**PERIGLACIAL MASS-WASTING LANDFORMS ON MARS SUGGESTIVE OF TRANSIENT LIQUID WATER IN THE RECENT PAST: INSIGHTS FROM SOLIFLUCTION LOBES ON SVALBARD.**

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**Introduction:** Periglacial solifluction processes are common on slopes in polar regions on Earth [1]. Mars is currently a cold hyper-arid desert planet with its water resources locked up in frozen reservoirs such as the ice caps, glaciers and ground ice. However, features resembling terrestrial solifluction lobes have been observed on high-latitude slopes in close proximity to gully landforms and polygonal terrain [2,3]. In our study we have examined solifluction lobes on slopes on Svalbard (Fig. 1) in order to compare to the Martian small-scale lobate landforms. Morphology and morphometric relationships of the Martian lobes are consistent with a solifluction origin [2]. Moreover, they lack features typically associated with polycrystalline creep of ground ice such as compression ridges and furrow. These observations may point to a late phase in Mars history with transient liquid water in local environments. Specific questions we address are: how widely distributed are these lobate landforms on Mars and how do they associate to other ground-ice related landforms?

**Data and method:** The analysis on Svalbard is based on high resolution imagery with the High Resolution Stereo Camera - AX (HRSC-AX) [4], which is an airborne counterpart to the HRSC aboard the Mars Express orbiter. For comparison we use satellite imagery obtained by the High Resolution Imaging Science Experiment (HiRISE) which has a similar resolution of 25 cm/pxl. For our study we have catalogued the presence of lobate forms in all available HiRISE images connected to topography between 50° N and 80° N. For comparison to Svalbard we have chosen two impact craters which display particularly well-defined lobate forms. Image analysis is complemented by field work for ground truth. This method has proven to be useful in previous investigations [5,6,7].

**Svalbard:** The arctic archipelago lays well within the continuous permafrost zone. The periglacial landscape display a range of landforms with ground ice and active-layer affinity such as patterned ground, ice-wedge polygons, pingos and rock gaciers. In Svalbard solifluction is the dominant form of slow mass wasting [8]. It depends on frost creep and seasonal thawing of segregation ice within the active layer. Snowmelt in summer may add water and further increase movement of the upper surface layer.

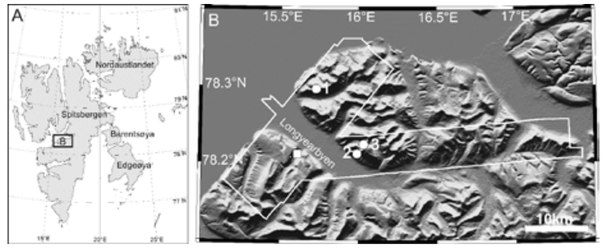


**Figure 1.** Study areas. (a) The archipelago of Svalbard and the area of investigation. (b) Shaded relief showing aerial HRSC-AX coverage (white outline) with investigated sites 1, 2 and 3 (white dots).

The present climate of Svalbard is arctic, with a mean annual air temperature ranging between -6°C at sea level and -15°C in the high mountains. Near the study site in Adventdalen lays the capital Longyearbyen, the coldest (February) and warmest (July) months have mean temperatures of -15.2°C and 6.2°C, respectively. The mean annual air temperature is -5.8°C (average 1975-2000), but can be as low as -15° in mountain areas. Precipitation is low and reaches only ~180 mm in central Spitsbergen [9]. The central part of Spitsbergen can therefore be considered to be a polar (semi-) desert, which is defined as an area with annual precipitation less than 250 millimeters and a mean temperature during the warmest month of less than 10°C [10].

**Observations:** The overall morphology of lobate landforms on Mars and Svalbard appear very similar (Fig. 2). The Martian lobate features occur as two distinct types, classed as non-sorted and sorted lobes, depending on the presence of clasts along the lobe front. Non-sorted lobes preferentially develop on slopes of homogenous sediments. Starting at the crater rim they form smooth-textured arcuate lobes with overlapping lobe fronts. Lobe height is typically in the order of 1-5 m. Sorted lobes occur on slopes with a high abundance of clasts. Clasts are concentrated at lobe fronts leaving the treads relatively clast free. Both sorted and non-sorted lobes are in close proximity to gullies and patterned ground, such as polygons and stripe-like patterns. At one lobe site, boulders with furrows upslope were observed (Fig. 4). Similar features on Earth, called ‘ploughing blocks’, are strongly associated with solifluction [11]. However, more quantitative studies are needed to constrain their mode of formation.

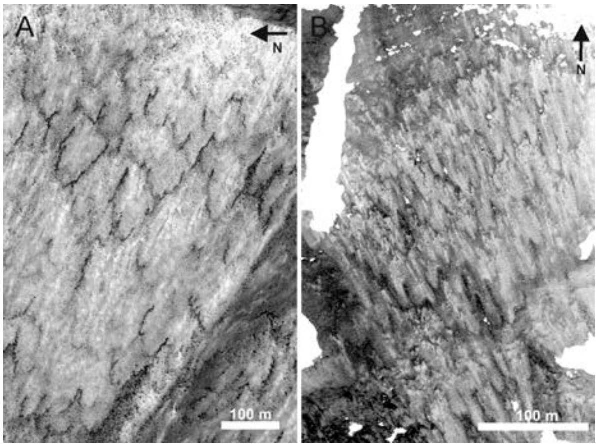


**Figure 2.** Portion of HiRISE showing well defined sorted lobes on an interior crater wall. (b) Solifluction lobes on Sheltingfjellet, Svalbard. Lobes are 10-20 m wide.

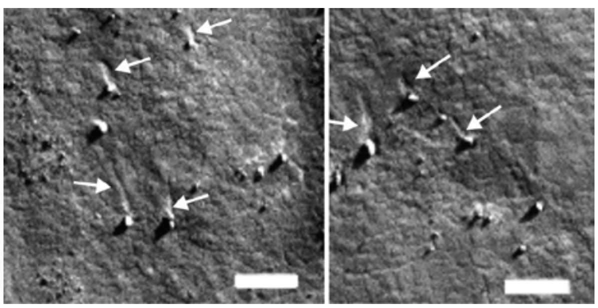

**Figure 4.** Subsets of HiRISE image showing parts of the S-facing exterior crater wall with numerous boulders which look strikingly similar to periglacial "ploughing boulders" (scale bar is 10 m in both images). Note the distinct furrow behind the boulders (white arrows) (north is up).

**Discussion:** The occurrences of small-scale lobate landforms on Mars raise the question if they are a result of freeze-thaw of an active layer or of another origin such as polycrystalline creep of ice. Even though an unambiguous interpretation is challenging, morphology and morphometric relationships are found to be consistent with solifluction. Albeit an active layer is highly unlikely today, seasonal thaw may have occurred in local environments such as the interior of craters or on hillslopes in the past [12]. In recent models crater floors or poleward facing slopes have been identified as specific locations for water ice stability and deposition of ice. [13] proposed a model which state that liquid water in the ground could be stable for enough time before being sublimated. In this case winter $CO_2$ frost may protect ground ice from sublimation before thawing [14]. The presence of perchlorates within the regolith could also act as a suppressor of the freezing point of water. In this scenario the lobes could be younger than 5 Ma as previously suggested [3]. A plausible mechanism for recharge is top-down melting of snow packs [15], which could be a viable mechanism to supply moisture for freeze-thaw cycles. In this case, the lobes may possibly be linked to the formation of gullies since both landforms are favored by similar conditions. The presence of lobes on Mars may be an indicator of a freeze-thaw process, which in turn has implications for our under-standing of near surface water dynamics and the Martian climate. However, further work is needed to determine the timing of formation.

**Conclusions:** (I) Using morphology alone in the interpretation of planetary landforms is challenging, and a clear distinction between solifluction and creep of polycrystalline ice is not easily made. However, our analysis of typical diagnostic features and the landform assemblage at each of our study sites on Mars favors a solifluction origin of the observed lobes: (1) the Martian lobes share several diagnostic morphologies with known solifluction lobes in Svalbard, (2) a situation similar to the analogous landforms on Svalbard is the close spatial proximity to known fluvial and periglacial landforms such as braided gullies and periglacial thermal contraction fractures, and (3) lobe morphometry is distinct from permafrost creep landforms and implies a freeze-thaw origin for the Martian lobes. (II) Freeze-thaw induced mass wasting might have been a common process on Martian northern high latitudes in the recent past. Though not firmly proven, we find it very likely that the hemispheric distribution of lobes points to a latitude-dependent process affecting crater environments over large regional extents. Consequently, the presence of lobes implies transient liquid water within numerous crater environments, which might also bear important implications for the habitability of Mars. (III) The pristine morphology, superposition relationships of other young landforms and crater frequency analysis of the catalogued lobes suggest a very young age of the lobes. This may be linked to recent climate changes or be due to the effects of soil salts that depresses the melting point of water.

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**References:** [1] French H.M. (2007) [2] Johnsson A. et al. (in press) *Icarus.* [3] Gallagher C. and Balme M. (2011) *Geol. Soc. London.* 87–110. [4] Neukum G. et al. (2001) *Photogrammetric Week '01, p. 117-131.* [5] Reiss D. et al. (2011) *Geol. Soc. Am.* [6] Hauber E. et al. (2011) *Geol. Soc. Am.* [7] Hauber E. et al. (2011) *Geol. Soc. Lon.* [8] Åkerman H.J. (1984) *Geogr. Ann. 267-284.* [9] Hanssen-Bauer and Førland (1998) *Climate Res. 143–153.* [10] Walker, A.S. (1997) *USGS Online Book. http://pubs.usgs.gov/gip/deserts/.*[11] Ballentyne C.K. (2001) *Permafrost Perigl. 267-288.* [12] Kreslavsky M. et al. (2008) *EPSL, 289-302.* [13] Hecht M. H. (2002) *Icarus, 373-386.* [14] Costard et al., (2002) *Science, 295, 110-113.* [15] Christensen P. R. (2003) *Nature, 45-48.*