MARTIAN GEOMORPHOLOGY FROM STATISTICS OF DRAINAGE NETWORKS. M. L. Collier[1], T. F. Stepinski[2], S. M. Clifford[2], P. J. McGovern[2], [1]*Department of Earth Science, Rice University, Houston, TX 77005, USA. (spaceman@rice.edu)*, [2]*Lunar and Planetary Institute, Houston TX 77058-1113, USA, (tom@lpi.usra.edu, mcgovern@lpi.usra.edu, clifford@lpi.usra.edu).*

Abstract. Martian terrains are represented as a series of drainage basins, regardless of the historical presence or absence of actual fluid flow. A statistical analysis of each drainage network, computationally extracted from an underlying topography based on the MOLA data, yields a network descriptor, a compact, numerical characterization of a network. These descriptors are used to compare different martian surfaces. Altogether, 386 drainage networks, representing all major epochs and geological units, were extracted and analyzed. We have found that our approach can distinguish morphologically different terrains, but only in a statistical sense. In particular, the method could be used to measure the degree of surface cratering and thus the age of the surface. In addition, for surfaces that are not heavily cratered the method is capable of distinguishing between different geological units. We have found no global trends in the character of martian drainage networks, their network descriptors show no systematic dependence on location or elevation.

Introduction. We propose that a drainage network, overlaying a given martian terrain, constitutes a convenient compression of the entire topographical information contained in this terrain. Although the network does not uniquely determine the terrain, it nevertheless, reflects its general character. Thus, we submit that a quantitative comparison of drainage networks is tantamount to a quantitative comparison of landscapes. It is important to stress that a "drainage network" can be computationally extracted from any terrain, including terrains that never experienced any real flow.

Comparative geomorphology of landscapes based on the Drainage Network Analysis (DNA) constitutes a quantitative and objective method that supplements traditional, descriptive comparative geomorphology. The purpose of this work is to study whether the DNA method is sensitive to the age of the terrain and whether it can recognize geological units.

Data and Methods The martian terrains are modeled by digital elevation models (DEMs) that were constructed using the 1/64 degree per pixel MOLA data set. We have chosen 74 locations from around the martian globe to represent all three major epochs and 16 geological units: Npl1, Npl2, Npld, Nple, Nplr, Nh1, Had, Hh3, HNu, Hpl3, Hr, Hvk, Ael1, Aoa, Apk, Aps (1). Together, these terrains cover $\sim 3\%$ of the martian surface, and the sampled geological units are representative of $\sim 50\%$ of the planet. We have computationally extracted 386 drainage networks from these chosen locations using an algorithm developed for studies of terrestrial river basins (2).

We describe networks in terms of probability distribution functions (PDFs) of drainage quantities defined at any point S on a network. Thus, in our DNA method the statistics of drainage quantities constitute the fingerprints of a landscape. Following (3) we describe the network by statistical properties of the following drainage quantities: a - a total contributing area at S, l - length of the longest upstream path starting from S, e - dissipated potential energy, a product of the flow and the elevation rise along a segment of the network terminating at S. Because networks are fractals, the PDFs of these quantities are power laws, $P(a) \propto a^{-(1+\tau)}$, $P(l) \propto l^{-(1+\gamma)}$, $P(e) \propto e^{-(1+\beta)}$, and a given network can be statistically characterized by the power law indices τ, γ, and β. In addition, a drainage density, D, is defined for a sub-basin terminating at S and measures the average area drained per unit length of stream. We cannot unambiguously calculate the value of D, however we can calculate ρ, the ratio of the mean to the dispersion of the random variable D. The quantity ρ measures the uniformity of D, large values of ρ indicate high uniformity of D and point to a highly eroded surface. A morphology of a given network, and thus the morphology of an underlying landscape, can be encapsulated in a list, A, of four numbers $A = (\tau, \gamma, \beta, \rho)$ which we call the network descriptor. In our study several networks are extracted from a landscape of interest and the network descriptor, A, is calculated for every network.

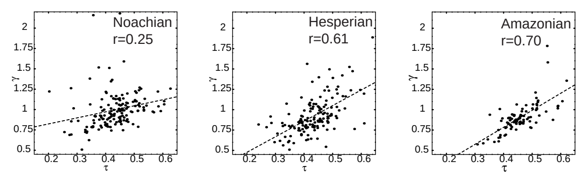

Figure 1: The $\tau - \gamma$ diagrams for Noachian, Hesperian, and Amazonian terrains. The dashed line represents the best linear fit to the data, and r is the correlation coefficient.

Results. The mean value of a martian network descriptor, averaged over all 386 networks that we have extracted, is $\langle A \rangle_{Mars} = (0.44 \pm 0.07, 0.95 \pm 0.22, 0.71 \pm 0.23, 2.39 \pm 0.45)$. We report here the results of the following calculations: comparison of terrains of different ages, comparison of terrains in different Noachian geological units, different Hesperian geological units, and different Amazonian geological units.

Terrains of different ages. There are 152 networks extracted from Noachian surfaces, 145 from Hesperian, and 89 from Amazonian. Comparing the average values of A for networks extracted from these three types of surfaces does not provide a clear statistical distinction between them, nevertheless the DNA method can distinguish between different epochs by the degree of correlation between values of τ and γ, which is larger for younger, more cratered surfaces (see Fig. 1). We suggest that the DNA method offer a potentially interesting alternative to crater count as an age determining technique. A calibration between the correlation coefficient and the age needs to be established which is beyond the scope of this paper.

Noachian geological units. Of 152 networks extracted from Noachian surfaces, 101 came from just three geological units. These units are: Npl1 (28), Nplr (31), and Npld (42). The average values of A calculated for networks in these three units are not significantly different from each other. Thus, comparing the average values of A does not provide distinction between different Noachian geological units. Instead, some level of distinction is provided by the degree of correlation between τ and γ. Fig. 2 shows the $\tau - \gamma$ diagram for networks extracted from Npl1, Nplr, and Npld geological units, respectively. The Npld networks are distinguished from the rest by significantly higher value of r and higher value of $\langle\rho\rangle$. It is particularly interesting because the Npld terrains are as heavily cratered as the Npl1 terrains, and yet their networks are more "regular" as indicated by more uniform drainage density and apparent adherence to "Hack's law." (correlation between τ and γ).

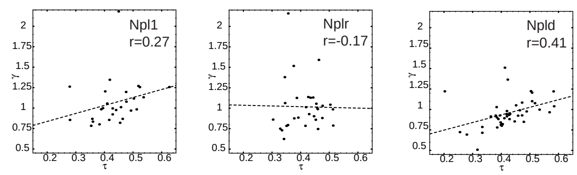

Figure 2: The $\tau - \gamma$ diagrams for Npl1, Nplr, and Npld Noachian terrains. The dashed line represents the best linear fit to the data, and r is the correlation coefficient.

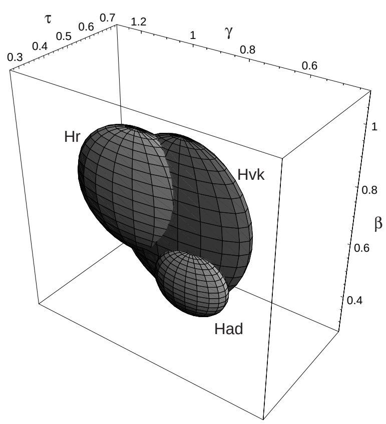

Figure 3: Typical values of network descriptors for Hesperian geological units, Hr, Hvk, and Had as represented by ellipsoids in the (τ, γ, β) space.

Hesperian geological units. We compare network statistics for three Hesperian geological units: Hr (72 networks), Hvk (32), Had (15). These units lack extensive cratering and their morphologies are quite distinct. Fig. 3 represents a spread of A for each of the three units. A unit is represented by an ellipsoid with a center located at $(\langle\tau\rangle, \langle\gamma\rangle, \langle\beta\rangle)$ and lengths of its semi-axes are equal to standard deviations of corresponding quantities, $(\delta\tau, \delta\gamma, \delta\beta)$. Darker shade of an ellipsoid surface indicate larger value of ρ. Thus, we expect that values of A for a given unit are inside its ellipsoid. If ellipsoids for two units are disjoined the DNA method can distinguish between those units. Conjoined ellipsoids mean that unique categorization may not be possible, although values of ρ (coded by the shade of the ellipsoid surface) may provide the additional information necessary for distinction. Overall, the DNA method is capable of differentiating between these three Hesperian units.

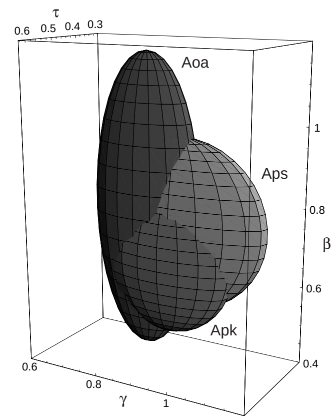

Figure 4: Typical values of network descriptors for Amazonian geological units, Apk, Aps, and Aoa as represented by ellipsoids in the (τ, γ, β) space.

Amazonian geological units. We compare network statistics for three Amazonian units: Apk (38 networks), Aps (26) and Aoa (14). The Aoa unit encompasses aureole deposits surrounding Olympus Mons. Visually, the morphologies of Apk and Aps terrains are not strikingly different, but the morphology of the Aoa terrains is very distinct. Fig. 4 represents a spread of A for each of the three units. This is the same type of figure as Fig. 3. Overall, the DNA method can differentiate between the Aoa and the either Apk or Aps terrains, but not between Apk and Aps terrains.

Finally, we have studied a dependence of components of A on terrain's latitude and geographical location. No significant correlation was found.

References

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