NEW DATA REVEAL MATURE, INTEGRATED DRAINAGE SYSTEMS ON MARS INDICATIVE OF PAST PRECIPITATION. B. M. Hynek and R. J. Phillips, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University (One Brookings Drive, St. Louis, MO 63130 hynek@levee.wustl.edu).

Introduction: Valley network systems on Mars remain the most unequivocal evidence that water carved the surface of the planet in the distant past and the climate was different than today. Most of these systems date from the Noachian [1], the period of heavy bombardment which is >3.7 Ga [2], although local or regional formation seems to have continued to more recent times [3]. The discovery of valley networks sparked a long-lived debate over the amount and importance of water at or near the martian surface. Both surface runoff and groundwater processes have been attributed to formation of valley networks but the relative importance of each is still unclear. In this study we analyzed recent Mars Global Surveyor (MGS) data in and around the Arabia Terra region with new techniques and found far more valley networks and mature drainage systems than previously observed. Certainly, both groundwater and surface runoff sculpted the martian landscape, however, our findings argue for a substantial contribution of surface runoff, implying past precipitation.

Background: Drainage basin morphometry is often used to infer past climatic conditions and the importance of precipitation [e.g. 4]. Terrestrial categorization of basin morphometry incorporates the properties of stream length, order, and density to determine the degree of valley network integration and maturity. Quantitative analysis of stream order was developed by Strahler [5] and is a measure of the number and maturity of valley segments. Drainage density is simply defined as the average length of valley segments per unit area [6] and is a reflection of stream spacing in a drainage basin. The common procedure to calculate this parameter is to determine the area of a drainage basin and then divide by the total length of valley segments. On Earth, mature drainage basins are heavily dissected and typically have a stream order >5 and drainage density $>6 \times 10^{-2}$ km^{-1} [7]. Valley network systems in this category are believed to reflect a substantial contribution of precipitation and subsequent surface runoff.

Methods: Our technique to investigate drainage basin morphometry on Mars utilized the Mars Orbiter Camera (MOC) wide angle global image mosaic and Mars Orbiter Laser Altimeter (MOLA) data. These sets provide a considerable improvement in resolution and clarity of the martian surface over standard products such as the Mars Digital Image Mosaic (MDIM), which was produced with Mariner and Viking data. The MOC global image mosaic was coregistered to the MOLA-defined planetocentric coordinate system and overlaid on shaded relief data that we generated. Further, the original MOLA gridded product with a subtle color stretch was added as a separate layer. GIS software allowed us to use the shaded relief map as a base and vary the transparency, stretch, and many image-related parameters of the superposed layers. In this manner, underlying topographic data was visible in addition to the information contained in the image. The color layer of MOLA gridded data overlain on top revealed regional and local topographic trends essential for accurate mapping of valley networks. Thus, valley networks were identified and mapped in multiple data sets at the same time, greatly increasing the completeness and accuracy of mapping.

Results: When MGS data were analyzed with the technique outlined above, far more valley systems on Mars were identified than previously mapped by Carr [1]. Fig. 1 illustrates earlier and new mapping efforts and is an archetypical illustration of our results. Fig. 1a shows a valley network across the image with a northwest azimuth as mapped by Carr [1] on a base image of the highest resolution MDIM available. A long trunk segment with a few minor tributaries is visible and indicative of a poorly integrated and immature drainage basin. The valley system pictured is a third order system, includes 44 segments with a total length of 1308 km, and the basin has a drainage density of 7.6×10^{-3} km^{-1}. These values are consistent with an immature drainage basin formed primarily by groundwater processes. In contrast, Fig. 1b is the same region only now the base image is a combination of MOC and MOLA data as described above and our mapped valley networks are overlain on top. Following the same defining characteristics as Carr [1], over seventeen times more valley segments are evident in the new MGS data and many heads are seen reaching up to divides. Our mapping reveals that this third order system mapped by Carr [1] is really sixth order with many closely spaced tributaries. In total, 11,161 km of valley segments can now be positively identified, nearly nine times more than previous efforts. Moreover, the calculated drainage density is 6.5×10^{-2} km^{-1}, or roughly an order of magnitude larger than evident from earlier data.

Discussion: The example above is for a specific area of Mars located on highland terrain near the Schiaparelli impact basin. However, these results are typical of other regions of the cratered uplands that we have studied in detail. In nearly all areas reexamined with MGS data, valley segments originally mapped by Carr [1] can be traced a greater distance and the lowest order segments often reach right up to drainage divides. Moreover, a majority of previously identified individual valley segments are now seen as part of larger, integrated, dendritic drainage basins with lengths up to thousands of kilometers. Compared to earlier results, we found roughly an order of magnitude increase in total mapped valley length and drainage density in most drainage basins. Our drainage densities are comparable to low-end terrestrial values determined in a similar manner [7], who found a range of 6.5×10^{-2} to 2.09×10^{-1} km^{-1} for five varied regions in the United States.

We argue that the new data provide support for some degree of surface runoff (and by inference precipitation) on Mars in the ancient past. Surface runoff is the simplest explanation for the integrated drainage basins, valley heads near the top of divides, and drainage densities comparable to terrestrial values seen in MGS data. Later modification by groundwater processes and aeolian infill are likely. However, early precipitation and surface runoff may be necessary to explain some of the observed surface features of Mars, and thus the climate must have been significantly different in the past.

References: [1] Carr M. H. (1995) *JGR, 100,* 7479-7507. [2] Hartmann W. K. and Neukum G. (2001) *Space Sci. Rev.*, *96*, 165-194. [3] Scott D. H., Dohm J. M., and Rice J. W. (1995) *U. S. Geol. Surv. Misc. Invest. Ser. Map I-2461*. [4] Gregory K. J. (1976) in *Geomorphology and Climate*, ed. E. Derbyshire, Wiley, New York, pp. 289-315. [5] Strahler A. N. (1958) *Geol. Soc. Am. Bull., 69*, 279-300. [6] Ritter D. F. F., Kochel R. C., and Miller J. R. (1994) McGraw-Hill, Dubuque, 560 pp. [7] Carr M. H. and Chuang F. C. (1997) *JGR, 102*, 9145-9152.

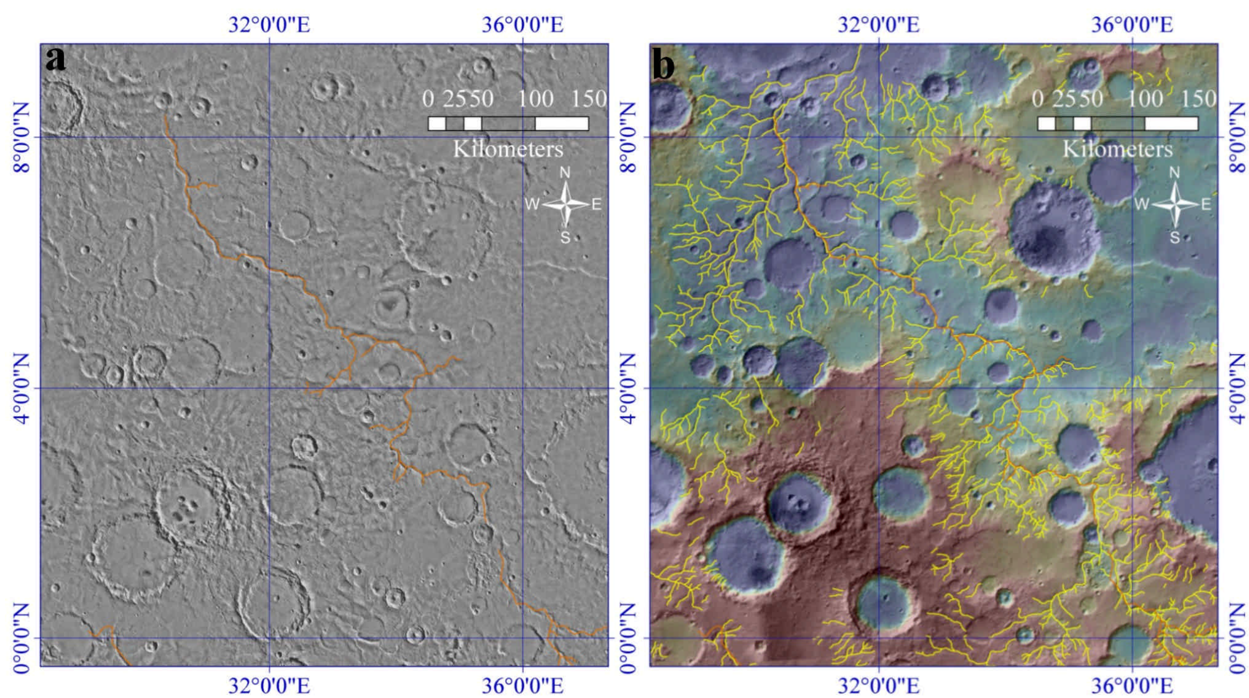

Figure 1. Comparison of valley network systems evident in pre-MGS data and new work using MGS data. Fig. 1a shows valley networks (orange) mapped by Carr [1] overlaid on the highest resolution Viking base image. Fig. 1b is the same region with new mapping of valley networks (yellow) overlain on a MGS image mosaic and topographic base. The number of valley systems and resultant drainage density seen in the MGS data are an order of magnitude greater than previously thought. Additionally, valleys are now seen reaching right up to topographic divides, including impact rims and massifs.