Morphology-derived Constraints on Martian Linear Gully Formation Mechanics. S. Diniega[1], M. Bourke[2,3], C.J. Hansen[2], J. McElwaine[4], J. Nield[5], K. Morales[6], M. Austria[7]. [1]Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove, Pasadena, CA 91109; serina.diniega@jpl.nasa.gov), [2]Planetary Science Institute, [3]Trinity College Dublin (Ireland), [4]Durham University (UK), [5]University of Southhampton (UK), [6]University of Southern California, [7]California Institute of Technology.

Background: Since "linear gullies" (LG) were first identified on the martian surface [1], these long, relatively uniform-width troughs (Fig. 1) have engendered much debate about their formation mechanism. Although likened to terrestrial debris flows and originally proposed to be formed by surface water flow due to meltwater following during a period of high obliquity [2-5] or present-day atmospheric condensates [6], their lack of debris aprons (and instead ending abruptly or with pits; Fig. 1) and observation of present-day linear gully activity [7,8] did not support this theory – in particular,

- laboratory experiments were unable to generate similar morphology without a careful (and likely physically unrealistic) adjustment of boundary and input conditions [8-11], and
- a source for water extruded from the *tops* of these dunes remained unexplained (and at the volumes estimated from morphology [2,5], which is orders of magnitude larger than what may be available [12]).

Instead, [13] proposed that these features are more similar to boulder-tracks (explaining the trough morphology) formed due to a block of seasonal carbon dioxide ice (i.e., "dry ice") that breaks off from the seasonal frost layer during the springtime sublimation and falls onto the warmer dune sand. Sublimation at the base of this dry ice then lifts the block (i.e., the Leidenfrost effect), allowing it to roll or slide down the dune slope, carving out a trough. Upon stopping, the dry ice block would continue to sublimate, digging out a pit that then would be the remaining record, as the block disappears. Field experiments on terrestrial dunes [13-16] and laboratory experiments [17] that examine pit formation have shown that it is feasible for the "hovercrafting dry ice block" model to broadly produce the observed LG morphologies.

However, questions remain about environmental conditions and controls, and the interpretation of individual LG morphology characteristics/measurements. These include:

- why are pits generally wider than the parent trough?
- is there a "typical" length formed within one Mars winter and/or what controls the length of a LG?
- how is sinuosity developed within these troughs – is it due to repeat activity, the nature of the block movement (e.g., rolling), and/or characteristics of the parent dune-slope?
- is the small-scale present-day LG activity [7,8,18] (Fig. 2) similar to/consistent with past activity?

As dry ice does not naturally form on the Earth's surface and no terrestrial analog has been identified for the proposed dynamics involved in the formation of martian linear gullies [13], we aim to constrain our conceptual model of LG formation and evolution via observations of linear gullies on Mars – focusing on their morphology and activity, and in particular differences detected at the regional scale on Mars. Our aim is to correlate differences in the LG activities and morphologies to regional environmental differences, and from that (assuming a causal connection) to refine the LG formation model.

Our study: The first survey of martian linear gullies [18] identified three regions containing linear gullies – referred to here as Hellespontus-region, Aonia Terra-region, and Jeans Crater-region. As shown in Table 1, Hellespontus- and Aonia Terra-regions are both in the southern mid-latitudes, but on opposite sides of the planet; Jeans Crater-region is in the southern polar region. Furthermore, these LG are found on the slopes of dunes with a range of shapes and sizes.

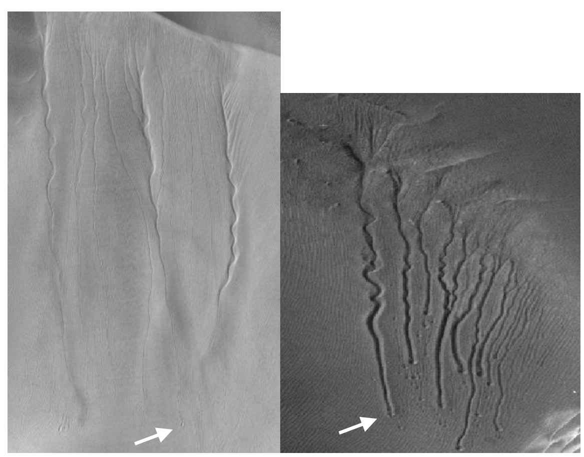

Figure 1. Examples of linear gullies: primarily composed of a trough of near-constant width, sometimes bounded with small levees. Most have no or a very diffuse alcove (left), but some have well-defined alcoves (right). All end abruptly or with pit(s) (e.g., see arrows) which could be attached to the trough or e.g., a disjoint chain of pits. HiRISE images ESP_030624_1295 (Aonia Terra) and ESP_020467_1305 (Hellespontus) (NASA/JPL/UA).

This survey measured the morphology of six linear gully sites within the Hellespontus-region (including Russell Cr.). For our study, *we have examined an additional seven sites, distributed through all three regions* (Tab. 1). We have collected morphological measurements (similar to those collected in [18]) and evidence of present-day activity, over the last four Mars years.

We find the same general trends that have been previously reported – such as that all LG are on south-facing (or pole-facing) slopes. Combining our results with those of [18], we also have identified some key differences in the morphologies and activities within the range of LG sites. Some LG differences appear connected to the region – and we hypothesize that these are due to differences in the environmental conditions found within these three regions, related to their latitude and general geologic context. Additionally, we find that some LG differences appear connected to differences in the parent dune slope's local topography and orientation, which relate to seasonal frost/ice accumulation. We use this information to generate additional constraints for the physical model of LG formation and evolution.

References: [1] Mangold et al., 2002, *at* EGS Gen. Assem. Conf., vol. 27, 3080. [2] Mangold et al., 2003, *JGR* 108 (E4), 5027. [3] Miyamoto et al., 2004, *GRL* 31 (13), L13701. [4] Mangold et al., 2010. *JGR* 115 (E14), E11001. [5] Jouannic et al., 2012, *PSS* 71, 38–54. [6] Reiss et al., 2003, *GRL* 30 (6), 1321. [7] Dundas et al., 2012, *Icarus* 220 (1), 124–143. [8] Reiss et al., 2010, *GRL* 37 (6), L06203. [9] Coleman et al., 2009, *PSS* 57, 711–716. [10] Conway et al., 2011, *Icarus* 211, 443–457. [11] Védie et al., 2008, *GRL* 35, L21501. [12] Vincendon et al., 2010, *JGR* 115 (E14), E10001. [13] Diniega et al., 2013, *Icarus* 225, 526-537. [14] Bourke et al., 2016, *at* LPSC 47, Ab. 2407. [15] Bourke et al., 2016, *at* EGU 2016. Ab. 10450. [16] Bourke, et al., 2016, *at* The Geologic Society (London, UK). [17] McKeown et al., *submitted*, [18] Pasquon et al., 2016, *Icarus* 274, 195-210.

Acknowledgements: This work was funded by MFRP grant, and relies heavily on JMARS. We also thank the JPL/Caltech/NASA Education Programs (SURF & NASA UI) for enabling the student contributions.

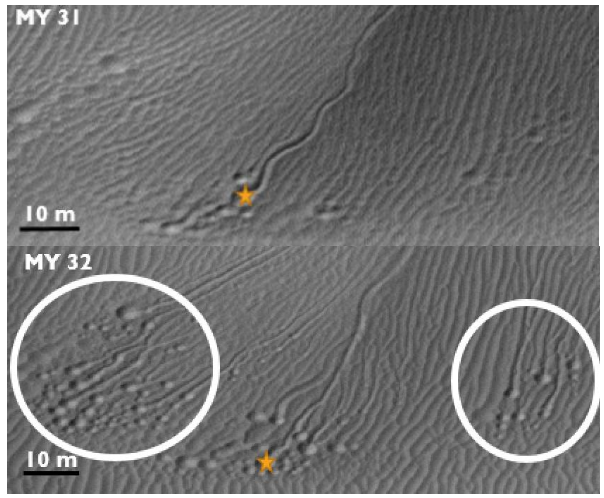

Figure 2. Present-day activity seen in field 16/Hellespontus-region: pit formation (see circled differences between top and bottom image: the star indicates the same location) sometimes accompanied by trough formation/elongation. There are also changes in channel sinuosity above the star. HiRISE images ESP_024950_1325 (L_s 33 MY 31) and ESP_038453_1325 (L_s 211 MY 32) (NASA/JPL/UA).

Region, # LG sites, # LGs meas.	ID [from 18] (location) of LG site	Some linear gully (LG) characteristics
Hellespontus (52°S, 23°E), 10, 32	16 (47.2°S, 34°E) 19 (49°S, 27.2°E) 24 (51°S, 18°E)	• Most lengths are 100-500m • Mix of sinous and straight LGs within an area • Many pits, including many new pits • Some trough formation or elongation; changes in sinuosity • Generally initiate at dune brink
Aonia Terra (50°S, 294°E), 3, 15	23 (50.3°S, 292.1°E)	• Most lengths of 300-800 m • LGs found within clusters, and of similar length within a cluster • Mix of sinuous & straight LGs within same cluster • Sometimes start partway down dune slope • No activity observed
Jeans Crater (70°S, 153°E), 6, 11	30 (64.5°S, 158.3°E) 32/Jeans (69.5°S, 27.2°E) 33 (70.35°S, 178.2°E)	• Long (some >2 km) and wide LGs • Longest LGs follow the lowest-point "between" the dunes (i.e., run parallel to dune crests) towards the edge of the dune field • Few pits are visible • No activity observed

Table 1. LG sites examined, and some of the measurements that suggest inter-regional differences.