FRETTED CHANNELS AND CLOSED DEPRESSIONS IN NORTHERN ARABIA TERRA, MARS: ORIGINS AND IMPLICATIONS FOR SUBSURFACE HYDROLOGIC ACTIVITY. C.A. Denton[1] and J. W. Head[1], [1]Department of Earth, Environmental & Planetary Sciences, Brown University, Providence RI 02912 USA (adeene_denton@brown.edu).

Introduction: The Arabia Terra (AT) plateau contains numerous unusual geologic features, including fretted channels and closed depressions, two classes of large, elongated channel-like features concentrated within the northern margins of the plateau (Fig. 1) [1,2]. The fretted channels and closed depressions are believed to have formed during the Late Noachian-Early Hesperian (LN-EH) [2,3]; however, their origins and connections to hydrologic activity remain outstanding questions. Previous investigations have proposed overland flow of water as a crucial formation mechanism through fluvial erosion and/or extensive flooding of the plateau [4-6], implying long-term surficial stability of liquid water. Here, we (1) report on an in-depth geomorphologic analysis of the fretted channels and closed depressions to assess overland flow as a potential formation mechanism, and (2) explore alternative processes and consider their implications for the geologic and climatic history of early Mars.

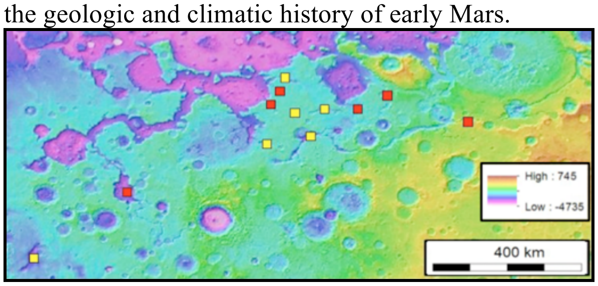

Fig. 1. MOLA-derived topographic map of northern AT annotated with locations of fretted channels (red boxes) and closed depressions (yellow boxes).

Study Area: The AT plateau was selected for investigation because it contains a record of key geologic and climatic events during the LN-EH. Its critical location may provide insight into the evolution of the dichotomy boundary. It also contains the largest concentration of fretted channels and closed depressions on the martian surface. Previous researchers have identified the surface of the AT plateau as the culmination of multiple episodes of mid and late Noachian flood volcanism [2, 3]. The plateau is defined by a laterally extensive basaltic caprock that may overly Borealis Basin ejecta as well as pre-Noachian basement and megaregolith material. A complex series of fluvial landforms modified this surface during the LN-EH, which was then overlain by a fine-grained mantling deposit [2, 7]. Extensive Amazonian glaciation, indicated by lineated valley fill [8], obscures the floors of the fretted channels and closed depressions.

Analysis of the fretted channels and closed depressions was performed in ESRI's ArcGIS software using MOLA 128 pixel/degree topography [9], 100 m/pixel THEMIS daytime imagery [10], and high-resolution (6 m/pixel) CTX images [11]. After assessing their spatial distribution and geographic relationships within the plateau, individual fretted channels and closed depressions were selected for further specific analysis.

Observations and Interpretations: Our analysis of the fretted channels indicates consistent morphology despite wide-ranging channel depth, length, and width across the plateau. From an assessment of channel surface area and depth, we find the total volume removed to produce the fretted channels is ~2.51 x 10^3 km^3, ~1.7 cm global equivalent layer (GEL) of sediment. Specific analysis of the largest fretted channel, Mamers Valles (Fig. 2), reveals that the main channel floor incises into local topographic highs that should otherwise divert fluvial flow and prevent channel formation. Additionally, fracture patterns and slumping within the channel walls are observable at multiple points down-channel, suggesting removal of substrate support of the caprock unit. These observations, in conjunction with the paucity of effluent material near the Mamers channel mouth, support the interpretation that subsurface rather than surface flow is a major component of channel formation, producing fracturing of overlying plateau material and minimal observable sediment transport.

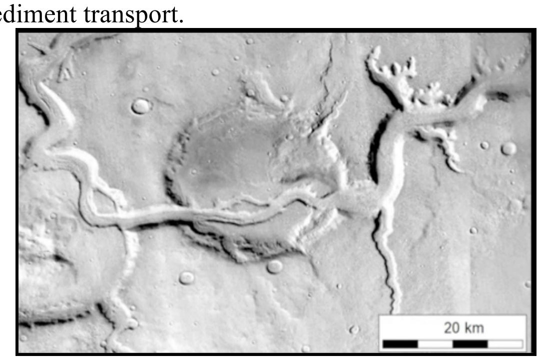

Fig. 2. Subset of upper Mamers Valles as shown in a CTX mosaic in which irregular channel patterns are visible.

Analysis of regional closed depressions reveals "sagging" of local topography in the immediate vicinity of the depressions. From an assessment of depression surface area and depth, we find the total volume removed to produce the closed depressions is ~3.28 x 10^3 km^3, equivalent to ~ 2.2 cm GEL of sediment. Further analysis of a specific closed depression indicates a lack of inlet channels that would be required for overland flow; additionally, the lack of observable sediment deposits or any visible sink for removed material argues against overland flow (Fig. 3). As Fig. 3 indicates, a transport direction cannot be inferred from the consistently flat glacially-modified surface of the depression floor. As such, we suggest that depression formation was dominated by a combination of vertical collapse and subsurface lateral transport to produce the elongate morphology observed, without significant surficial movement of material. The topographic depressions that extend beyond the immediate vicinity of the amphitheater-shaped headwalls may indicate further material loss and collapse outside of the depression itself, consistent with a regionally-connected subsurface system.

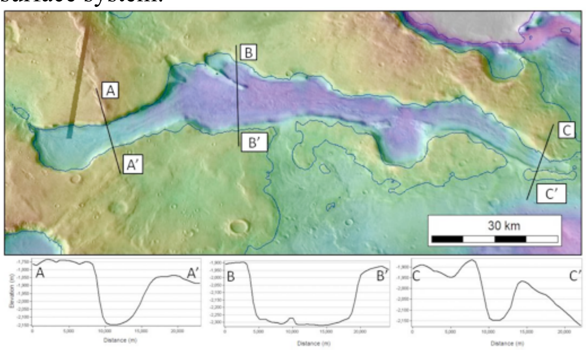

Fig. 3. MOLA global gridded topography overlain by THEMIS daytime imagery of the selected closed depression. Three topographic profiles perpendicular to the closed depression are shown, traversing west to east; the consistent depth of the floor is visible.

Based on these morphologic observations, the fretted channels and closed depressions both appear to be inconsistent with formation through overland flow. Instead, the observed morphologies are interpreted to indicate a significant component of subsurface removal of material, based on (1) channel formation irrespective of surface topography, (2) pervasive evidence of collapse in both the fretted channels and closed depressions, (3) extended slumping of topography beyond the observed channel/depression cavities, and (4) the massive volumes of missing material required to produce the observed cavity volumes. The distribution of these features suggests ubiquitous subsurface removal across AT (Fig. 1). Thus, in determining the geologic processes that produced the fretted channels and closed depressions, processes capable of massive local disruption across the entirety of the northern AT plateau are likely required.

From these observations, we consider five potential options for formation of the fretted channels and closed depressions capable of producing regional drainage and collapse: (1) sublimation/melting of a laterally extensive ice-cemented cryosphere, (2) sublimation/melting of lenses of buried snow and ice, (3) circulation and release of a liquid groundwater reservoir, (4) dissolution of highly soluble minerals (e.g., magnesium sulfates) and (5) some combination of the above. Melting and/or dissolution of material in the subsurface could be facilitated by the emplacement of local lavas during the LN-EH, whose thicknesses may exceed several hundred meters [12]. As a first-order assessment of these hypotheses, we derive estimates for the amount of water required in each of the water-based scenarios based on estimates for cavity volumes, available pore space [13], and expected water/sediment transport ratios [14]. For a cryosphere-dominated scenario the amount of water required is ~4 mm GEL, but necessitates melting of the cryosphere up to a depth of 10 km. In a scenario dominated by liquid groundwater, the necessity of additional material transport raises the potential water required to ~22-76 m GEL. We find that the most volumetrically efficient scenario is one in which extensive ice lensing and/or highly-soluble mineral layers dominate an ice-cemented upper subsurface, which requires a more realistic subsurface melt depth of ~100-300 m. This scenario may be consistent with the complex hydrologic history of the AT plateau.

Conclusions and Outstanding Questions: Analysis of the observed fretted channels and closed depressions indicates that these features are morphologically inconsistent with formation through overland flow, which is also inefficient for the large volumes of sediment removed. Instead, the formation of these features may be dominated by vertical and lateral transport of material in the subsurface. We have developed a series of candidate hypotheses to describe the formation of unusual geologic features within the AT plateau, consistent with the information provided by higher-resolution data. Melting of buried snow and ice, e.g., through top-down heating and melting by superposed lavas [15], is a potentially favorable mechanism for the formation of these features as it is volumetrically and temporally efficient. Further work will quantitatively analyze these options for their feasibility and consistency with the observed geology, as each formation mechanism has strong implications for the climate of Mars during the LN-EH.

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