A Spatial Analysis of Gullies on Mars. L. Kincy[1], C. Currit[1], D. Butler[1], and S. Fuhrmann[1]; [1]Department of Geography Texas State University-San Marcos, 601 University Drive, San Marcos, Texas 78666 (lkincy@aol.com).

Introduction: The possibility of life on Mars has intrigued people for over a century. A necessary requirement for life is water, a substance confirmed to exist on Mars. Gullies are features typically created by flowing water. Although Mars today is a desert planet, numerous geologically young gullies exist. The presence of these gullies on the surface of other features, such as craters, suggests the gullies are young relative to the features on which they lie [1]. Many images of Martian gullies have been studied and compared to gullies on Earth to try to determine the origin of Martian gullies. A gully is defined as a surficial feature having an alcove above a channel, and channels are typically associated with water [1].

Methodology: Mars Reconnaissance Orbiter (MRO) spacecraft's High Resolution Imaging Science Experiment (HiRISE) is the source for most of the images used in this research. Thirty three images are selected from nearly 500 images identified as having gullies by the HiRise archivists. These 33 images are selected because of their clarity and the high level of gully branching (high gullies). Thirty three additional images identified as having gullies, by the archivists of the MRO images, are randomly selected and mapped (low gullies). Using GIS, 33 randomly located points are created for the study area as an experimental control. Gully images, gully shapefiles, and elements data are loaded into GIS. Data from the Odyssey spacecraft's Gamma Ray Spectrometer (GRS) was used as GIS layers. The values of five elements (H, Cl, Fe, Si, and K/Th) along with more than 95 geologic formations are overlayed and spatially joined to the center point of all 66 images and 33 random GIS points. Each point identifies the location of high branching, low branching, or randomly placed points.

Color image composites are created to display elemental concentrations on Mars. These images are then imported into GIS and overlayed with gully layers.Water and chlorine are used in each layer stack, because water is in all proposed gully formation hypotheses, except CO_2 and dry flow is the principle fluid component

Average Nearest Neighbor Analysis (NNR) and Euclidean Distance are used to determine the spatial dispersion of the high gullies, the low gullies, and the random GIS points. Finally, a decision tree is a non-parametric technique used to determine rules for distinguishing gullies from non-gully sites where the elemental, geologic, and spatial data are independent variables. A decision tree creates a series of nested rules based on the data entered, and the resulting tree may predict the conditions where a gully might exist.

Results: *Average Nearest Neighbor* NNR analysis is performed to determine if the spatial distribution of Martian gullies is clustered, dispersed, or random. A nearest neighbor ratio (NNR) equal to one indicates randomness; a NNR less than one indicates clustering, and a NNR greater than one indicates dispersion. Table 1 shows the results of the Average Nearest Neighbor test. As expected the randomly created GIS points have a NNR close to 1.0. The high gullies have a NNR of 0.47 and the low gullies have a NNR of 0.85, indicating that they are clustered spatially.

Table 1. Average Nearest Neighbor

type of gully or point	Observed Mean Distance	Expected Mean Distance	Nearest Neighbor ratio	Z score
random	17.82	16.09	1.11	1.18
low	12.85	15.15	0.85	-1.67
high	7.49	15.79	0.47	-5.78

Figures 1-3 are the results of the ArcMap Euclidean Distance procedure. White areas in Figures 1-3 are unsampled areas (by the GRS). With the exception of K/Th. In Figure 1, only four yellow ellipses (approximately 10 decimal degrees in diameter) contain two or three points, and the map has little shades of magenta and blue—locations far from a point (up to 60 dd in diameter). In contrast, a majority of the low and high gullies appear within yellow ellipses. More significantly, all of the high gullies appear in only four orange

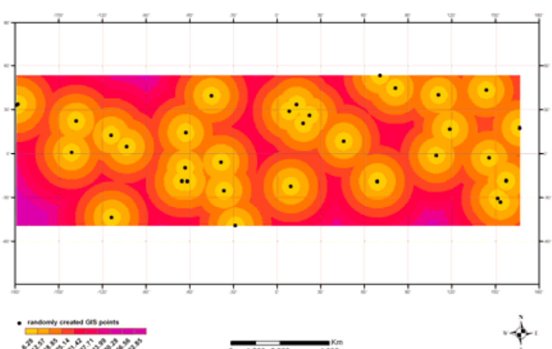

Figure 1. Euclidean distance between randomly created GIS points. GIS was used to measure the distance between gullies (in decimal degrees).

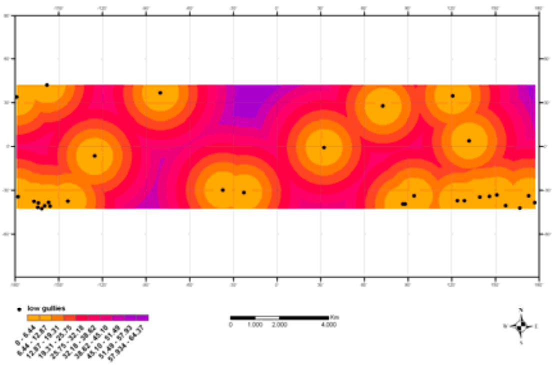

Figure 2. Euclidean distance between low gullies. As measured in decimal degrees.

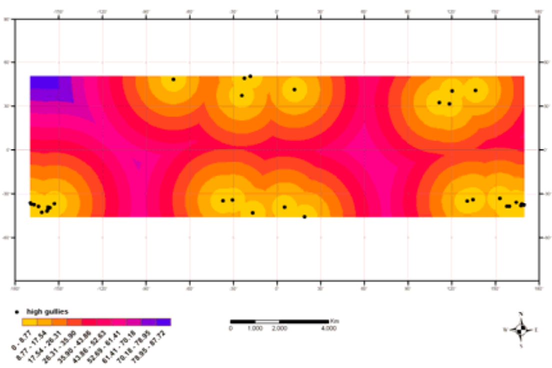

Figure 3. Euclidean distance between high gullies. As measured in decimal degrees.

zones, and the map contains more magenta and blue. These maps indicate that the randomly placed points are indeed randomly placed, and suggest that the actual locations of gullies are clustered.

Layer Stack Figure 4 is an overlay of high gullies, and a chlorine-water-iron layer stack., the 31 out of 33 high branching gullies appear in areas of magenta, indicating the presence of chlorine, and similarly high levels iron, and water levels are relatively low.

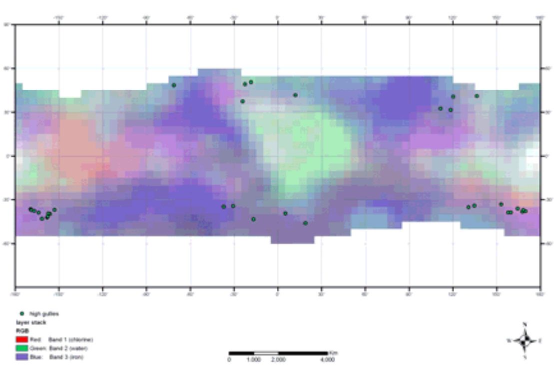

Figure 4. **Fe Global layer stack.** Water, chlorine, and iron GRS data, with high gully locations.

Decision Tree The decision tree process produces a tree with 13 nodes, 8 of which are terminal, and a depth of 3. High gullies are most likely (10 out of 12 or 83%) found in node 6, areas with an iron concentration between 12.96% and 14.71%, and a water concentration less than 4.57%, and a chlorine concentration > 0.51%. Similarly, 60% of low branching gullies are found in the same locations. In contrast only 3 out of 12 random GIS sites are found in the same locations. These results indicate chlorine, iron and water are predictors of gully formation. It should also be noted that both chlorine and iron are often salt and brine components.

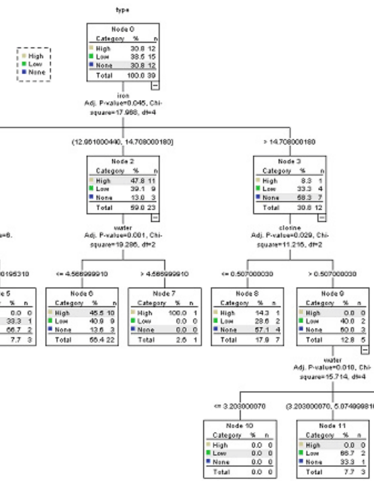

Figure 5. **Decision tree.** Graphical representation of a robust decision tree.

Conclusion Nearest neighbor ratios of 0.47 and 0.85 for high and low gullies respectively and several large Euclidean Distance gaps greater than 45° for both high and low gullies indicate both the low and high gullies are clustered. Both nearest neighbor ratio and Euclidean distances indicate the randomly created GIS points are in fact random.

Findings both the southern low and high gullies are found in areas high in chlorine, low in water, K/Th, Fe, and Si. One very interesting spatial aspect of these results is that there are no gullies in the largest heavily water rich areas in the central parts of the planet. In fact, few gullies are found within 30° of the equator. One possible explanation may be the water flow models presented by [2] and [3], and others, in which water is transported from the equator to the polar regions where it eventually condenses and mixes with other minerals. My research therefore strongly points to brine as the fluid source for most gullies on Mars.

Referrences: [1] Malin, Michael C. and Kenneth S. Edgett. (2000) Science 288, no. 5475: 2330-2335 [2] Clancy, R. T. et al.(1996) Icarus 122: 36–62. [3] Kuzmin, R. O. (2007) Solar System Research 41, no. 2: 89-102.