THE FRACTAL CHARACTERISTICS OF MARTAIN DRAINAGE BASINS: IMPLICATIONS FOR THE TIMING, INTENSITY, AND DURATION OF RAINFALL. T. F. Stepinski, *Lunar and Planetary Institute, Houston TX 77058-1113, USA, (tom@lpi.usra.edu)*, M. M. Marinova, *Massachusetts Institute of Technology, Cambridge, MA 02139,* P. J. McGovern, S. M. Clifford, *Lunar and Planetary Institute, Houston TX 77058-1113, USA.*

Abstract. We use statistical properties of drainage networks on Mars as a measure of martian landscape morphology and an indicator of landscape evolution processes. MOLA data is used to construct high resolution digital elevation maps (DEMs) of several, mostly ancient, martian terrains. Drainage basins and channel networks are computationally extracted from DEMs and their topological structures are analyzed and compared to drainage networks extracted from terrestrial and lunar DEMs. Our results are consistent with the roughening of ancient martian terrains by combination of rainfall-fed erosion and impacts, although roughening by fluvial processes other than rainfall cannot be excluded. The notion of sustained rainfall in a relatively recent Mars history is inconsistent with our findings.

Introduction. Extensive studies of terrestrial drainage (river) networks showed that their topological structure is fractal. Probability distribution functions (PDFs) of several network quantities, such as contributing area, a, stream length, l, and dissipated potential energy, e have power-law forms with indicies, $-(1+\tau)$, $-(1+\gamma)$, and $-(1+\beta)$, respectively. These quantities are defined at any point S on a network. In addition, we define ρ, the ratio of the mean to the dispersion of drainage density D, to measure the uniformity of D. A morphology of a given network can be encapsulated by a list $A = (\tau, \gamma, \beta, \rho)$, which we call the network descriptor.

Drainage basins can be extracted from landscapes regardless of whether any liquid actually flowed over these terrains. The morphology of a drainage network reflects a roughness of an underlying landscape (1). Although all natural and many artificially contrived roughening processes lead to surfaces that yield fractal drainage networks, the networks can be sorted into different classes on the basis of their A values. Thus the network descriptor may serve as a diagnostic tool, linking, in a statistical sense, the nature of a surface to the process by which it formed. The class A_{Ter} links terrestrial landscapes to the rainfall-fed erosion process, and the class A_{Lun} links the lunar landscape to erosion by bombardment. A collection of network descriptors calculated for a number of martian drainage basins defines a class set A_{Mars}; $A_{Mars} \approx A_{Ter}$ would point to rainfall-fed erosion and provide support for a warm period in the Mars past, whereas A_{Mars} different from A_{Ter} would indicate an absence of persistent and widespread rainfall.

Methods To study martian drainage networks we have constructed DEMs (500m resolution) of 12 areas on the surface of Mars (2) from which 20 basins were extracted. Several chosen areas contain visually identifiable fluvial features, while others do not. To facilitate comparison between different planetary surfaces we have also extracted 9 basins from two DEMs available for the lunar surface and 19 terrestrial basins from US Geological Survey DEMs. Drainage basins

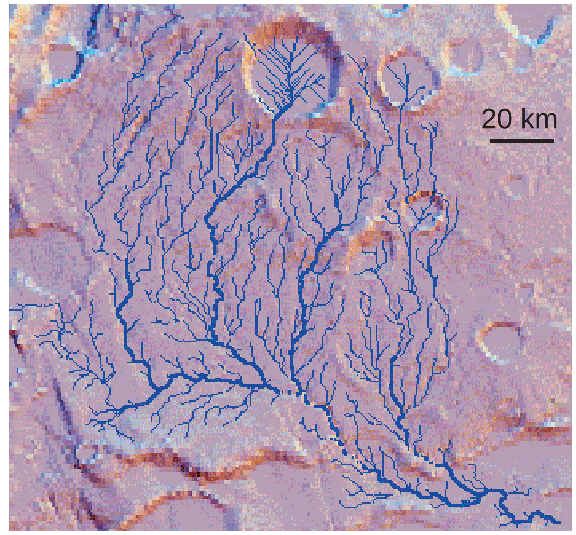

Figure 1: Extracted drainage network of the terrain centered on about 45.5S, 267.5E in the area where Viking images yield a classic example of a valley network strongly resembling terrestrial river networks. The network is drawn on the top of a perspective view of terrain topography with exaggerated vertical dimension.

are extracted from DEMs computationally using an algorithm developed for studies of terrestrial river basins (3). Empirical cumulative distribution functions (CDFs) of a, l, e, and D are constructed using their values at the nodes of the extracted network. Fig. 1 shows an example of an extracted martian drainage network. Values of the exponents τ, γ and β are estimated by a least-squares parametric fit to the respective CDFs. The value of ρ is calculated directly from the data; large values of ρ indicate high uniformity of D. Fig. 2 shows network descriptors for martian, terrestrial, and lunar drainage basins.

Results. The striking feature of the (τ, γ) diagram is that the martian and terrestrial data points are intermingled in the same, well bounded region of the diagram and disjoined from the much more scattered lunar data points. Moreover, there is the same significant correlation ($r = 0.6$) between values of τ and γ in terrestrial and martian data, but the lunar data lacks any $\tau - \gamma$ correlation. Although the planar characteristics, (τ, γ), of martian and terrestrial drainage networks have a high degree of similarity, indicating the possibility of rainfall-fed erosion, the (ρ, β) diagram shows a relatively non-uniform drainage density and low values of β for martian basins, features that are not consistent with an erosion by sustained and uniformly distributed rainfall.

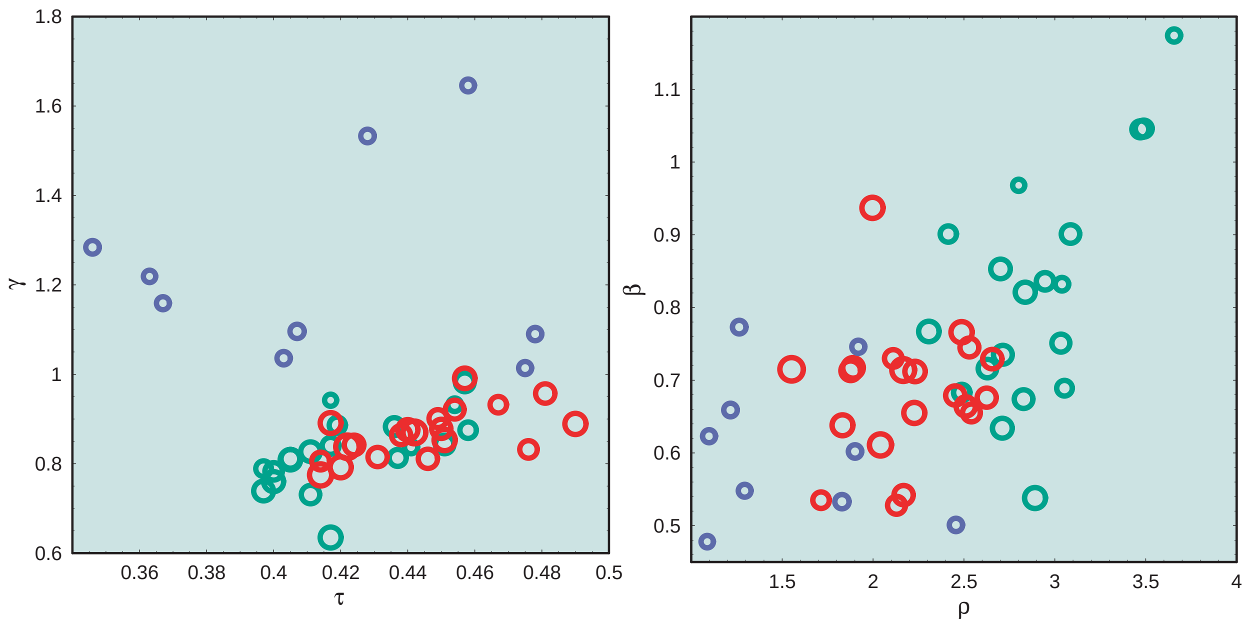

Figure 2: The network descriptor, A, for martian (red), terrestrial (green), and lunar (blue) drainage basins. The size of a circle symbol is proportional to the logarithm of a basin total area. The left panel shows the (τ, γ) diagram and the right panel shows the (ρ, β) diagram.

We have not found any correlations between values of network descriptor and the large-scale morphology and geology of martian sites. In particular, there are no statistical differences between basins incorporating visible fluvial features and those that are identified exclusively from topography. This suggests that the extent of A_{Mars}, much like the extent of A_{Ter}, is not caused by spatial variation of erosional processes, but rather by a non-causal scatter intrinsic to a single erosional process and uncertainties in deriving values of A.

A plausible interpretation of our finding is that the roughness of the ancient martian landscape is not due to a single, predominant process, but rather due to a superposition of roughening by meteorite bombardment and the rainfall. Such an interpretation accounts for the Earth-like planar characteristics of the martian networks, that was imprinted during the time when Mars possessed an early climate that was conducive to rainfall, but which disappeared before the end of heavy bombardment (4 Ga). The pattern of the rainfall-eroded landscape was subsequently modified by impacts, causing the observed relative non-uniformity of D and the Moon-like character of the vertical structure of drainage networks. This interpretation implies that networks identified on younger terrains, such as Alba Patera, should have values of A different (in a statistical sense) from that for the networks extracted from older terrains. No such distinction is found in our results, although the number of younger surfaces in our sample is too small for any statistical inference to be significant. An alternative interpretation is that A_{Mars} does not reflect superposition of rainfall and impacts, but instead is associated with another roughening process, such as erosion associated with local hydrothermal discharges or from fluvial processes at the base of glaciers and snow packs. Regardless of this ambiguity, our results are not consistent with the idea that Mars has experienced sustained rainfall after the end of heavy bombardment, or the notion that Mars underwent recurring episodes of rainfall of sufficient duration and intensity to redistribute the volume of water associated with a northern ocean ($\sim 10^7$ km^2) into the southern highlands multiple times during the planet's history (4). In both cases, we would expect the roughness of the martian surface to have an unambiguous signature of the rainfall-fed erosion.

References

(1). Dodds, P.S. & Rothman, D.H. 2000, Annu. Rev. Earth Planet. Sci. 28, 571.

(2). Sinus Sabaeus (13S, 24N), Tyrrhena (22S, 101E), Hecates Tholus (33N, 150E), Ma'adim Valles (13S, 175E), Tader Valles (49S, 209E), Alba Patera (46N, 248E), Warrengo Valles (43S, 267E), Bosphorus Planum (34S, 288E), Melas Fossae (25S, 289E), Nanedi Vallis (5N, 312E), Nirgal Vallis (27S, 316E), Margaritifer Valles (30S, 337E).

(3). Tarboton, D.G., Bras, R.L., and Rodriguez-Iturbe, I. 1989, Technical Report no. 326, Ralf M. Parsons Lab., Massachusetts Institute of Technology, Cambridge, MA.

(4). Baker, V.R., Strom, R.G, Dohm, J.M., Gulick, V.C., Kargel, J.S., Komatsu, G., Ori, G.G., and Rice, J.W. Jr. 2000, Lunar Planet. Sci. Conf. [CD-ROM], XXXI, abstract 1863.