearest neighbor
n = number of points.

Results

Point density: The areas of highest densities for the two populations (figure 1) differ considerably in location. As expected, the highest density for *all craters* is in the southwest within the oldest terrains (Noachian and Hesperian). The highest density of *rampart craters* is southwest of the middle of Utopia basin in Amazonian terrain.

NNI: We found that *all craters* is clustered, surprisingly even more clustered then rampart craters (table 1). This is also true when the craters are grouped by terrain age. The populations of *Amazonian all, Amazonian rampart, Hesperian all, Hesperian rampart, Hesperian/Noachian all, and Hesperian/Noachian rampart* are significantly clustered whereas *Noachian all* and *Noachian rampart* are not clustered. We ran a Z-test for difference of means [9] (equation 4) to test if the difference is significant in clustering among the various populations of *all craters* and *rampart craters*. The results show that all populations of *all craters* that are clustered are significantly more clustered then the clustered populations of *rampart craters*.

difference of two population means

$$Z_T = \frac{NNI_1 - NNI_2}{\sqrt{\frac{SD_1^2}{n_1} + \frac{SD_2^2}{n_2}}} \tag{4}$$

Discussion: Within Utopia the density distribution for *rampart craters* is similar to the density distribution for *all craters*. Because *rampart craters* is a subset of *all craters*, and they have a similar pattern of density distribution, we expected the highest density for both populations to be in Noachian aged terrain. For *rampart craters* we unexpectedly found that the highest density is in the Amazonian, the youngest terrain. Recent research indicates the wettest time on Mars was during the Noachian or Early Hesperian [10, 11, 12]. This poses the questions of why is the highest density of *rampart craters* different than *all craters* and why is it in the Amazonian terrain?

We did not expect that *all craters* within several different age terrains would be clustered. Even less expected was that those populations in all instances are more clustered then the *rampart crater* populations. For Utopia as a whole the existence of different age terrains explains the clustering, with the oldest terrain having the most craters. However that leaves us with the Amazonian and Hesperian terrains that show clustering in both populations and more clustering for *all craters* then *rampart craters*. Once again more questions: why are the craters clustered and why are *all craters* more clustered then *rampart craters*?

As they should, these descriptive statistics bring up some interesting questions about *rampart crater* distributions, whose answers could lead to a better understanding of the history of past water on Mars. Ongoing research will address these questions.

References: [1] Carr, M.H., and G.G. Schaber, (1977), *J. Geophys. Res*., 82, 4039-4045, 1977. [2] Schultz, P. H. and Gault, D. E., (1979), *J. Geophys. Res*. 84, 7669-7687, 1979. [3] P. Mouginis-Mark, (1981), *Icarus*, 45, 60-76. [4] N. Barlow, (2006) *LPSC XXXVI*, Abstract # 1337. [5] K.L.Tanaka, *et al*., (2005), USGS survey map 2888. [6] B.W. Silverman, *Density Estimation for Statistics and Data Analysis*, New York: Chapman and Hall, 1986. [7] J. C. Davis, (1986), *Statistics and data analysis in Geology*, ed. 2, Wiley and Sons. [8] M. Sawada, (2002), Nearest neighbor program, ESRI. [9] R. Khazanie, (1990), *Elementary statistics in a world of applications*, ed. 3, Harper-Collins. [10] S.C. Solomon, *et al*., 2005, *Science*, Vol.307. [11] M.H. Carr, 1995, *J. Geophys. Res*., Vol. 100, No.E4, p.7479-7507. [12] B.M. Hynek and R. J. Phillips, 2003, *Geology*, V. 31, N. 9.

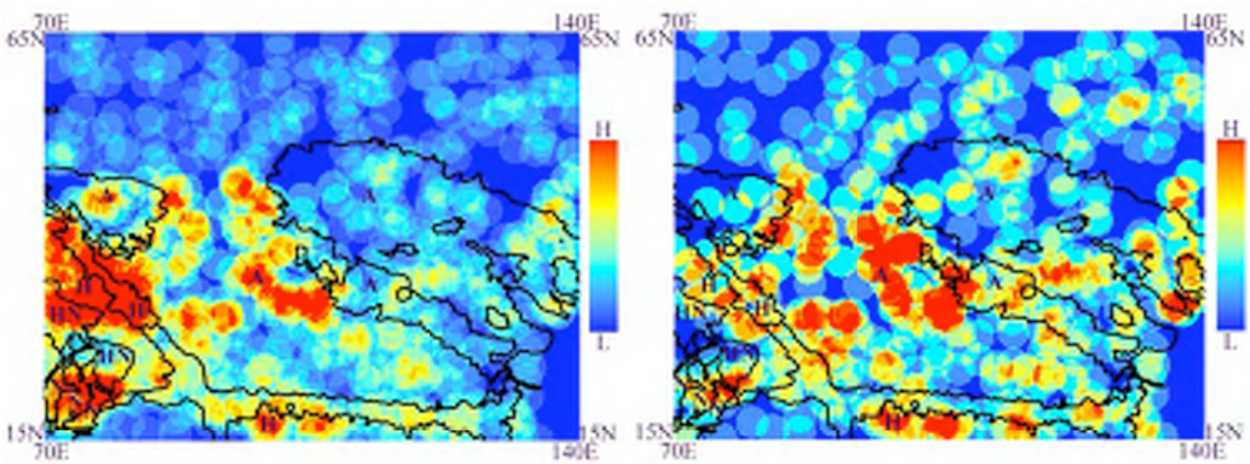

Figure 1 -The top figure shows the density of all craters > 5 km in Utopia and the bottom figure shows the density of all rampart craters >5 km in Utopia. The scales represent relative density within the population. The Red represents areas of relative high density within a population and blue represents low density. The letters represent the age of the terrains: A = Amazonian, H = Hesperian, HN = Hesperian/Noachian, and N= Noachian. The figures show different locations for the highest density within each population

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Table 1- Results from NNI (Nearest Neighbor Index) calculations.

Geologic Terrain	NNI all	ZS all	n all	NNI rampart	ZS Rampart	n rampart	ZT
Utopia	0.69261	20.63199	1231	0.76668	10.93369	600	17.2188
Amazonian	0.66161	17.71686	749	0.70289	12.05744	450	-27.52
Hesperian	0.69926	9.848	293	0.86559	2.63482	105	-34.65
Hesperian/Noachian	0.02853	6.11313	74	0.89485	0.69682	12	-17.22
Noachian	1.14667	2.06183	54	1.01013	0.699	13	3.07