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Small-scale lobes in the southern hemisphere on Mars: Implications for transient liquid water in the recent past.

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Abstract
We have catalogued small-scale lobes in the southern hemisphere on Mars. Small-scale lobes are restricted to crater walls and hillslopes but are morphologically distinct from viscous flow features (VFF) or other putative glacial landforms. Instead they show striking resemblance to terrestrial solifluction lobes. Previously it was shown by several authors that they are common in the northern mid and high latitudes. Here we show that they represent a hemispherical bimodal and latitude-dependent landform such as gullies and polygonal terrain. We hypothesize that they form by freeze-thaw activity and represent geomorphologic indicators for repeated transient liquid water close to the ground surface in Mars recent climate history.

1. Introduction
On Earth, solifluction is a common slow mass-wasting process in permafrost regions (Fig. 1). The main solifluction processes include frost creep, and/or gelifluction which occur within the seasonally thawing and freezing soil layer on top of permafrost [Matsuoka, 2001]. On Earth solifluction lobes are strong indicators of past or present freeze-thaw activity. As such they may represent a useful source of paleoclimatic information [Åkerman, 2005].

Figure 1: Examples of stone-banked solifluction lobes in Ugledalen, Svalbard. Lobes are approximately 10 m wide.

Previously, well-preserved small-scale lobes were reported in the northern mid-and-high latitudes on Mars by several authors [Balme et al., 2013 and references therein]. Based on morphology and integrated landform analyses [Gallagher et al., 2011; Gallagher and Balme, 2011], morphometry and Earth-analogue studies [Johnsson et al., 2012] the proposed mechanism is by solifluction. By implication, this suggests active-layer formation and transient liquid water close to the surface at repeated times in the recent climate history on Mars in contrast to general climate modeling [Kreslavsky et al. 2008].

Previously, small-scale lobes have only been observed at a few sites in the south using Mars Orbiter Camera (MOC) images [Mangold, 2005]. The first question we ask is therefore: what is the distribution of small-scale lobes on southern Mars as seen in HiRISE and CTX datasets? Secondly, is there a link to other mass wasting landforms that have been associated with melting of ice/snow such as gullies? And thirdly, how do the southern small-scale lobes compare to the northern counterparts?

2. Data and method
In this study we extend our search to the latitude band 40°S and 80°S on Mars. We have investigated all available HiRISE that were acquired between 2007 and 2013. A total of 2200 HiRISE images have been studied in detail. The Charitum Montes region contains a high concentration of small-scale lobes but HiRISE coverage is sparse. Here we used 20 CTX images for our mapping.

3. Observations and results
Like the northern counterparts, the observed small-scale lobes in the south show striking similarities to solifluction lobes on Earth (Fig. 2) and they are typically located in a context associated with thermal

contraction polygons and gullies. The small-scale lobes are tens to hundreds of meters wide with well-defined lobe fronts (risers). The risers are in the order of decimeters to a few meters high (<5m). Individual lobes overlap or occur as sheet-like landforms. They are restricted to crater walls and hillslopes and are not confined by valley topography. They lack attributes typically associated with creep/deformation of ice or ice-rich debris such as crevasses, compression ridges and furrows. Hence they are morphologically different from glacial landforms such as VFF [Milliken et al., 2003] and lobate debris aprons [e.g. Mangold 2003].

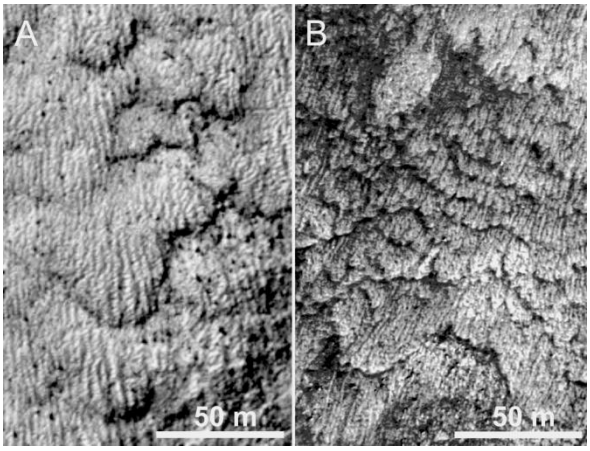

Figure 2: Comparison of lobes of similar scale on Mars and Earth. (A) Pole-facing small-scale lobes in a well-preserved mid-latitude crater on Mars. Note the stripe-like pattern superposing the lobes. (B) Solifluction lobes on a valley wall on Svalbard. Lobes are superposed by stone stripes.

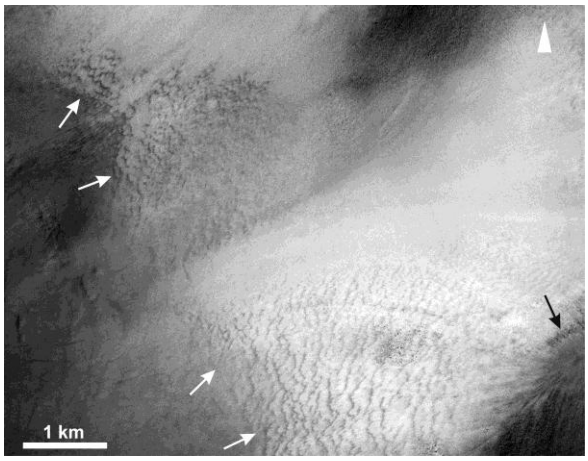

Figure 3: CTX image showing west-facing lobes in Charitum Montes. White arrows represent the lower boundary where lobes are observable. Black arrow points to summit in the area.

Particularly well-developed lobes are concentrated in the Charitum Montes region (Fig. 3), but lobes are also found elsewhere in the mid-latitudes, typically in well-preserved craters. We call these two populations: (1) crater lobes and (2) Charitum Montes lobes. The former show changes in aspect depending on latitude. Lower latitudes typically have pole-facing lobes and higher latitudes show a preference for equator-facing lobes. The Charitum Montes lobes are restricted to hillslopes of ancient terrain. They are well-developed and have modified large areas. They are typically restricted to west to north-facing slopes.

Our results show that small-scale lobes are widely distributed across the southern hemisphere of Mars. In the latitude band surveyed about 80 sites containing small-scale lobes have been found. They range in latitude between 40°S and 70°S. Their close spatial proximity and superposition relationship to gullies suggests that they may form under similar climatic conditions. Their close proximity to polygonal terrain suggests they form in an ice-rich substrate.

4. Summary and Conclusions

To date more than 2200 HiRISE images and 20 CTX images have been investigated for small-scale lobes in Mars' southern hemisphere. Results show that the small-scale lobes are distributed more equatorward than in the north. Like in the north morphometry and morphology suggest that they are distinct from permafrost creep. Although landforms indicative of freeze-thaw activity may be rare on flat terrain on Mars, there is growing evidence that freeze-thaw conditions may have been met on mid-and-high latitude slopes on both hemispheres. Small-scale lobes may therefore be strong indicators of past transient liquid water and be useful sources of paleoclimatic information on Mars.

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