GULLIES EMANATING FROM THE MARGINS OF LOBATE FLOW FEATURES IN NEREIDUM MONTES, MARS. Daniel C. Berman[1], David A. Crown[1], and Susan J. Conway[2], [1]Planetary Science Institute, 1700 E. Ft. Lowell Rd., Suite 106, Tucson, Arizona 85719 (bermandc@psi.edu); [2]CNRS, UMR 6112 Laboratoire de Planétologie et Géodynamique, Université de Nantes, France.

Introduction: Gullies on Mars have been documented on sloped features such as crater interior and exterior walls, hillslopes, pit and channel walls, and dune slopes [1,2]. Here we document evidence for well-developed gullies on the margins of lobate flow features, which are suggested to be glacier-like forms and contain large amounts of water ice. These observations are consistent with the formation of gullies due to melting of water ice, contrary to competing hypotheses of dry flows [e.g., 3] or carbon dioxide frost [e.g., 4-6].

Gullies: Gullies on Mars generally consist of three components: a head alcove, an incised channel, and a depositional apron [1]. They are commonly found in the mid- to high latitudes (~30-80 degrees) and show a preference for pole-facing orientations [2]. Previous work has demonstrated a spatial relationship between gullies and ice-rich flow features [e.g., 7-11], however debate regarding aspects of their relationship remains.

Lobate flow features: Lobate, viscous flow features (also known as glacier-like forms, GLFs) are observed on slopes (e.g., crater walls and hills) throughout the southern mid-latitudes [e.g., 8, 12-20]. These features are typically bound by moraine-like ridges and their surfaces are commonly pitted and contain lineations and crevasses. The size and shape of the lobes are controlled by local topography. They are generally thought to be derived from downslope movement of ice-rich mantling deposits [7, 8, 14] and have been interpreted to be debris covered glaciers or rock glaciers [13, 15-17].

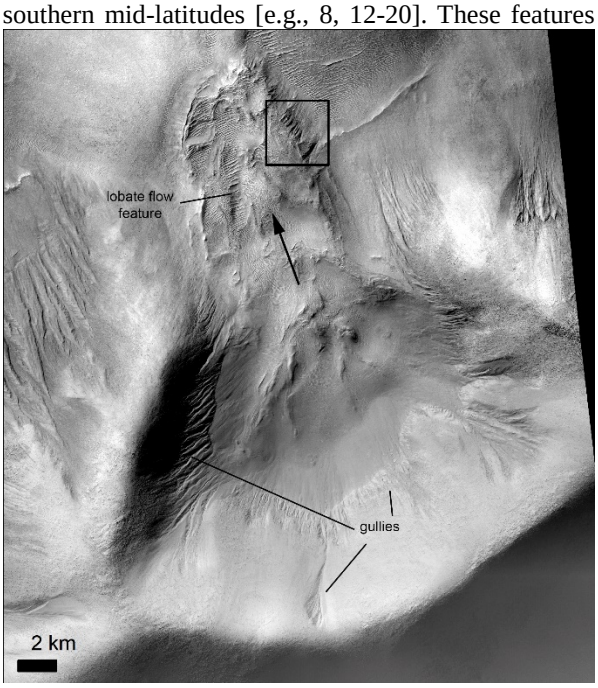

Figure 1. Portion of CTX image P16_007218_1335 showing a lobate flow feature extending from an alcove on a massif. Gullies are observed on the alcove walls. Black arrow indicates inferred glacial flow direction. Black box indicates location of gullies at the lobe margin of the flow, shown in detail in Fig. 2.

Nereidum Montes: Nereidum Montes, along the northern rim of Argyre basin (~35°-45°S, ~300°-330°E), contains large concentrations of ice-rich flow features. Many lobate flows in this region retain clear examples of well-preserved ice-rich deposits within their margins, rather than deflated and/or degraded morphologies as are commonly observed elsewhere. Large viscous flow features observed emanating from massifs contain surface flow features such as lineations, crevasses, and lobate margins [e.g., 18].

Berman et al. [20] documented a SHARAD radar observation over a lobate flow feature in Nereidum Montes that revealed a reflector not observed in simulations, indicating a high ice content within the lobe. Surface textures of this flow feature (e.g., flow lineations) are also consistent with a debris-covered glacier. This suggests that similar lobate flow features in the region may have high ice contents as well.

Gullies on lobate flows: We have documented evidence of gully alcoves, channels, and aprons at the margins of several lobate flow features in the Nereidum

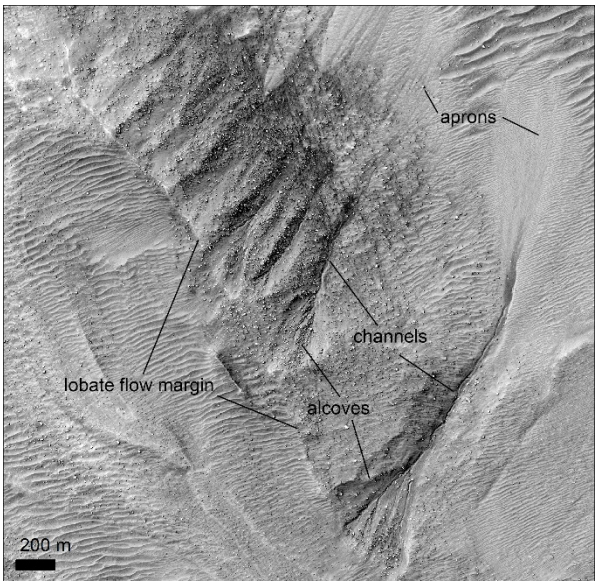

Figure 2. Portion of HiRISE image ESP_058223_1335 showing gully alcoves, channels, and aprons emanating from the margin of the lobate flow shown in Fig. 1.

Montes region. Fig. 1 shows a large lobate flow emanating from a massif alcove. Gullies can be observed around the margins of the alcove where smooth mantling deposits appear. The lobate flow has a ridged moraine-like margin and its surface is partially obscured by aeolian ridges. Fig. 2 shows a closeup of the northeastern margin of the lobate flow, with gully alcoves, channels, and aprons observed along its margin. Fig. 3 shows a large number of angular blocks on the surface of the flow feature. These blocks are found throughout the surface of the feature, including the terminus, far from the potential source hillslope, where these blocks are more numerous and more concentrated, suggesting they were carried by glacial flow. Figs. 4 and 5 show additional examples of gullies on lobate flow margins in the Nereidum Montes region.

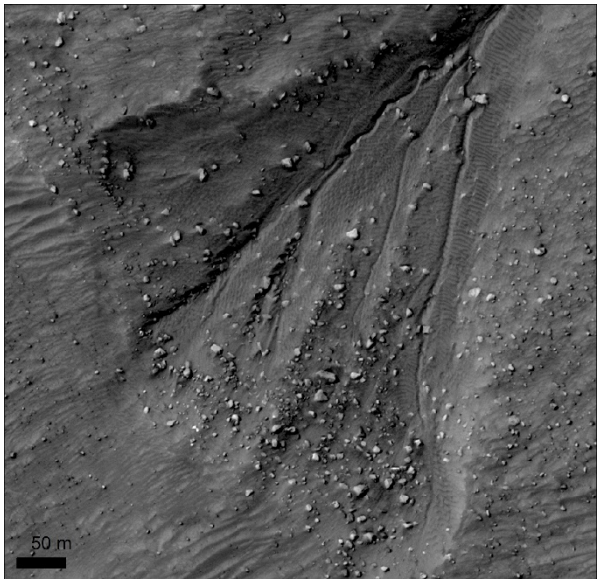

Figure 3. Closeup of gully alcove and channel shown in Fig. 2. Note numerous surface blocks.

Conclusions: The presence of gullies on the margins and fronts of lobate flow features that are likely composed of nearly pure water ice strongly suggests that the gullies formed due to the melting of that ice. The exact mechanism is unclear, but could be similar to melting of ice-cored moraines on Earth [e.g., 21] or release of trapped volatiles [e.g., 22]. These observations also are not consistent with a groundwater source for gully formation, but suggest rather an atmospheric source.

References: [1] Malin, MC and KS Edgett (2001), *JGR 106(E10)*, 23429-23570. [2] Harrison, TN et al. (2015), *Icarus 252*, 236-254. [3] Treiman, AH (2003), *JGR 108(E4)*. [4] Cedillo-Flores, Y et al. (2011), *GRL 38(21)*. [5] Dundas, CM et al. (2015), *Icarus 251*, 244-263 [6] Núñez, JI et al. (2016), *GRL 43(17)*, 8893-8902. [7] Berman, DC et al. (2005), *Icarus 178*, 465-486. [8] Berman, DC et al. (2009), *Icarus, 200*, 77-95. [9] Reiss, D et al. (2009) *PSS 57*, 958-974. [10] Conway, SJ et al. (2018) *Geomorphology 318*, 26-57. [11] Conway, SJ et al. (2018), *GSL 467*, SP467-14. [12] Milliken, RE et al. (2003), *JGR 108*. [13] Hartmann, WK et al. (2014), *Icarus 228*, 96-120. [14] Head, JW et al. (2003), *Nature 426*, 797-802. [15] Whalley, WB and F Azizi (2003), *JGR 108(E4)*, 8032. [16] Arfstrom, J and WK Hartmann (2005), *Icarus 174*, 321-335. [17] Sounness, C et al. (2012), *Icarus 217*, 243-255. [18] Hubbard, B et al. (2014), *Cryosphere 8*, 2047-2061. [19] Brough, S et al. (2019), *EPSL 507*, 10-20. [20] Berman, DC et al. (2018), *LPSC 49*, #1544. [21] Ewertowski, MW and AM Tomczyk (2015), *Geomorphology 234*, 211-227. [22] Bollati, IM et al. (2019), *Geomorphology 327*, 248-263.

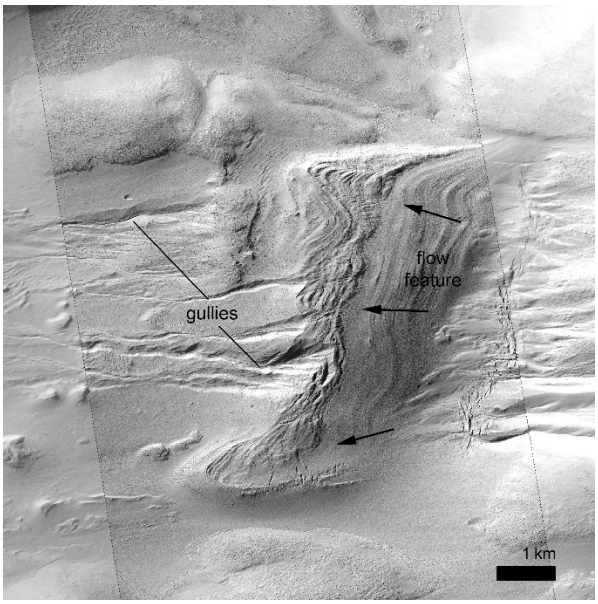

Figure 4. Portion of HiRISE image ESP_017265_1345 over CTX mosaic showing an ice-rich flow feature with a lobate front with gullies emanating from it. Black arrows show flow direction, with massif out of view to the right.

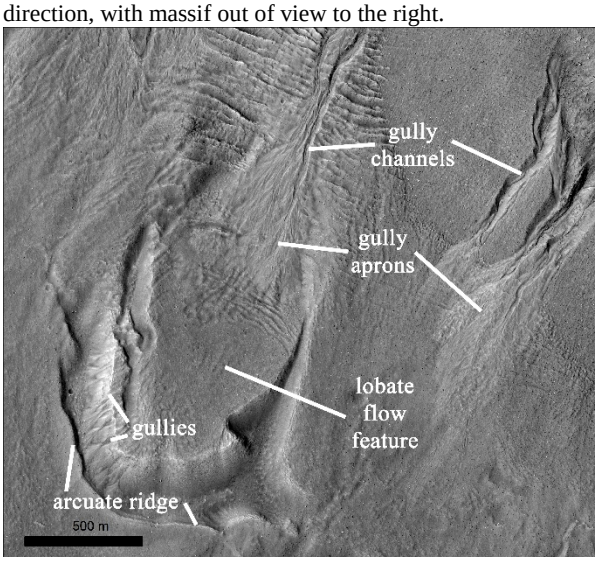

Figure 5. Portion of HiRISE image ESP_039643_1400 showing a lobate flow feature with gullies, an arcuate ridge, and smooth mantling deposits, with additional gullies dissecting its front.