MAPPING THE FRETTED TERRAIN NORTH OF ARABIA TERRA, MARS: RESULTS AND IMPLICATIONS FOR DICHOTOMY BOUNDARY EVOLUTION.

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Introduction: The origin of the complex martian fretted terrain has eluded full scientific understanding since its discovery in Mariner 9 data [1]. The fretted terrain is composed of plateaus, mesas, knobs, and mounds in a highly irregular configuration separated by wide, flat-floored channels, valleys and troughs, and is observed at multiple locations along the boundary between the southern highlands and the northern lowlands [1, 2]. Previous investigations have proposed different hypotheses to explain the apparent breakup and removal of material, including fluvial or aeolian erosion [2-4], subsurface removal via groundwater flow [2, 5], and faulting/tectonism [1, 6-7]. Here, we perform an in-depth geomorphological and morphometric analysis of the fretted terrain north of Arabia Terra as well as the Arabia Terra plateau itself to better constrain candidate formation mechanisms.

Study Area: The fretted terrain north of the Arabia Terra plateau was selected for component analysis mapping due to its extensive study and prominence in previous formation hypotheses (e.g., 1-3, 5, 7). This section of the fretted terrain covers ~1.12 x 10^6 km^2 north of Arabia Terra (AT) based on furthest extent of visibly associated features as defined by [1] (Fig. 1). The stratigraphy of the AT fretted terrain is thought to be similar to the stratigraphy of the AT plateau (Fig 2) [e.g., 1, 4]: bedrock is capped by mid- and/or late Noachian flood volcanics [4] overlying Borealis Basin ejecta and pre-Borealis basement material/megaregolith. In some locations the volcanic caprock is unconformably overlain by a friable mantling unit, also emplaced in the late Noachian [8]. This stratigraphic column then experienced incision and partial removal during the late Noachian and/or early Hesperian[1-2, 9]; the exact age and duration of fretted terrain formation remains unconstrained. Amazonian glaciation influenced the fretted terrain and fretted channels [10], and a regional ice sheet is interpreted to have covered the mid-latitude plateau and fretted terrain [11].

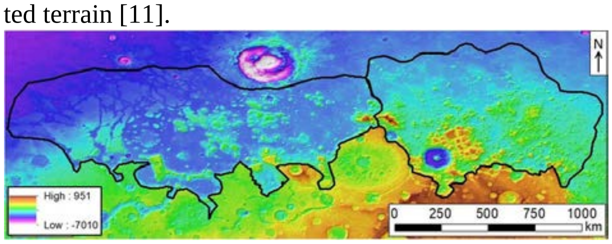

Fig. 1. MOLA-derived topographic map of the AT fretted terrain study area with east and west AT study areas indicated by black lines.

Motivating Questions: These include: 1) Was AT a continuous plateau sloping toward the north? 2) How much material was removed in the fretting process? 3) What process(es) removed the material? 4) Where did the material go? 5) When did the removal process(es) take place and over what time period? 6) How do the fretted channels relate to FT formation?

Analysis: To address these questions, we mapped FT components (individual mesas, plateaus, etc.) to determine surface area and volume of removed material and document variations in morphology using 128 degree/pixel MOLA topography [12] and 100 m/pixel THEMIS daytime infrared data [13]. On the basis of these data, we then conducted an analysis of nearby landforms in the AT plateau to assess formation hypotheses. Using the AT FT component maps as well as intervening area and topography, we estimated the volume of material removed from the fretted terrain to be ~2.8 x 10^5 km^3 for the entire study area, approximately one-fourth of the volume of the current martian north polar ice cap. Removal of material varies significantly across the region (20% by volume in the west; 60% in the east)(Fig. 1). The large total amount of missing sediment volume, combined with no obvious proximal deposits representing the removed material, requires highly effective local removal process(es), or wide dispersal, perhaps into the northern lowlands. Lateral differences in morphology, morphometry and amount of material removed may be the result of lithologic differences across the study area or variations in the removal process(es).

Fig. 2. Simplified stratigraphic column for the AT plateau. Approximate ages of units are noted where assessed by [3, 9]. The LN volcanic unit is ~150-200 m thick [21] while the MN unit is unconstrained. Lower layers are not exposed and have not been observed [3.9].

Following determination of missing volumes, we analyzed the suite of unusual features within the AT plateau for evidence of contemporary processes modifying both regions, as they have a common stratigraphy and geologic history until the fretting event(s) disrupted the region. The AT plateau possesses 1) numerous medium to large impact craters buried by the Noachian flood lavas, 2) a suite of landforms indicative of terrain disruption and potential subsurface removal of material (chaos-floored craters, deep closed depressions, fretted channels), and 3) sapping-like features (Fig. 2). Multiple observations of buried and embayed craters along the dichotomy boundary are consistent with previously mapped volcanic activity in the late Noachian [9], while chaos-floored craters, closed depressions and fretted channels indicate heterogeneous removal of subsurface material on both large (the 20 km-wide fretted channels) and smaller scales (collapsed crater floors) [2, 5, 14]. These features preserve evidence of disruption of the upper subsurface and are inconsistent with overland flow – chaos-floored craters and closed depressions lack inlet channels as sources for fluvial erosion, and fretted channels exhibit steep walls, flat floors, and amphitheater-shaped headwalls inconsistent with morphologies observed in martian features formed through fluvial activity (i.e., valley networks). These features suggest a component of undercutting and collapse that persisted across the AT plateau in the vicinity of the fretted terrain. The sapping features could be due to subsurface erosion but could also be due to overland flow [15].

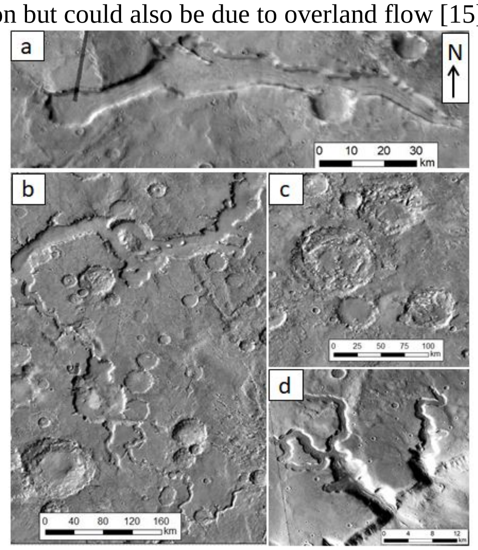

Fig. 3. MOLA hillshade overlain by THEMIS daytime images **a**. closed depression. **b.** Mamers Valles, a fretted channel. **c.** chaos-floored craters **d.** CTX imagery of sapping channel.

Given the presence of numerous landforms indicative of persistent subsurface loss of material across the AT plateau, we reevaluate previous hypotheses invoking overland and groundwater flow in the formation of the fretted terrain. Given the shared geologic history of the AT plateau and the fretted terrain, subsurface evacuation of mass may also have been a significant component in destabilizing and removing material from the fretted terrain. Previous hypotheses considering the formation of the fretted terrain have primarily considered fluvial and groundwater activity in a warm and wet early Mars with a vertically integrated hydrologic system, mean annual temperatures near or > 273 K, and active groundwater circulation [2, 13,16-17]. Few investigations have considered the cold and icy climate endmember, in which the hydrologic system is horizontally stratified and surface temperatures are ~225 K with punctuated periods of intermittent warming and liquid water surface stability [18-19]. To fully assess the suite of possibilities for formation of the fretted terrain, we explore the two end-member climate scenarios for their ability to produce disruption of the upper subsurface in AT: 1) Global groundwater flow in a warm and wet climate scenario could drive sapping-based erosion on a regional scale as previously proposed [e.g., 2, 5, 17]. 2) Alternatively, it is known that the AT Plateau and the FT were covered with regional glacial snow and ice deposits during the Amazonian [10,11]. The presence of regional surface snow and ice during the Late Noachian flood lava emplacement [3] could drive disruptions of the stratigraphy through both contact melting of surface ice and deferred melting of buried ice [20]. Furthermore, punctuated climate change driving sublimation or melting of subsurface ice could efficiently remove mass from the subsurface without requiring a material sink, while glacial meltwater could produce highly erosive outburst floods capable of material removal of the large scales required [21].

Conclusions and Outstanding Questions: Analyses of fretted terrain and AT plateau features indicate that material removal was facilitated by disruption of the subsurface, likely through the migration of liquid water. We are currently assessing the relative proportions of surficial removal mechanisms (i.e., overland flow) and subsurface hydrous activity (groundwater flow, ice melting, cryosphere destabilization) as mechanisms for removal of material from the AT fretted system in a range of climate scenarios.

References: [1] Sharp (1973) *JGR 78*. [2] Carr (1995) JGR 100 E3, 7479-7507. [3] McGill (2000) JGR 105 E3, 6945-6959. [4] Irwin et al. (2004) JGR 109. [5] Carr (1996) Water on Mars. [6] Irwin and Watters (2010) JGR 115. [7] Mason et al. (2017) LPSC XLVIII, Abstract #1626. [8] Fassett and Head (2008) Icarus 198, 37. [9] Tanaka et al. (2014) USGS SI Map 3292. [10] Head et al. (2010) EPSL 294, 306-320. [11] Fastook et al. (2011) Icarus 216, 23-39. [12] Smith et al. (2001) JGR 106 E10, 23689-23722. [13] Christensen et al. (2004) Space Sci. Rev 110 (1-2), 85-130. [14] Denton and Head (2018) LPSC XLIX, this volume. [15] Lapotre and Lamb 2015 JGR 120 (7), 1227-1250. [16] Craddock and Howard (2002) *GRL* 10710, 5111. [17] Andrews-Hanna et al (2007) Nature 446, 163. [18] Forget et al. (2013) *Icarus* 222, 1. 81-99. [19] Wordsworth et al. (2013) I*carus* 222, 1. 1-19. [20] Cassanelli and Head (2016) *Icarus* 271, 237-264. [21] Denton et al. (2017) LPSC XLVII, Abstract #2182.