MARTIAN GULLIES AS STRATIGRAPHIC MARKERS FOR LATITUDE-DEPENDENT MANTLE EMPLACEMENT AND REMOVAL. J. L. Dickson[1], J. W. Head[1], L. Barbieri[2]. [1]Department of Geological Sciences, Brown University, Providence, RI (jdickson@brown.edu), [2]N.E. Center for Circus Arts, Brattleboro, VT.

Introduction: Mid-latitude gullies on Mars are strongly correlated at global [1-2] and local [3-4] scales with the latitude-dependent mantle (LDM), an ice-rich layer which drapes most of Mars poleward of 50° in each hemisphere and is dissected between 30°-50° [5-6], where the majority of gullies are found [7-12]. The erosional component of gully systems, the channel, only erodes the LDM and not the underlying bedrock [13], and some of this eroded material is preserved at the surface in the form of gully fans. Given the strong correlation between LDM and gully distribution, it has been proposed that the life cycle of young gullies is dependent upon the evolution of the LDM: If the LDM is removed through sublimation and eolian activity at low-obliquity, it takes the bulk of the record of gully activity that it hosted with it.

Numerical solutions for the orbital properties of Mars [14-15] predict that the LDM should go through cycles of emplacement and removal as a consequence of astronomical forcing over the last 10 Myr, driven by redistribution of polar volatiles in the mid-latitudes at high-obliquity and desiccation of the mid-latitudes at low-obliquity [6]. Unless the LDM is completely removed during these low-obliquity periods, one would expect to see a stratigraphic sequence at the surface that reflects these dramatic fluctuations in the orbital state of Mars, and some locations in the southern hemisphere reveal layering that may represent this cycle [16].

If the formation of gullies, no matter what causes them, is part of the mantle removal process, then gullies should post-date some episodes of mantle emplacement and pre-date successive episodes of emplacement. Two examples, to date, have documented stratigraphic relationships that may reflect this cycle. *Schon et al.* [17] found young gully fans that superpose secondary craters that impacted onto older fan material, while we documented an example of gully channels/fans cross-cut by fractures within the mantle and gully channels that in turn cut those fractures [2], proving that gullies at these locations could not have formed in a single event. If mantle evolution is controlled by astronomical forcing of polar volatiles, relationships of this type should be unexceptional.

Therefore, we set out to document further examples of stratigraphy within gully systems that require episodic gully activity and cyclical emplacement of ice-rich mantling material at high-obliquity and desiccation of this layer at low-obliquity, with gullies representing just one mode of mantle erosion/removal. As we show below, these relationships are common.

Survey: While conducting a CTX survey investigating ice-related features that spanned 10,261 images total between 20°-60° latitude in each hemisphere [18], we noted all occurrences of recent gully activity. HiRISE footprints that overlapped with these locations were isolated and used for this investigation, totaling 479 acquisitions through MRO orbit 24000. Gullies were classified as to whether they showed evidence for stratigraphy, and what the stratigraphic relationship was (mantle fracturing, secondary crater populations, etc.).

Results: Of the 479 HiRISE images of gullies in this study, 108 showed distinct examples of multiple episodes of gully activity (Figure 1), separated stratigraphically by decay of the LDM, in which lower units of gully fan material are fractured by mantle-related processes and upper units of gully fan material are not (Figure 2). With only one exception in northern Utopia, all of these examples are equatorward of 53° latitude, where the dissected nature of the mantle at these lower latitudes reveals these older gully units in the stratigraphy. The longitudinal distribution of these stratigraphic relationships correlates well with the general population of gullies in the lower mid-latitudes of each hemisphere [7-12], with no evidence for distinct clustering.

While no more examples of stratigraphic relationships with secondary crater clusters were observed, in 20 separate locations we documented examples of linear/sinuous ridges that trend down steep slopes and are found in close proximity to gully channels. With regard to morphology and distribution, they share all of the same properties of traditional gully channels. We consider two hypotheses reasonable for their emplacement: (1) They represent inverted gully channels, where coarse material was transported and concentrated in channel floor and remained in place while the mantle into which the channel was carved was removed, and (2) they are remnants of levees from previous generations of high-energy, high sediment/water ratio debris flows. Both hypotheses could be accurate for separate examples and both necessitate multiple episodes of gully activity at these locations.

In one example (Figure 3), these ridges are cut by recent gullies, exposing a cross-section of the LDM and allowing us to place these ridges in their proper stratigraphic context. These ridges were emplaced on an older generation of LDM, and have been buried at their upslope extent by a more recent generation of LDM. This more recent generation of LDM was then incised by the youngest feature within the scene, the gully channels. Given this stratigraphy, we are confident that documentation of these downslope ridges is documentation of multiple episodes of gully activity, whether they represent inverted gully channels or remnant leveed channel walls. In close proximity to the downslope ridges observed in Figure 3 are mantled examples of leveed channel walls that yield debris flow-like tongues on the floor of this crater (Figure 4). This is a morphology not observed with classic young gullies [7], suggesting that, at least at this location, Mars was more capable of debris flow activity in its past than it has been during this most recent phase of gully activity. If this example is representative across the mid-latitudes of Mars, then it would suggest that the recent observations of contemporary gully activity on Mars [18-21] may not be sufficient to explain the higher-energy events that may have initiated these features in the first place.

Conclusions: These results confirm initial observations [2,17] that show that gullies are intimately associated with the evolution of the LDM. More specifically, gullies are one mechanism by which the mantle is dissected and eroded, which explains their strong concentration at lower mid-latitudes (30°-50°), where ice that is deposited as part of the LDM is not stable over successive orbital cycles.

References: [1] Milliken, R. et al. (2003) *JGR,* 108, 5057. [2] Dickson and Head, 2009, Icarus. [3] Schon, S. and Head, J. (2012) *Icarus,* 218, 459. [4] Raack, J. et al (2012), *Icarus*, 219, 129. [5] Mustard et al. (2001) *Nature*, 412, 411. [6] Head, J. et al. (2003) *Nature*, 426, 797. [7] Malin, M and Edgett, K. (2000) *Science,* 288, 2330. [8] Heldmann, J. and Mellon, M. (2004) *Icarus*, 168, 285. [9] Balme, M. et al. (2006) *JGR*, 111, 5001. [10] Bridges, N and Lackner, C. (2006) *JGR*, 111, 9014. [11] Dickson, J. et al. (2007) *Icarus*, 188, 315. [12] Heldmann, J. et al. (2007) *Icarus*, 188, 324; [13] Dickson et al. (2010), *LPSC*, 41, 1002. [14] Laskar, J. et al. (2002) *Nature*, 419, 375. [15] Laskar, J. et al. (2004) *Icarus*, 170, 343. [16] Schon, S. et al. (2009) *GRL*, 36, L15202. [17] Schon, S. et al., *Geology*, 37, 207. [18] Dundas et al. (2010), *GRL*, 37, L07202. [19] Diniega, S. et al (2010), *Geology*, 38, 1047. [20] Reiss, D. et al. (2010), *GRL*, 37, L06203. [21] Dundas, C. et al. (2012), *Icarus*, 220, 124. [22] Head, J. et al. (2008), *PNAS*, 105, 13258.

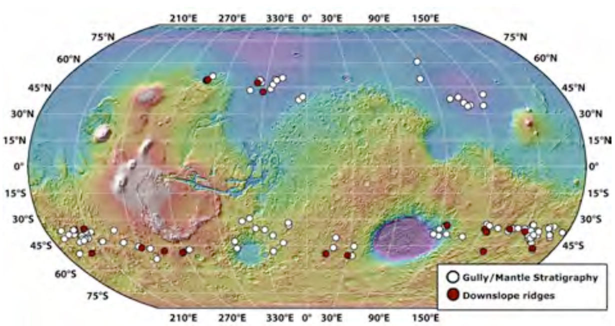

Figure 1. Global distribution of gullies that show evidence for episodic activity (N = 108).

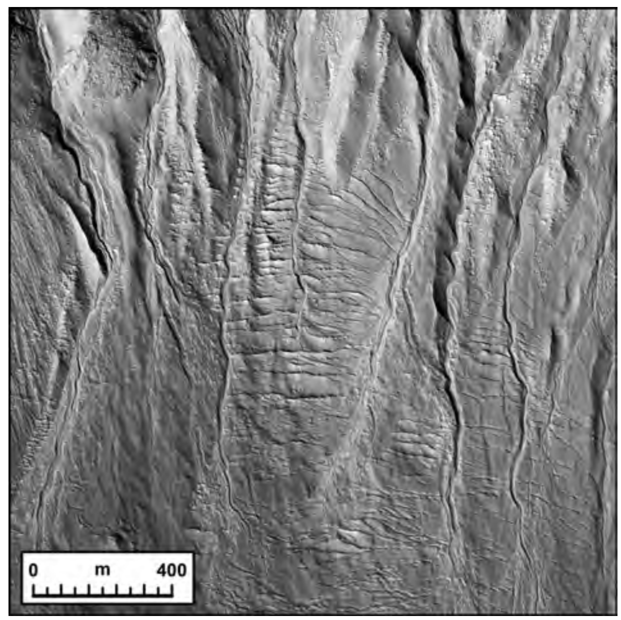

Figure 2. Typical example of gully fans cross-cut by fractures in the LDM, which are then cut by more recent gullies (similar to [2,22]) (ESP_011428_1380).

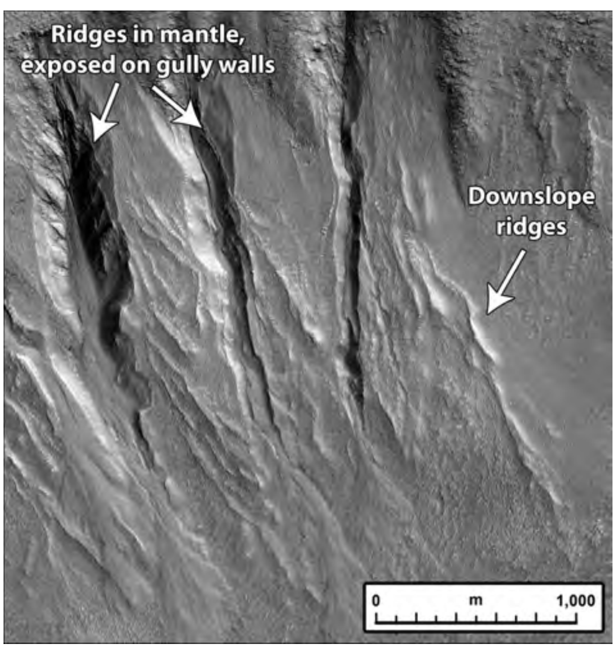

Figure 3. Ridges trending downslope in close proximity to young gully channels. Channels expose LDM in cross-section, revealing buried ridges (ESP_022841_1300).

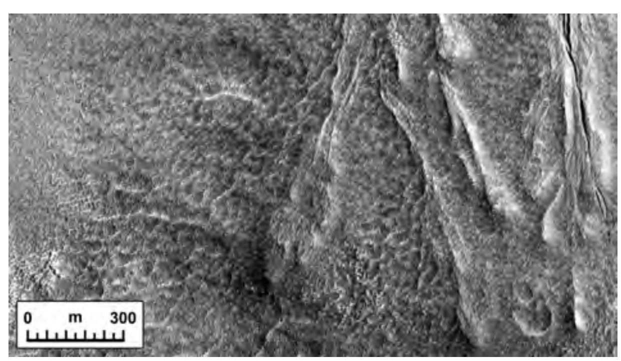

Figure 4. Leveed channel yielding a debris flow-like tongue deposit at the base of a crater wall. All features are mantled by recent LDM (ESP_022841_1300).