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# Small-scale lobes on Mars: solifluction, thaw and clues to gully formation.

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**Abstract:** The existence of solifluction lobe-like landforms on Mars may, potentially, have important implications for our understanding of the distribution of thaw liquids and its geomorphic effects in recent climate history. In this study we made an inventory of all HiRISE images between 40°S-80°S acquired between 2007 and 2013 and show their distribution and their close spatio-temporal relationship to other ice-related landforms such as gullies and polygons. Based on Earth-analog studies and landscape analysis we conclude that a hypothesis of freeze/thaw may better explain their origin then current ”dry” models.

**1. Introduction:** Small-scale lobes (SSL) on Mars are landforms that show remarkable morphologic resemblance to terrestrial solifluction lobes [1,2]. Solifluction is the net downslope movement of soil driven by phase changes of near surface water due to freeze-thaw activity [3]. SSL on Mars consists of a clast-banked arcuate front (riser) tens to hundreds of meters wide [1]. Risers are typically decimeters to a few meters (<5m) in height and the tread surface is relatively clast free [1]. SLL often display overlapping of individual lobes. Hitherto SLL's have only been studied in detail in the northern hemisphere on Mars [1,2,4-6] where they have been found to be latitude-dependent landforms [1,2]. In contrast, only a few observations have been made in the southern hemisphere [7,8]. Several authors argue for a freeze-thaw hypothesis for SSL formation on Mars [1,2,4-8]. If this interpretation is correct, the implication is significant since it would require transient $H_2O$ liquids over large areal extents. Thus a better understanding of SLL will allow identifying environments that possibly may have experienced transient liquid water in the shallow subsurface.

This study aims to determine the distribution of SSL in the southern hemisphere and to investigate their relationship to other landforms with possible ground ice affinity such as patterned ground, polygonal terrain and gullies. Collectively, these landforms may be linked to phase changes of water at the surface or in the shallow subsurface.

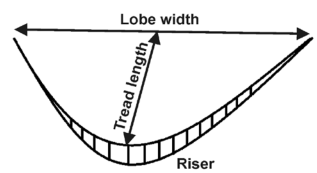


Figure 1. Sketch showing the lobe components. Lobe front points downhill.

**2. Data and methods:** We used images obtained by the High Resolution Imaging Science Experiment (HiRISE) that has a spatial resolution of ~25–50 cm/pixel. We catalogued and investigated all available HiRISE images that were acquired between 2007 and 2013 in the latitude band 40°S and 80°S on Mars. A total of 2200 HiRISE images have been studied in detail. For comparison to terrestrial solifluction lobes we used the airborne High Resolution Stereo Camera (HRSC-AX) [9]. The benefits of using HRSC-AX are its ability to render detailed DTM's and a similar pixel size (20 cm/pixel) as HiRISE.

**3. Observations:** SLL's are observed on impact crater walls. SLL's observed in HiRISE (n: 30) show a close spatial association with gullies (77%) and polygonal terrain (47% [Fig. 2]). Moreover some lobes are superposed by striped patterns (Fig. 3). Stripes were also observed separately from SLL but within the same crater environment. On Earth stone stripes and sorted stone stripes are landforms that develop in the active layer, a layer that undergoes seasonal and/or diurnal freezing and thawing. SLL's are often, but not always, associated with slopes covered by latitude-dependent mantle (LDM) [10]. Several SLL locations show evidence of dissected mantle (26%). Moraine-like landforms were observed at ten locations (25%).

**4. Discussion and conclusions:** Here we show that the distribution of SLL in the southern hemisphere roughly mirrors that in the northern hemisphere distribution. Hence, SLL are hemispherically bimodal-distributed landforms, similar to polygonal terrain [e.g. 6] and gullies [e.g. 12]. However, despite more abundant sloping terrain in the southern hemisphere, fewer SLL are observed. This is in contrast to gully landforms which are more abundant in the southern hemisphere.

Martian gully landforms and their formative processes have received considerable attention in the last decade and there are currently conflicting ideas whether liquid water [e.g. 13] or $CO_2$–triggered mass wasting [e.g. 14] are the primary agents of erosion. As there are no $CO_2$ frost triggered hypotheses that can explain the occurrence of SSL, a thaw-based hypothesis could explain both landforms. In this scenario gullies and SLL may form a hydrologic continuum where available water content governs the type of landform produced. Solifluction would require ice lens formation (excess ice) to develop. Excess ice was encountered by the Phoenix Lander in 2008 [15]. Furthermore, modelling attempts may suggest that ice lenses could be widespread on Mars [16]. However more work is needed to understand the physical environment related to the $CO_2$ paradigm and the full suite of slope landforms predicted by it. Hence, we suggest that any model to explain gully formation must incorporate the geomorphologic context in which they occur.

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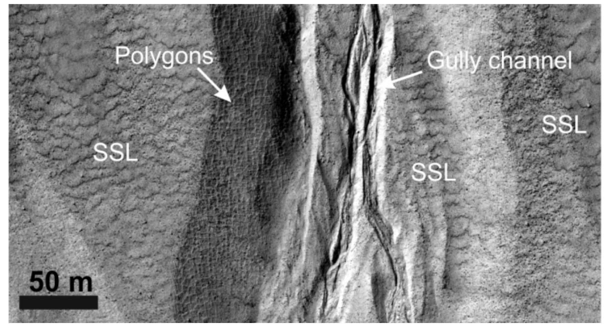

Figure 2. SLL, polygons and gullies in Ruhea crater (43.26°S/173.08°E). Fresh appearing gully channels with polygonal patterns on the gully walls. SLL dominate the scene covering the adjacent walls with overlapping lobes. The stratigraphy suggest close temporal relationship.

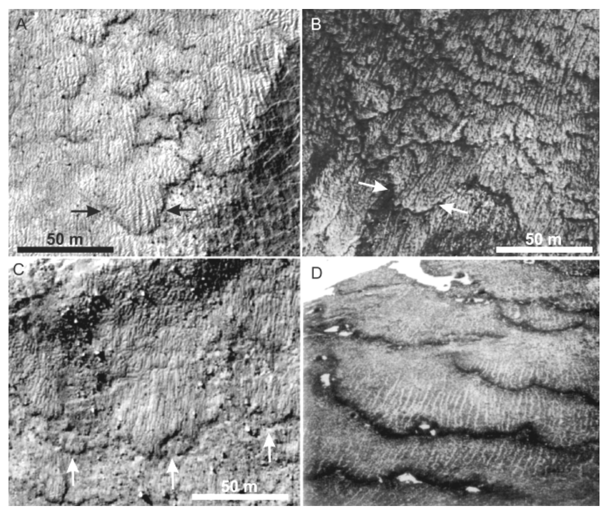

Figure 3. Examples of martian SSL and solifluction lobes on Earth. A) SSL in Ruhea crater, Mars. Overlapping lobes superposed by striped pattern. Note the polygonal terrain in lower right corner. B) Solifluction lobes superposed by stone stripes in Adventdalen, Svalbard. C) SSL in unnamed crater, Mars (45.42°S/25.74°E). Stripes are seen on the lobes. D) Solifluction lobes in New Zealand superposed by sorted stone stripes. Lobe front ~25 cm high (modified from [17])