IMPACT CRATERING AS A MAJOR FACTOR CONTROLLING VALLEY DISSECTION DENSITY ON MARS - A GEOGRAPHICAL DETECTOR APPROACH.

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Introduction: Previous studies have mapped Martian valley networks (VNs) on a global scale [1, 2] and revealed higher dissection density than previously thought, pointing to a warm and wetter climate and fluvial erosion as the major mechanism for the origin of VNs [1, 2]. Although many factors (such as slope, aspect, roughness) have been considered to play some role in controlling the spatial variation and distribution of VNs [1], there still lacks quantitative analysis of the relative importance of these factors on a global scale. This abstract applies an innovative "geographical detector" method, which have been developed to discover the spatial pattern of diseases and the environmental factors that cause the disease [3], to determine the relative importance of factors that may cause an area to have higher or lower VN dissection density and how these factors interact with each other to control the spatial variation of VN dissection density.

Method: The geographical detector method is based on spatial variance analysis and its strength is in analyzing categorical data (e.g., rock types) [3]. The underlying assumption is: if an environmental factor F leads to a disease D, this disease D would exhibit a spatial distribution similar to that of the environmental factor F. In the perfect case that factor F completely explains the disease pattern, the spatial variance of disease D within a subdivision (or stratum) of factor F would be 0. Thus the power of determinant (PD) is defined as

$$PD = 1 - \frac{1}{N\sigma^2}\sum_{i=1}^{L} N_i\sigma_i^2 \qquad (1)$$

where N and σ are the total number of samples and the global variance of the disease rate of the study area, respectively; N_i and σ_i are the number of samples and the variance of subregion i, repsectively; L is the number of subregions. Note again, when the subdivision of a factor completely explains the disease pattern, the second term is 0 and $PD = 1$ (assuming $\sigma \neq 0$). Higher PD means the risk factor has a stronger contribution to the occurrence of the disease. F-tests is used to compare whether the accumulated variance of each subregion is significantly different from the variance of the entire study region. This is termed "factor detector" [3].

The method can also determine which subregion of a factor has higher health risk. This is accomplished by comparing the differences in average disease rates between subregions of a risk factor and by testing their statistical significance with t-test [3]. This is termed "risk detector" [3]. In addition, the method also examines the interaction effect of different factors, i.e., do they enhance or weaken the risk of disease by comparing the combined contribution of two individual risk factors to a disease and their independent contributions. This is termed "interaction detector" [3]. More details of the method can be found in [3] and the software for conducting the analysis can be downloaded at http://www.sssampling.org/Excel-Geodetector/.

Factors, Processing and Results: In this study, the dissection density of VNs on Mars, defined at each pixel based on the downslope distance to the nearest valley [1, 4], is equivalent to the disease rate in health studies, and the potential factors influencing spatial distribution of VNs are equivalent to the environmental risk factors in heath studies. Based on a survey of literature, the following factors as shown in Table 1 have been selected/derived from the Global GIS Mars dataset (ftp://pdsimage2.wr.usgs.gov/pub/pigpen/mars/Global_GIS_Mars/):

Table 1 Selected factors, sources, and processing

Factor	Sources and processing
Elevation	MOLA; [5]
Slope	Derived from MOLA DEM
Aspect	Derived from MOLA DEM
Curvature	Derived from MOLA DEM
Roughness	Derived from MOLA DEM
Geology	Simplified from [6] with the first letter of geologic unit symbol
Crater density	Derived from [7] using 50 km moving window radius
Night Thermal inertia	TES; [8]
Water concentration	GRS; [9]

Most of the factors have been discretized into 6 levels (or zones) using quantile method, which classifies data so that each zone will have roughly equal number of units (or area). This method has been demonstrated to be optimal in discretizing continuous variable [10]. Geology is already categorical with 8 classes after simplification by the first letter of geologic unit symbol (usually indicates age). Crater density is discretized into 5 levels using natural break method because of its highly skewed distribution. A sampling grid of with 10-km spacing is used to sample the dissection density and all 9 factors, resulting in 245,596 data points (covering only the areas with dissection density values) and each point with 1 dissection density value and 9 factor values. The data are entered into the excel tool to complete the analysis.

Table 2 shows the *PD* values of the factors sorted in descending order. The highest contributing factors are crater density, geology, water concentration, and slope. The contributions from the rest of the factors are below 3%. The remaining discussion will focus on the first 4 highest contributing factors.

Table 2 PD values from "factor detector"

Factor	PD
Crater density	0.2420
Geologic	0.1791
Water concentration	0.1234
Slope	0.0789
Elevation	0.0247
Roughness	0.0247
Night time Thermal inertia	0.0231
Curvature	0.0080
Aspect	0.0027

The risk detector results are show in Figure 1. The highest dissection density is located in zones with relatively high crater density (levels 2 & 3). The dissection density generally increases with water concentration and slope. For geology, the highest dissection density is in Noachian (level 2), impact material (level 4) and tear-drop shaped bar or island (level 8). The latter two may be biased due to their small areas. Amazonian (level 1), Hesperian (level 3), smooth crater floor (level 5), and mountain (level 7) all have low dissection density.

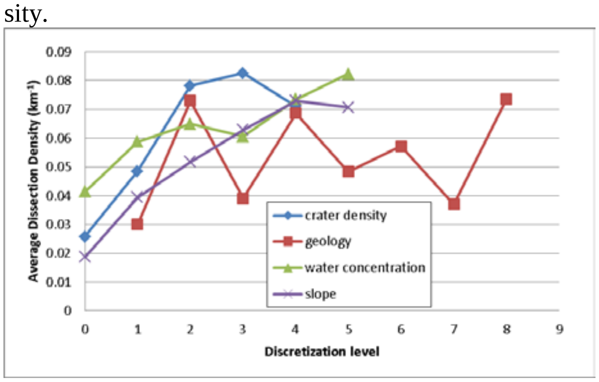

Figure 1 Risk detector result

The interaction detector shows that the *PD* values between any two pairs of the four highest contributing factors are higher than any individual factors, i.e., the interaction of these factors enhances the "risk" of having a higher dissection density. For example, considering crater density and geology together, the PD value is 0.2923, higher than crater density (0.2420) or geology (0.1791) alone.

Discussion and conclusion: Applying the innovative geographical detector method to Martian VN dissection density reveals that, of the factors considered, the most important in controlling the spatial distribution of dissection density are impact cratering, geology, slope, and water concentration. Although it may be possible that crater density only serves as another proxy for the geographical location of the highly dissected region [1], the geographical detector results based on rigorous quantitative analysis demonstrate that this is not a coincidence. The likely scenario is that impact cratering created the local topography, which led to VN development under rainfall runoff erosion. This can be further corroborated by relatively significant contribution of local slope (*PD* ≈ 8% at baseline 463 m) to the dissection density and the fact that the longer the base-line for deriving the slope, the smaller the *PD* value (*PD* ≈ 5% for 5-km baseline slope, *PD* ≈ 1% for 100-km baseline slope). Furthermore, the fact that aspect has the lowest *PD* value of the factors considered is also consistent with impact cratering scenario, where the impact cratering greatly disrupted the preferred VN development along regional aspect, unlike what typically occurs on Earth [11].

The relatively large *PD* value (12%) for water concentration (water-equivalent concentration of hydrogen) as measured by Gamma Ray Spectrometer (GRS) on board Mars Odyssey Mission may simply reflect groundwater storage resulted from past VN water recharge. The contribution from the rest of factors (elevation, roughness, thermal inertia, which represents material property, curvature) are all small (<3%).

In summary, the impact cratering may have played a much more important role in forming VNs on Mars than previously thought. The interactions between cratering, geology, and slope all enhance the dissection density. This study also shows that geographical detector is an promising tool in planetary research.

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