EVOLUTION OF THE LATITUDE DEPENDENT MANTLE ON MARS: THICKNESS ESTIMATES AND EVIDENCE FOR CYCLICAL EMPLACEMENT AS REVEALED BY LATE AMAZONIAN GULLIES

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Introduction: While initial observations of gullies on Mars using Mars Orbiter Camera (MOC) data suggested that gullies appeared to always cross-cut or superpose adjacent features [1], higher resolution data provided by the High Resolution Imaging Science Experiment (HiRISE) has shown that while gullies are indeed very young [2], they frequently occur stratigraphically above and below units of the latitude dependent mantle (LDM) [3-6]. The LDM is a smooth unit that drapes much of the surface at mid- and high-latitudes, and is thought to represent the surface product of cyclical transport of ice from the poles to the mid-latitudes and back as the obliquity of Mars changes [7-8].

Understanding how gullies and the LDM interact with each other can provide valuable information regarding the water cycle of Mars in the Late Amazonian. In this contribution, we utilize new HiRISE stereo-derived digital elevation models (DEMs) to provide the first minimum thickness estimates of the LDM based upon its degradation and erosion by young gullies.

Gullies cross-cutting LDM fractures: The most common example of gullies occurring both above and below units of LDM occurs when older gully fans exhibit along-slope fractures, and that fan material is cross-cut by younger gully channels and superposed by gully fans without fractures [3-6, 9] (Figure 1). This relationship is common in both hemispheres (Figure 2) and provides evidence for multiple episodes of gully activity separated by at least enough time to degrade the initial fan to form the fractures. The LDM is considered to be ice-rich [7], and if these features are forming in the LDM, the rimless fractures are consistent with coalescence of sublimation pits with associated downslope movement on these steep slopes.

Recently acquired stereo image pairs from the HiRISE instrument allow for a quantitative assessment of the depth of these fractures (Figure 1), which provide a minimum estimate of LDM thickness. In the example provided in Figure 1, fracture depth ranges from sub-meter in pits that have not yet coalesced to form a continuous fracture, to 2.5 m at further developed fractures.

Gully-associated ridges: A less common but still globally distributed feature indicative of multiple gully events are downslope ridges found on slopes that also host classic mid-latitude gullies. These ridges appear to be inverted channel systems that share many of the morphological characteristics of gullies (sinuosity, inferred channel width, anastomosing patterns, etc.), in addition to their similar distribution. As shown in Figure 3, these ridges are exposed in the walls of younger gullies and show that they were emplaced before the most recent deposition of LDM material.

If these ridges do represent inverted channels, then the ridge crest represents the floor of the channel when the gully was incised. Calculations made on DEMs of this site show that these ridges are ~10 m in height on

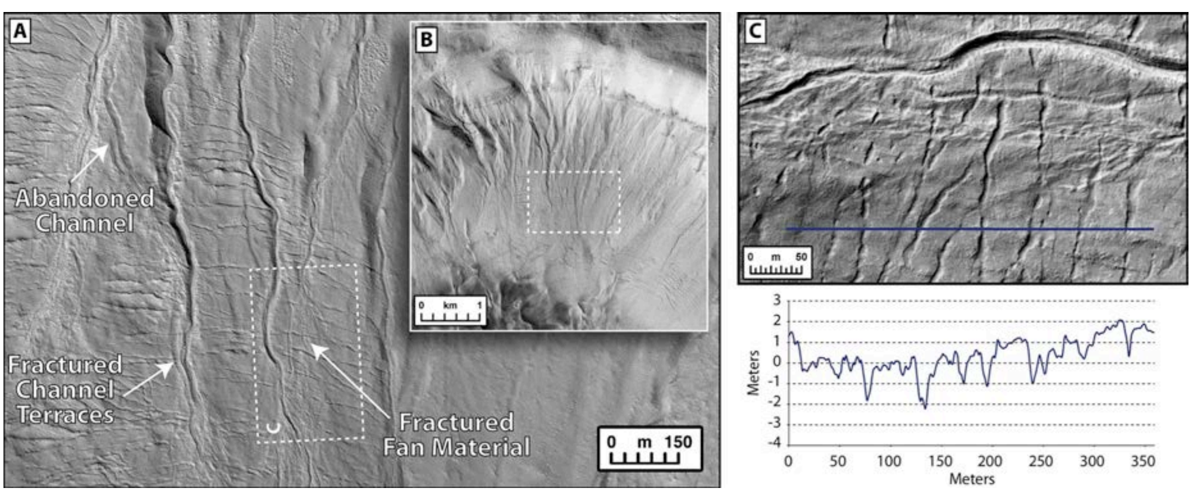

Figure 1. Typical example of multiple episodes of gully activity, separated by periods of mantle degradation. (A) HiRISE image PSP_005943_1380 showing along-strike fracturing of the LDM. (B) Context showing the pole-facing wall of a ~15 km impact crater at 41.5°S, 202.3°E. (C) Subframe showing older gully fan material that is fractured adjacent to a younger gully channel that is not fractured. Pits are generally ~1 m to ~2 m in depth. Profile extracted from USGS HiRISE DEM of PSP_005943_1380 and ESP_011428_1380.

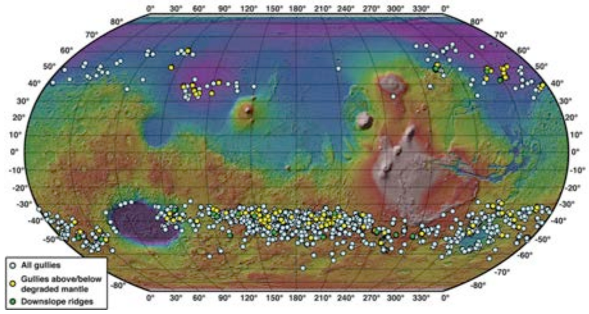

Figure 2. Global distribution of young gullies (blue), sites where gully activity both pre-dates and post-dates mantle degradation (yellow) and sites with sinuous ridges (green).

average, providing a minimum thickness of the mantle that has been lost. Total LDM thickness at this location was likely considerably higher than this value, depending upon the maximum channel depth at the time of emplacement.

Further evidence for significant LDM removal at this site is found when measuring the azimuth of the ridges that represent older gully activity compared to the azimuth of the younger gully channels (Figure 3). While the fresh gullies reflect the azimuth of the host crater wall at this location, the ridges are uniformly rotated to the north by an average of 17.1°. Thus, gully orienation at the time of maximum LDM thickness was controlled not by the underlying slope of the crater wall, but by the surface slope of the LDM itself. As the LDM degraded, gully azimuth eventually reflected the underlying host surface.

Implications: Gullies are the only features yet observed on Mars that both pre- and post-date LDM emplacement events. As such, they provide a unique opportunity to quantitatively assess the thickness and volume of LDM material. These stratigraphic relationships are relatively common in both hemispheres (Figure 2). Thus, the techniques described here may potentially be used to provide global assessments of LDM thickness during climate regimes more favorable to ice-accumulation at or near the surface than today.

References: [1] Malin and Edgett, 2000, *Science*, 288, 2330. [2] Schon et al., 2009, *Geology*, 37, 207. [3] Dickson and Head, 2009, *Icarus*, 204, 63. [4] Dickson et al., 2010, *LPSC*, 41, 1002. [5] Barbieri et al., 2010, *LPSC*, 41, 2745. [6] Dickson et al., 2013, *LPSC*, 44, 1012. [7] Head et al., 2003, *Nature*, 426, 797. [8] Laskar et al., 2004, *Icarus*, 170, 343. [9] Head et al., 2008, *PNAS*, 105, 13258.

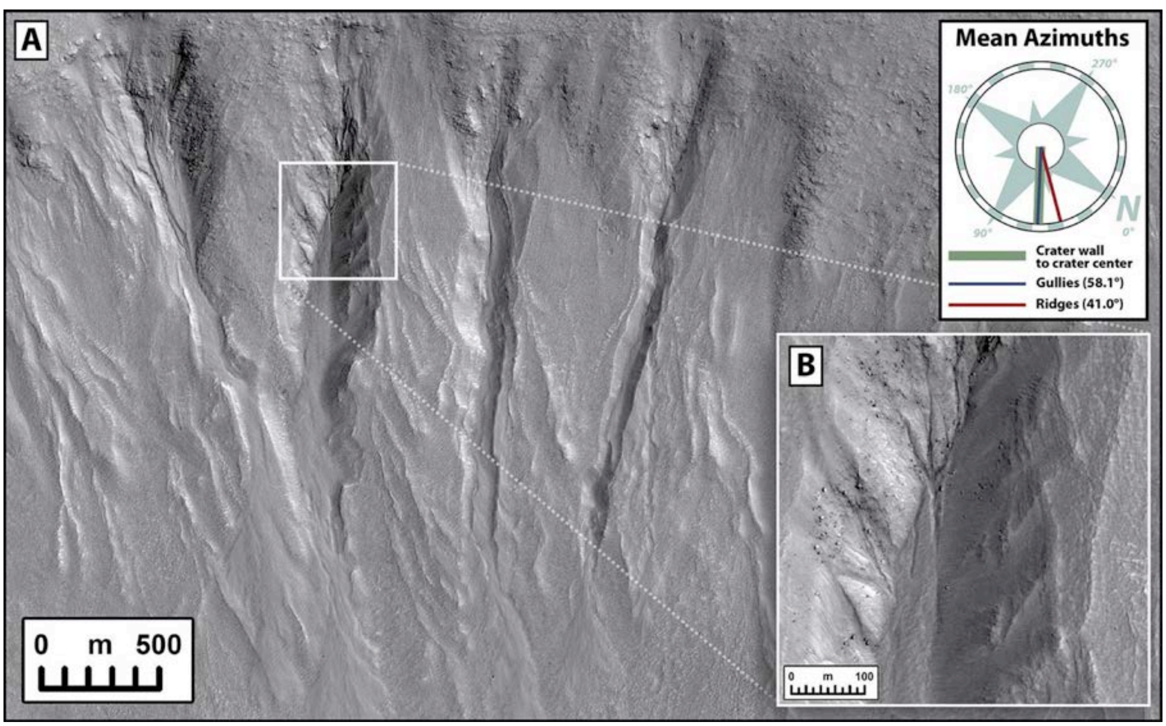

Figure 3. (A) Equator-facing slope of a ~27 km impact crater in the southern mid-latitudes of Mars (49.7°S, 13.9°E) seen in HiRISE ESP_022841_1300. Gullies erode the mantled slope, exposing ridges within the cross-section of the mantle. Azimuth measurements were performed on the four fresh gully channels and the ridges that occur along the same arc of the crater wall, revealing a 17.1° disparity in mean azimuth between the two, suggesting a different surface topography of the mantle when the two features were formed. (B) Inset showing the ridges exposed along the walls of the fresh gully channel. The ridges are separated in the stratigraphy by multiple layers of smooth mantle.