DEBRIS FLOW FANS AND PERMAFROST LANDFORMS ON SVALBARD (NORWAY): TERRESTRIAL ANALOGUES FOR MARTIAN MID-LATITUDE PERIGLACIAL LANDSCAPES.

E. Hauber[1], D. Reiss[2], M. Ulrich[3], K. Krohn[4], F. Preusker[1], F. Trauthan[1], M. Zanetti[2], H. Hiesinger[2], S. van Gasselt[4], R. Jaumann[1], L. Johansson[5], A. Johnsson[5], M. Olvmo[5]. [1]Institut für Planetenforschung, DLR, 12489 Berlin, Germany, Ernst.Hauber@dlr.de, [2]Institut für Planetologie, Westfälische Wilhelms-Universität, 48149 Münster, Germany, [3]Alfred-Wegener-Institut, 14473 Potsdam, Germany, [4]Institut für Geologische Wissenschaften, FU Berlin, 12249 Berlin, Germany, [5]University of Gothenburg, 40530 Göteborg, Sweden.

Introduction: Many young landforms on Mars that were probably formed by exogenic processes show a latitude-dependent geographic distribution. They include surface mantling [1-3], lobate debris aprons, lineated valley fill, and concentric crater fill [e.g., 4], viscous flow features [5], gullies [6,7], and patterned ground [8-10]. Collectively, these landforms are hypothesized to represent the surface records of Martian ice ages [e.g., 11] that were induced by astronomical forcing [12] and associated climate changes [13-17].

Previous studies often considered just one of the features in isolation (e.g., gullies), without taking into account the geomorphologic context. A more comprehensive investigation of the full assemblage of landforms (landscape analysis), however, has the potential to reduce the ambiguity in interpreting landforms (the problem of equifinality, e.g., in the case of pingos [18]), and to reveal the evolution of the climatic environment in more detail. Here we present permafrost landforms of Svalbard (Norway) as useful terrestrial analogues for the suite of possible periglacial landforms that are typically found at mid-latitudes on Mars. We build on our previous investigations of gullies and fans [19], and include a number of classical periglacial landforms (patterned ground, rock glaciers, pingos) that all have close morphological analogues on Mars. Based on this comparison, we propose an evolutionary scenario which helps to understand the sequential formation of the Martian landforms into their present state.

Data and Methods: We investigate the morphology and topography of Martian landforms with image (HRSC, CTX, HiRISE; Fig. 1, left) and topographic (MOLA, HRSC) data. Color orthoimages (20 cm/pixel) and corresponding Digital Elevation Models (DEM) with a cell size of 50/cm and a vertical accuracy of 20 cm of Spitsbergen (the largest island of the Svalbard archipelago) were acquired with HRSC-AX, an airborne version [20] of the HRSC on Mars Express [21] (Fig. 1, right). Field work was performed on the Brøgger peninsula (W Spitsbergen) and in Adventdalen (central Spitsbergen) in summer 2008 and 2009.

Preliminary Results and Conclusions: Detailed morphologic and morphometric investigations reveal several close similarities between Martian gullies and fans and their counterparts on Svalbard (Fig. 1a) [19]. Dimensions, slopes, and overall morphology are comparable. Certain morphologic characteristics, however, seem to be different (fewer leveed channels on Mars [30]). GIS-based investigations on

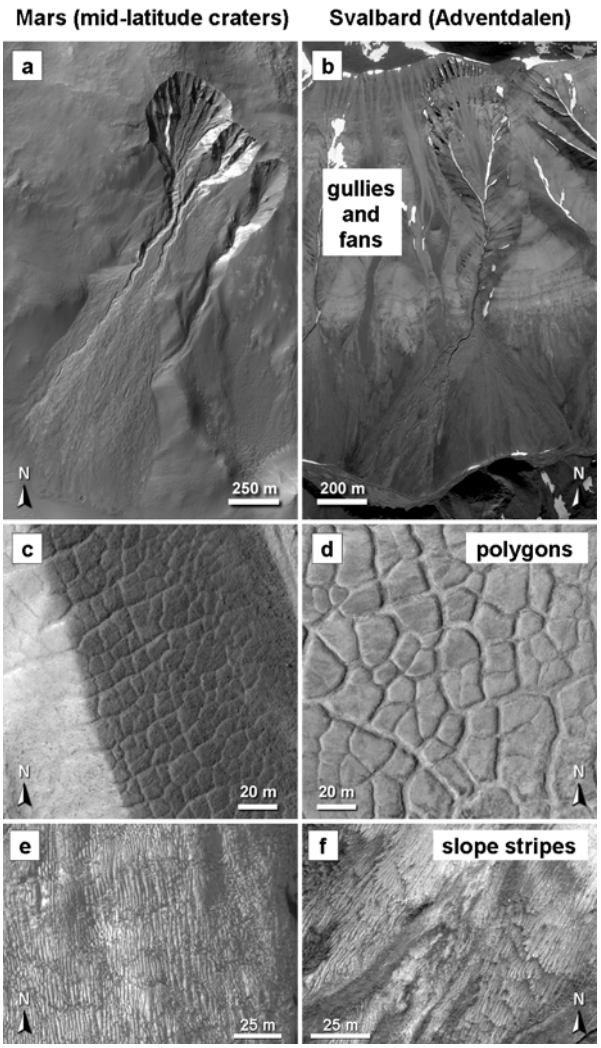

Figure 1. Comparison of cold-climate landforms on Mars (left) and Svalbard (right). Mars images are from HiRISE [22], Svalbard images from HRSC-AX [20]. **(a)** Gully and fan on S-facing slope of Martian crater (HiRISE PSP_006888_1410; 38.5°S/319.8°E). **(b)** Gully and debris flow fan on Svalbard [19]. **(c)** polygons on S-facing inner wall of Hale Crater (PSP_004072_1845; 34.6°S/323.1°E). **(d)** Thermal contraction cracks (ice-wedge polygons) on Svalbard [23]. **(e)** Alternating bright and dark bands on the S-facing inner wall of crater (PSP_001684_1410; 38.9°S/196.0°E). **(f)** Sorted stripes (caused by frost heave [24]) on Svalbard. Note the striking similarity in morphology and scale among the Martian and terrestrial landforms. On Svalbard as well as on Mars, these landforms occur in close spatial proximity (few hundred meters to a few kilometers).

additional morphometric properties and their mutual relationships (e.g., area, ruggedness of catchment) are underway. Fans on Svalbard form when the soil is saturated with water (e.g., from snow melt) and some rare event (e.g., extreme rain on snow or rockfall) triggers a debris flow. Recurrence rates are very low (decades or centuries). This model of fan and gully formation can be considered as a type of gravity-driven debris transfer system [31]. Fans on Mars form over long periods of time [e.g., 32] and seem to be dominated by fluvial activity [30], although debris flows can occasionally occur [19,33]. Most Martian gullies and fans are located on the south-facing inner walls of craters in the southern mid-latitudes [34]. The same craters host diverse landforms that are collectively interpreted here as evidence for permafrost environments, with close analogues in similarly close spatial proximity on Svalbard (review by [35]). These landforms include polygons (Fig. 1b) [23], sorted stripes (Fig. 1c) [19], rock glaciers or debris-covered glaciers (Fig. 2a,b) [36], and pingos (Fig. 2c) [37]. Despite significant differences in the climates of Mars and Svalbard, it appears that a very analogous suite of landforms developed, perhaps over enormously different timescales. We will present a model of landscape evolution that is derived from terrestrial examples [e.g., 38], but might be applicable to different scenarios of Martian permafrost environments (e.g., "wet" [39] vs. "dry" [40]).

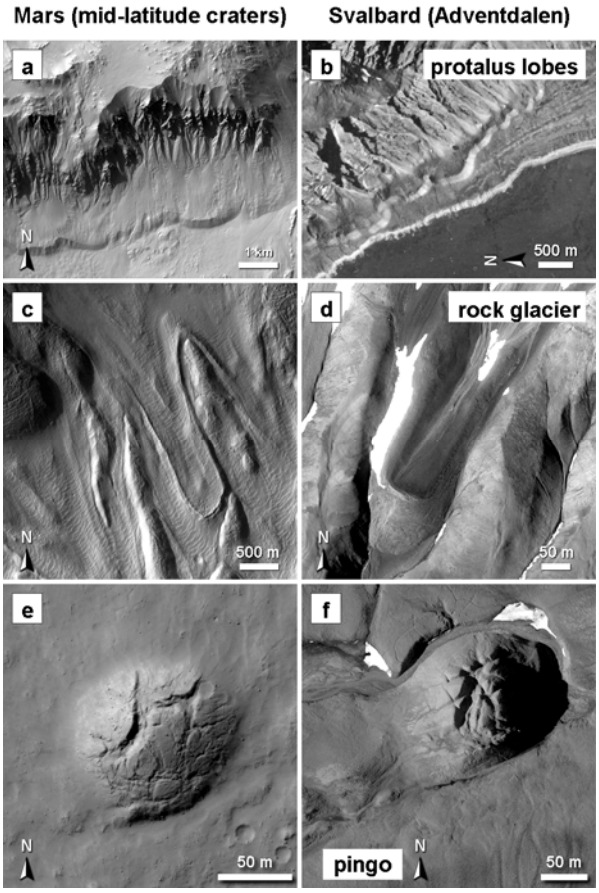

Figure 2. Comparison of additional cold-climate landforms on Mars (left) and in Adventdalen (Svalbard) (right). Images as in Fig. 1, and CTX [25]. **(a)** Talus slopes with concave-upward topographic profile and steep distal scarp on the foot of a high scarp on the inner, S-facing wall of Hale Crater (CTX P15_006756_1454; 34.6°S, 323.1°E). **(b)** Protalus lobes (a class of rock glaciers) on Prins Karls Forland off the western coast of Spitsbergen [26]. Aerial photo S 704128, Norsk Polarinstitutt, Oslo, Norway (modified from [27]). **(c)** Tongue-shaped viscous flow feature at inner wall of an unnamed crater (CTX P03_002386_1444; 35.5°S/111.9°E). **(d)** Tongue-shaped rock glacier in Adventdalen (very close to other tongue-shaped rock glaciers described by [28]). **(e)** Fractured mound on floor of crater in southern hemisphere (HiRISE PSP_007533_1420; 37.9°S/347.2°E). **(f)** Pingo in Eskerdalen (few km east of Adventdalen), mapped by [29]. As in Fig. 1, the morphology and scale of the landforms is closely analogous. The only exceptions are the tongue-shaped flow features: The Martian feature is one order of magnitude larger and appears degraded. The interpretation as rock glacier is tenuous, as it could also be a degraded (debris-covered) glacier.

References: [1] Kreslavsky M.A. and Head J.W. (2000) *JGR 105*, 26,695–26,712. [2] Mustard J.F. et al. (2001) *Nature 412*, 411–414. [3] Morgenstern A. et al. (2007) *JGR 112*, E06010, doi: 10.1029/2006-JE002869. [4] Squyres S.W. (1978) *Icarus 34*, 600–613. [5] Milliken R.E. et al. (2003) *JGR 108*, 5057, doi:10.1029/2002JE002005. [6] Balme, M. et al. (2006) *JGR 111*, E05001, doi : 10.1029/2005JE002607. [7] Kneissl T. et al. (2010) *Earth Planet. Sci. Lett.*, in press. [8] Seibert N.M. and Kargel J.S. (2001) *GRL 28*, 899–902. [9] Kuzmin R.O. and Zabalueva E.V. (2003) *LPS XXXIV*, abstract 1912. [10] Mangold N. (2005) *Icarus 174*, 336–359. [11] Head J.W. et al. (2003) *Nature 426*, 797–802. [12] Laskar J. (2004) *Icarus 170*, 343-364. [13] Toon O.B. et al. (1980) Icarus 44, 552-607. [14] Jakosky B.M. and Carr M.H. (1985) *Nature 315*, 559-561. [15] Mischna M.A. et al. (2003) JGR 108, 5062, doi: 10.1029/2003JE002051. [16] Forget F. (2006) *Science 311*, 368–371. [17] Schorghofer N. (2007) *Nature 449*, 192-194. [18] Burr D.M.(2009) *Planet. Space Sci. 57*, 579-596 [19] Hauber E. et al. (2009) LPS XV, abstract 1658. [20] Gwinner K. (2000) *EOS Transactions, AGU 81(44)*, 513–520. [21] Jaumann R. et al. (2007) *Planet. Space Sci. 55*, 928–952. [22] McEwen A.S. et al. (2007) *JGR 112*, CiteID E05S02, doi: 10.1029/2005JE002605. [23] Christiansen H. (2005) *Permafrost Periglac. Process. 16*, 87-98. [24] Van Vliet-Lanoë B. (1991) *Permafrost Periglac. Process. 2*, 123-139. [25] Malin M.C. et al. (2007) *JGR 112*, CiteID E05S04, doi: 10.1029/2006JE002808. [26] Berthling, I. et al. (1998) *Permafrost Periglac. Process. 9*, 135-145. [27] André M.-F. (1994) *Geogr. Ann. 76 A (4)*, 235-245. [28] Isaksen K. (2000) *Permafrost Periglac. Process. 11*, 241-257. [29] Tolgensbakk J. et al. (2000) *Adventdalen, geomorphological and quaternary geological map of Svalbard*, scale 1:100,000, Spitsbergen sheet C9Q: Tromsø, Norsk Polarinstitutt Temakart nr. 32. [30] Reiss D. et al. (2010) *LPS XVI*, this conference. [31] Johnson P.G. (1995) *in* Slaymaker O. (ed.) *Steepland Geomorphology*, Wiley, Chichester, p. 27-44. [32] Schon S.C. et al. (2009) *Geology 37*, 199-202. [33] Levy J.S. et al. (2010) *Earth Planet. Sci. Lett.*, in press. [34] Dickson J.L. et al. (2007) *Icarus 188*, 315-323. [34] Levy J.S. et al. (2009) *Icarus 201*, 113-126. [35] Humlum O. et al. (2003) *Polar Res. 22*, 191-215. [36] Milliken R.E. et al. (2003) *JGR 108*, CiteID 5057, p. 11-1, doi: 10.1029/2002JE002005. [37] Dundas C.M. and McEwen A.S. (2010) *Icarus*, in press. [38] Häberli W. (1996) *Norsk geogr. Tidsskr. 50*, 3-9. [39] Mellon M. (2009) *JGR*, doi: 10.1029/2009JE003418, in press. [40] Levy J.S. et al. (2009) *GRL 36*, L21203, doi: 10.1029/2009GL040634.