QUANTITATIVE ANALYSIS OF THE FRETTED TERRAIN DRAINAGE NETWORK, ARABIA TERRA, MARS. K. A. Mason[1], J. M. Hurtado[1], P. Whelley[2], [1]The University of Texas at El Paso, 500 W. University Ave., El Paso, TX, 79902, kamason@miners.utep.edu, [2]NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD, 20771.

Introduction: The fretted terrain (FT) is a distinct topographic feature on Mars that formed in the Late Noachian to Early Hesperian [1] and is characterized by deeply-carved valleys and distinct polygonal mesas [2]. The northern ~5x10^6 km^2 of Arabia Terra (AT) is the type location for FT on Mars. Some suppose the FT valleys to have been generated by fracturing [1], while others see the valleys as being formed exclusively due to fluvial, glacial, and/or mass wasting erosive processes [3,4,5].

The Late Noachian to Early Hesperian remains an ambiguous time in Mars history. The northern-southern hemisphere dichotomy boundary was formed just prior to this time, the evolution of which is still highly debated [6]. During this time, water-driven processes dominated throughout the planet [3], super eruptions potentially larger than any on earth are thought to have occurred in AT [7], and the enigmatic friable deposits found throughout AT were deposited [8]. Therefore, studying the evolution of the FT might provide critical insights into the ancient climate and tectonomagmatic history of Mars. In order to determine the origin of the FT, a first-order question to address is: *Was the original formation of the FT valleys directly influenced by processes such as post-depositional fracturing?* This study addresses this question by analyzing the geometry and morphology of the FT drainage network.

Valley Mapping and Analysis: First, the drainage patterns in the FT were mapped from the 128 pixel-per-degree resolution Mars Oribiter Laser Altimeter (MOLA) Digital Elevation Model (DEM) using the D8 Flow Direction Algorithm [9], a technique employed previously on Mars for mapping valley networks objectively [10]. The algorithm automatically segments the valleys at their vertices. All valley segments (n = 5,048) were grouped into three separate approximately equal geographic areas. (Deueteronilis Mensae, Protonilis Mensae and Nilosyrtis Mensae; Fig. 1). Each of these three areas subtends ~1,500 km along the dichotomy boundary.

The azimuth of each valley segment was calculated and sorted into 10° bins for each geographic location from which rose diagrams were generated. The rose diagrams were scaled by the total cumulative valley length for each bin. The modes of the valley azimuths determined from the data were compared to the down slope direction (DSD) that characterize each area. For each geographic location, the DSD was determined by randomly selecting 1% of the DEM pixels, fitting a flat plane to those elevation values using a least-squares regression, and finding the aspect of that plane. The DSD represents the expected preferred orientation for valley networks carved by gravity-driven water or ice flow. The more similar the valley azimuths are to the DSD, the more likely a potential fluvial or glacial origin for the valleys, while the further the values from each other, the more likely the valleys are influenced by other processes such as fracturing.

Finally, bifurcation ratios (*BR*) were calculated for the valley networks in each geographic area. $BR = N_i/(N_{i+1})$ [11], where N is the total length of the ith Strahler order valleys [11]. This study calculated *BR* for i = 1 and i = 2 because all three locations had stream orders between 1 and 3. On Earth, *BRs* calculated for valley networks incised into homogeneous lithologies have a value between 3 and 5. *BR* values significantly different from those are typically indicative of non-fluvial/non-glacial processes such as tectonism[11]. The *BR* values will also provide a basis for comparison of drainage networks between the three study areas.

Results: The majority of valleys throughout Nilosyrtis and Protonilis have sub-rectangular geometries, indicative of a tectonic origin [12], while those in Deuteronilis display some parallel valley geometries, indicative of a fluvial or glacial origin [12] (Fig. 1). The azimuths of valley segments become progressively more distributed towards the east, from a single mode in Deuteronilis (290°), to two modes in Protonilis (30° and 340°), to five modes in Nilosyrtis (340°, 280°, 180°, 40°, 20° and 10°) (Fig. 2). The DSD for each geographic location are as follows: 21.4° for Nilosyrtis, 359.5° for Protonilis, and 343.3° for Dueteronilis. Overall, the modes of the valley segment azimuths do not follow the DSD as one would expect if the valleys were erosively carved out of a homogeneous and non-fractured lithology. In addition, while bifurcation ratios between 3 and 5 indicate homogeneous lithology on Earth, *BR* values for the FT are <3, increasing from 1.77 to 2.32 for i = 1 and 0 to 1.47 for i = 2 from east to west.

Implications: Based on observed drainage patterns, valley deviation from DSD, and *BR* values, we suggest that the valley networks in the FT were originated by fracture driven processes such as tectonism and subsequently accentuated and modified by erosive processes such as glaciers and rivers. Fracturing seems to be most pronounced in the east and gradually become diminishes to the west Alternatively, fluvial and glacial processes dominate towards the west and are more subtle towards the east. The size of the individual fractures, their characteristic graben-like appearance, and the overall scale of the FT suggests the possibility of a Late Noachian to Early Hesperian extensional system, as has been previously suggested for this region [6]. One hypothesis is that an extensional system driven by the dichotomy boundary formation produced either tectonic grabens or dike-driven grabens similar to those at Tractus Catena [13]. An alternative interpretation is that the fracturing is caused by down-dropped crustal blocks produced by ice melt in a setting similar to the Chaos region on Mars [14] as suggested previously [2].

Continuing Work: To provide insight into the origin of fracture formation in the FT, valleys will be mapped at both MOLA and CTX resolution. We expect if the fractures formed from down-dropped blocks that the fracture patterns will be randomly oriented and the mesas will be tilted in random directions. Extensionally related grabens will instead likely display a preferential oriention related to regional techtonic stresses. In addition, topographic profiles of valleys within the FT will be generated from CTX DEMs to compare graben geometries throughout the region to the topography at potential Mars analogues (i.e. Tractus Catena grabens and the Chaos region) and to simulated topography generated using the software COULOMB [15].

References: [1] Irwin, R.P, Watters, T.R., Howard, A.D., Zimbelman, J.R. (2004) *J. Geophys. Res., 109*, E09011. [2] Sharp, R.P. (1973). *J. Geophys. Res., 78*, 4073 – 4083. [3] Carr, M.H. (2001) *J. Geophys. Res., 106*, 23,571 – 23,593. [4] Fairen, A.G., Davila, A.F., Gago-Duport, L., Haqq-Misra, J.D., Gil, C., McKay, C.P., Kasting, J.F. (2011), *Nature Geo. Lett., 4*, 667-670. [5] Head, J.W., Nahm, A.L., Marchant, D.R., and Neukum, G. (2006). *Geophys. Res. Lett., 33*, L08S03. [6] Watters, T.R. and Robinson, M.S. (1999) *J. Geophys. Res., 104*, 18,981 – 18,990. [7] Michalski, J.R., Bleacher, J.E. (2013). *Nature*, *502*, 47-52 [8] Kerber, L., Head, J.W., Madeleine, J., Forget, F., Wilson, L. (2012). *Icarus, 219*, 358-381. [9] Tarboton, D. G. (1997) *Water Resources Research*, *33*, 309 – 319. [10] Stepinski, T.F., Collier, M.L. (2004). *J. Geophys. Res., 109*, E11005. [11] Strahler, A. N. (1957) *Eos, 38*, 913-920. [12] Howard, A.D. (1967) *Am. Assoc. Pet. Geol. Bull., 51*, 2246 – 2259. [13] Hardy, S. (2016). *Geology*, *44*, 107-110. [14] Meresse, S., Costard, F., Mangold, N., Masson, P., and Neukum, G.. (2007). *Icarus, 194*, 487-500. [15] Toda, S., Stein, R.S., Sevilgen, V., and Lin, J., (2011) *USGS Numbered Series, 2011-1060*.

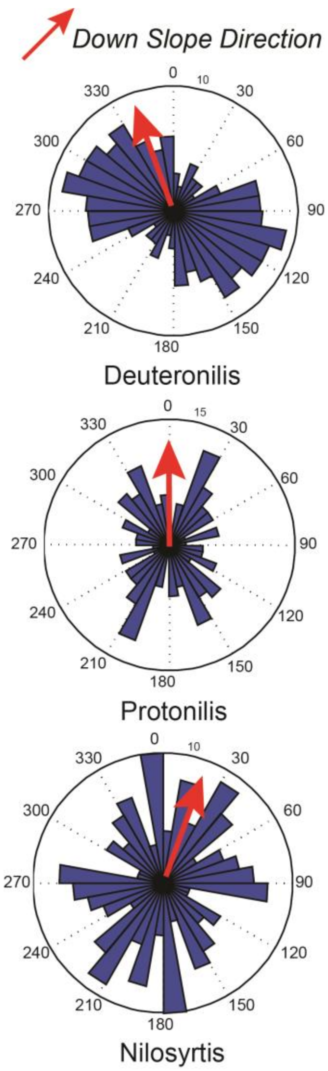

Figure 2 (left): Rose diagrams for valleys in each geographic location (Deuteronilis, Protonilis, and Nilosyrtis, from west to east). The magnitude of each rose diagram bin is scaled by the percent total length of valleys that fall into that 10° bin. Note that the data has been reflected to complete the other half of the rose diagram.

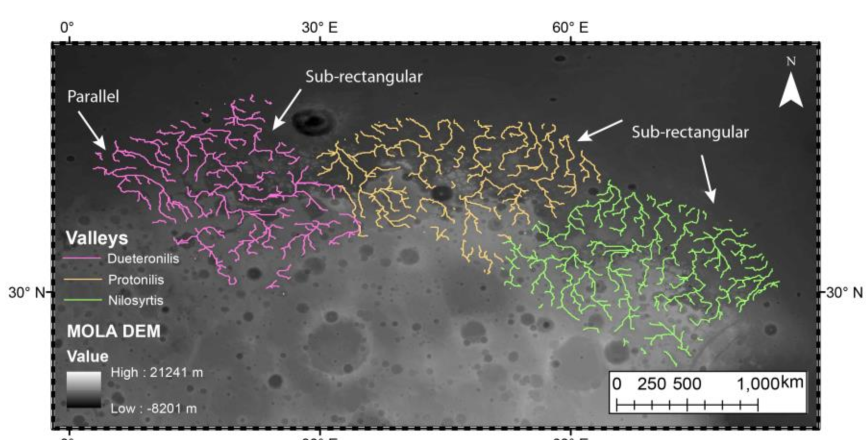

Figure 1 (left)**:** Study location with valleys mapped via the D8 Flow Direction Algorithm [9] overlain on the 128 degree-per-pixel MOLA DEM. The three geographic areas (Deuteronilis, Protonilis, and Nilosyrtis) are distinguished by color (pink, yellow, green). White arrows and text point out examples of sub-rectangular and parallel drainage patterns throughout the region.