NEAREST NEIGHBOR ANALYSIS, REGRESSION, AND SECONDARY CRATER PROSPECTING ON MARS.

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Introduction: The only way of constraining regional surface ages on Mars at present is through use of the impact crater size *vs.* frequency distribution system developed by Arvidson et al [1], Tanaka [2], Neukum and Ivanov [3], and Hartmann and Neukum [4], among others. The ideal size-frequency distribution follows a power law pattern, and its -1.8 slope is broadly consistent across martian surfaces. Actual size-frequency curves, however, typically show slight inflection points below saturation at either end of the diameter size scale: $\geq$~64 km and $<$ ~ 1 km.

Overrepresentation of subkilometer craters implies that surface age estimates could be inflated in imagery with fine spatial resolution. Secondary cratering has been put forward to explain such overrepresentation (e.g., Preblich et al [5]). Previous attempts to deal with secondary cratering have included segmenting the curve at the breaks and empirically fitting a slightly different slope to each section (e.g., Hartmann and Neukum [4]) or examining craters for irregular shapes due to the subsonic velocities of secondary impactors and visual inspection for alignments and clustering [6].

This paper proposes a variant on nearest neighbor analysis, combined with regression, to prospect for lineations among small craters in a region. The method identifies candidates for possible missing ray structures at least for near-field secondaries. The purpose of this paper is to present and assess this method on a test case image of a badly cratered region on Mars.

Data and Methods:

Image source. The test image was an MGS MOC Narrow Angle image (PIA02680) taken on 2 March 2006 of Terra Sabæa. The image, covering ~ 3 km by 6.6 km at 1.5 m/pixel resolution, is near 21.9S and 338.6W, in an area characterized by Noachian plateau dissected and ridged units [7].

Image preparation. A 150 m × 150 m grid was imposed on the image, and 36 of the resulting quadrats in the northernmost corner of the image were selected for crater extraction. The X and Y coördinates of the center of each identifiable crater were measured in meters with respect to the lower left (southernmost) corner of the grid and its diameter in meters. The 146 craters were mapped in OpenOffice Calc.

Data processing. The X and Y coördinates were used to calculate distance in meters between every crater and every other crater in the database using the Pythagorean theorem. These distances were then ranked for each crater, and the ranks were used to identify the nearest neighbor and the next nearest neighbors up to the 6th order.

The X and Y coördinates were also converted into azimuths through use of the arctangent in degrees, each crater serving as the origin and each of its 6 nearest neighbors as the destination for each azimuth. Starting with the azimuth between a given crater and its nearest neighbor, each of the other 5 higher order neighbor azimuths were subtracted from that of the original pair.

Testing for randomness in azimuth differences. The resulting 730 azimuth differences, 5 for each crater, were searched for differences that fell within a narrow cone of alignment. I experimented with 4 different standards for narrowness, trying to accommodate the look of lunar and martian ray structures, while also recognizing that a purely random scatter of points will generate a certain number of "alignments." To screen for randomly generated alignments, I counted "aligned" and unaligned azimuth differences for each crater, using 5°, 10°, 15°, and 20° cutoff standards. These counts were then compared to an expected distribution of random "alignments" among the five higher order neighbors generated from the binomial distribution. The significance of the discrepancy between observed and expected counts was calculated using the Chi-square goodness-of-fit test. Fifteen degrees was the tightest cutoff angle to produce significance below 0.05. So, I used 15° of separation around 0° and 180° as a cutoff criterion for identifying potential secondary cratering alignments.

Final selection of aligned crater chains. Azimuth differences among the 5 higher order neighbors for each crater and its nearest neighbor were only counted as alignments if there were at least 2 higher order neighbors aligned with the nearest neighbor pair, signifying an aligned group of at least 4 craters out of 6. This produced 33 groups of neighboring craters that were potentially lineations of the type produced by secondary cratering (n=87). These 33 were then scatterplotted, and a correlation and regression analysis was performed on each. Of the 33 chains, 18 had correlations greater than 0.80 (absolute). For any chain with $R < |0.80|$, I identified individual outlier craters that degraded R and experimented with removing them. This process identified 16 craters that damaged the alignments. Editing these outliers removed one entire chain and raised the correlations on all the remaining chains above |0.80|, leaving 71 craters of the original 146 in potential alignments.

Results: The resulting map (Figure 1) of short alignments of neighboring craters represents potential secondary crater chains. Several of these alignments are themselves lined up along the south and west of the image, an alignment beyond the scale of the original analysis confined to the 6 nearest neighbors of each crater. Three other short chains are notable for converging to a point ~400 m off the image to the north. Unfortunately, imagery of comparable resolution is not available for that adjacent area. Serendipitously, visual inspection of the craters in the study area turned up a fourth line of larger craters. Plotting their trajectory (with an R of 1.00) leads to intersection with the other 3 lines in the same vicinity.

Discussion: Lineations identified this way are not proof of a secondary impact ray structure, but they do identify candidates for such structures. These require geomorphic analysis to eliminate alternative explanations for lineation, such as a catena of sinkholes in a region subject to extensional stresses, a chain of rootless cones of phreatomagmatic origins, or a random alignment of craters of such different ages that they cannot be attributed to a single larger impact.

In this particular area, the first alternative is inconsistent with the presence of wrinkle ridges, which indicate a past or present compressional stress field in the region [7]. The second alternative would be surprising here, as rootless cones are mainly found in the Northern Lowlands of Mars [8, 9]. The third alternative remains viable pending further work.

One shortcoming to the method is that it did not distinguish craters by size, and the nearest neighbors to a large crater are likely smaller ones, not similarly sized larger craters. So the fourth chain of larger craters that converged with 3 smaller crater chains became apparent only upon visual inspection.

Another shortcoming, not of the method, but of its implementation, became apparent in hindsight: The condition of the crater should have been noted while its X and Y coördinates and diameter were being measured. Condition is related to age. If all the craters in each possible chain are in roughly the same condition, this would reïnforce the possibility that they were laid down simultaneously by the same primary event.

Conclusion: Even as is, however, this method does readily identify candidate chains and thereby focusses the search for alternative explanations for these lineations besides secondary cratering. It also helps bound the estimation of the prevalence of secondary cratering at the smaller end of the crater frequency and size relationship. In the current case study, nearly half the craters were in lineations consistent with secondary cratering. Once these many candidates are sieved for lineations arising from alternative processes, the remaining estimates of secondary cratering could experimentally be removed from crater counts and the constants in the power law relationship re-estimated empirically. Would their deletion remove or reduce the inflection at the sub-kilometer size range?

References:

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