PROTONILUS MENSAE: ORIGIN BY CONTACT AND DEFERRED MELTING ASSOCIATED WITH EMPLACEMENT OF LATE NOACHIAN FLOOD VOLCANISM. C. A. Denton[1,], J. W. Head[1], and J.P. Cassanelli[1], [1]Brown University, Providence, RI 02912 USA (adeene_denton@brown.edu).

Introduction: The origin of the fretted terrain of Protonilus Mensae has eluded full scientific understanding since its initial discovery in Mariner 9 data [1]. The fretted terrain is composed of mesas, plateaus, and knobs in highly irregular configurations separated by wide, flat-floored channels (Fig. 1, 2). Previous hypotheses have invoked groundwater sapping, unusual valley network extension, or collapse through erosion [1] and ice-driven mass wasting [2]. Characterizing the fretted terrain with new data and assessing new ideas for its formation is important for understanding the long-term geologic and climate history, as viable formation mechanisms are directly tied to the nature of the climate on early Mars. Here, we assess the possibility that the fretted terrain formed by meltwater produced from the interaction of regional volcanic resurfacing with a widespread ice sheet proposed to cover the southern highlands in the Late Noachian icy highlands climate model [3,4].

Study Site: Protonilus Mensae (PM) (Fig. 1), one of the most well-developed areas of fretted terrain, is part of the northernmost section of the southern highlands, and is predominately middle to late Noachian in age [5].

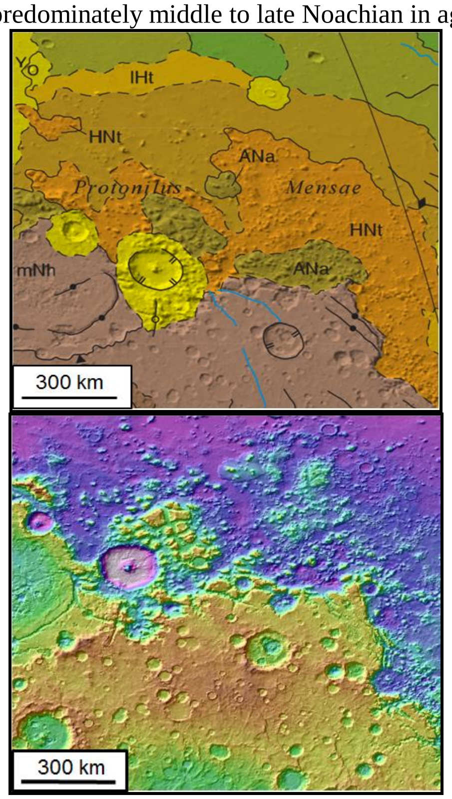

Figure 1a: Geologic map of the Protonilus Mensae region [5]. **1b:** Topographic map of the Protonilus Mensae region (MOLA 128-m topography). Centered on the coordinates of 43.86 N and 49.4 E.

PM borders the broad region of Arabia Terra to the west and south. This terrain is part of the transition zone between the hemispheres – the dichotomy boundary [5, Fig 1]. The dichotomy boundary in this region includes the fretted terrain, fretted channels, and younger debris-covered glaciers that have modified the older fretted channels and mesas (Fig. 2). Protonilus Mensae in particular contains a heavily dissected portion of the fretted terrain making up ~30% of the total.

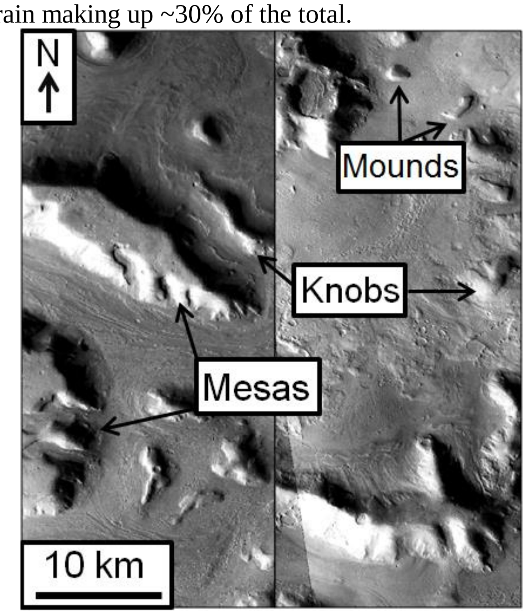

Figure 2: CTX images of the fretted terrain (including mesas, knobs, and mounded deposits) in increasing stages of degradation in Protonilus Mensae.

Stratigraphy and Geologic Setting: As originally defined [1], the fretted terrain seen in Protonilus Mensae is characterized by a complex series of features: 1) <u>mesas:</u> small, equidimensional islands of older highland material, 2) <u>plateaus:</u> larger, less equidimensional scarps, 3) <u>knobs:</u> smaller, more heavily altered embayments, and 4) <u>mounded deposits</u>: very small knolls of highland material that appear to be mostly eroded and lack cohesion, all of which are embedded in a smooth matrix of lowland material (Fig 2). Additional regional features include 5) <u>fretted channels</u>, sinuous, wide valleys with steep walls, flat floors, and unusually stout tributaries, as well as 6) <u>floor-fractured craters</u> and 7) <u>collapsed crater floors</u>, some of which are buried under younger lava flows and/or other burial mechanisms [1, 2]. The fretted channels of Protonilus lack sinuousity and appear to follow tectonic or structural trends rather than flowlines. These characteristics suggest that the formative processes have involved undercutting and collapse of large parts of the margin of the volcanic plateau, drainage of material and fluids to the north along at least some of the fretted channels, and removal of huge quantities of material intervening between the mesas.

The age of fretted terrain formation remains uncertain and has been estimated to be between the middle Noachian and early Hesperian [1-2, 5]. The mesa and plateau material that experienced dissection, most likely comprised of layers of pre- and early Noachian basement and mid-Noacian flood volcanics, predates fretting activity. The fretted terrain follows a pattern of decreasing size of the highland outcrops from south to north, as well as an increase in apparent erosive effectiveness (larger intervening areas), yielding to smoother, less ordered features. Many of the mesas in Protonilus Mensae directionally align with one another in pairs or groups, suggesting structural forcing [5].

Proposed Timeline: Protonilus Mensae experienced most of its deformation in Middle to the Late Noachian. Geologic interpretations of the region of Arabia Terra surrounding Protonilus Mensae suggest that two separate volcanic episodes formed the bulk of the plateau during the middle and late Noachian [5]. The second volcanic episode in the late Noachian produced ~150-200 m thick lava flows over ~ 8.3 X 10^6 km^2 of Arabia Terra in regionally distinct units. These volcanic episodes redefined the surface of Arabia Terra, and presumably interacted with the preexisting hydrological system that was active in the southern highlands during the late Noachian.

The two endmember models for the hydrological system and climate during the late Noachian are: 1) warm and wet (surface temperatures near or >273K) with vertical integration and surface meltwater [7, 8], and 2) cold and icy (surface temperatures ~225 K) with horizontal stratification and a global cryosphere [3-4, 13]. Previous work attempting to form the fretted terrain under warm and wet conditions has not conclusively resolved formation mechanisms due to the lack of a driving force for massive erosion and the absence of fluvial characteristics in the channels [1-2, 9]. No similar attempts have yet been made for the cold and icy scenario.

There are two possible mechanisms for producing meltwater from lava emplacement onto an ice sheet (Fig 3): 1) top-down contact melting at the intersection of the lava and ice and 2) deferred bottom-up melting at the ice sheet base from the addition of successive lava flows causing the melting geotherm to rise into the cryosphere or surface ice [10-11]. The distribution of water generated from these mechanisms depends on the thickness and emplacement times of the lava flows produced during the Noachian, including the length of time for emplacement and number of individual flows [10]. Estimates for ice sheet and late Noachian lava flow thicknesses suggest that both inputs existed south of Protonilus Mensae [12, 13]; e.g., later in the Amazonian this region was the locus for snow and ice emplacement over much of the plateau [14]. If the entire estimated thickness of the late Noachian volcanic episode (200 m) were emplaced rapidly onto a ~ 100 m thick ice sheet on the plains south of Protonilus, complete top-down melting and catastrophic subglacial outflow in regional sections could occur [10]. The resulting meltwater is estimated at 8.3 x 10^4 km^3, or 0.5 m GEL (2% of the total modern water inventory) based on the full amount of lava available in the late Noachian episode, and may then be released in a jökuhlaup-type scenario with highly erosive, high-volume discharge, producing the fretted terrain [15]. For the area of PM specifically, the resulting meltwater is 3.7 x 10^4 km^3, or 0.2 m GEL (roughly the volume of Lake Baikal).

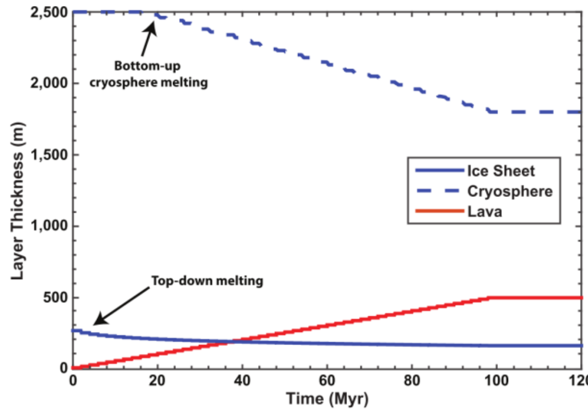

Figure 3: Top-down and subsequent bottom-up melting of the ice sheet and cryosphere from the incremental emplacement of a thick (500 m) lava flow over a 100 Myr timescale [10].

Interpretations and Outstanding Questions: The unique fretted features seen in Protonilus Mensae can feasibly be formed through expulsion of meltwater formed through volcanic activity melting an ice sheet that occupied portions of the southern highlands in the late Noachian. Instantaneous emplacement of the full thickness of the lava flow is sufficient to completely melt sections of the ice and allow for subsurface mobilization of meltwater in amounts that could plausibly remove the large volumes of material missing from the fretted terrain. It is possible that contemporaneous structural loading from the growth of the Tharsis province weakened target rock in the region, facilitating massive erosion by meltwater [16]. We are currently assessing the relative magnitude of these factors in shaping the fretted terrain.

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