TERRESTRIAL GULLIES ON SVALBARD AS PLANETARY ANALOGS FOR MARS. D. Reiss[1], E. Hauber[2], H. Hiesinger[1], R. Jaumann[2], F. Trauthan[2], F. Preusker[2], M. Zanetti[1], M. Ulrich[3], A. Johnsson[4], L. Johansson[4], M. Olvmo[4], E. Carlsson[5], H.A.B. Johansson[6], and S. McDaniel[7], [1]Institut für Planetologie, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (dennis.reiss@uni-muenster.de), [2]Institut für Planetenforschung, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Rutherfordstrasse 2, 12489 Berlin, Germany, [3]Alfred Wegener Institute for Polar and Marine Research, Research Unit Potsdam, Telegrafenberg A43, 14473 Potsdam, Germany, [4]Department of Earth Sciences, University of Gothenburg, Box 460, SE-405 30 Göteborg, Sweden, [5]Swedish Institute of Space Physics, Box 812, SE-981 28 Kiruna, Sweden, [6]Stockholm University, AlbaNova University Center, S-10691 Stockholm, Sweden, [7]Reactive Surfaces, Ltd, 300 West Avenue, Austin, Texas 78701, USA.

Background: Martian gullies resemble terrestrial gullies, which are formed by a combination of processes including mass wasting, overland flow and debris flows [1]. The gullies on Mars show several morphologic features such as braided channels, multiple terraces, point bars and cutbanks, which indicate that fluvial processes were involved in their formation [2, 3]. However, it remains unclear whether fluvial processes or debris flows are dominating the formation of gullies on Mars. Debris flows are viscous slurry flows with water and fines as the interstitial fluid [4]. The flowing mixtures of fines, clastic debris and water has a relatively low water content (≤ 30 % water by weight) [5]. Stream flows and hyperconcentrated flows have a high water content and relatively low sediment supply (≥ 30 % water by weight) [5, 6]. The morphologies of debris flows fans show typical features such as levées, lobes, snouts and debris plugs [7, 8], which are not observed from purely fluvial processes. In this work we compare the morphology of terrestrial gully analogs from Svalbard with Martian gullies in order to constrain which formation process might be dominant on Mars, i.e. fluvial and/or debris flow processes.

Data and Methods: The analysis of gullies on Svalbard is based on high resolution imagery acquired during a flight campaign in summer 2008 with the airborne High Resolution Stereo Camera (HRSC-AX). The imaged region in the Adventdalen area covers approximately 450 km^2. The processed panchromatic nadir orthoimages have a spatial resolution of 20 cm/pxl. The gully analysis has been complemented by two field expeditions during the summer 2008 and 2009. For the comparision with Martian gullies we used satellite imagery obtained by the High Resolution Imaging Science Experiment (HiRISE) which has a similar spatial resolution of 25 cm/pxl to the terrestrial HRSC-AX. More than 60 HiRISE images from the mid-latitude southern hemisphere of Mars (30°S-60°S) was used for this study.

Svalbard: The archipelago of Svalbard is located in the Arctic Ocean between 76°-81° N and 10°-35°E. The study area is located near the capital of Longyearbyen, mainly on the northern side of Adventfjorden for which we have data from a flight campaign and ground truth. Because of the cold and dry periglacial environment, Svalbard is a potentially good analog for several Martian landforms. The present climate of Svalbard is an arctic desert and lies in the continuous zone of permafrost with low mean annual air temperatures (~6 ° C) and very low precipitation (~180 mm) recorded at Longyearbyen airport [9]. At Longyearbyen airport around 75 % of the precipitation events are reported as snow [10]. Gullies and debris flow channels occur frequently on the mountain slopes [11]. The main factor in eroding the slopes in the study area is fluvial erosion by snowmelt in the springtime [e.g., 12], whereas debris flow processes are generally triggered by heavy rainstorms in summer [e.g., 12, 13]. Rapid snow melting causing water saturation of till has triggered large debris flows only in a few known cases [14].

Morphologic Observations: Examples of gullies found on Svalbard and on Mars are shown in Figure 1. The overall morphology and dimensions appear very similar. All of them show typical characteristics of gullies consisting of an alcove, one or more main channels and a fan deposit. However, closer inspection of channels dissecting the fans and their deposits reveal large differences between terrestrial and Martian gullies. Figure 2 show three enlargements of the fan surface from the gullies in Figure 1. Nearly all gully fans on Svalbard are heavily affected by debris flows. This is also indicated by the poor stratification of the gully fan deposits observed at outcrops at the fan base (exposed by cut bank erosion by the valley rivers). They show typical morphological characteristics of debris flows like levéed channels and debris lobes on the gully fan (Figure 2A and 3A). There exist only a few examples of gullies on Svalbard where the fan deposits are less affected by debris flow processes. One example is shown in Figure 1B, 2B and 3B. These fan deposits are dissected by channels, which are predominately not levéed (Figure 3B) and there is an overall lack of debris flow tongues. If deposition from the gully channels onto the fan surface occurs, they form small fan-like deposits (Figure 3B). However, even on this gully fan lateral deposits along some channels occur, indicating that debris flow processes also contributed to erosion and deposition.

On Mars, channels incised into the gully fan surface are generally rare (Figure 1C and 2C) compared to the heavily dissected gully fans on Svalbard (Figure 1A-B and 2A-B). In most cases only one pristine main channel occurs which is partly overprinted by subsequent deposition (Figure 2C and 3C). The channels do not show levées and typically terminate in small fan-like deposits on the gully fan (Figure 3C). The majority of Martian gully fans appear to be composed of small fans overlapping earlier ones. Ongoing flow processes probably lead to the formation of the more complex and large fans of Martian gullies (Figure 4A). Smaller fan-like structures built up by single or even multiple flow processes are still visible on the larger gully fans near the termini of two pristine channels (Figure 4A). Only a few gullies in two regions showed morphological evidence for clear debris flow processes. One has been described recently by [15]. The other one is shown in Figure 4B. These gullies are located on the east-facing slopes of Hale crater. The channels have widths between ~1.5 m and ~10 m, show well-defined levées and terminate in most cases in debris tongues or more rarely in levéed snouts (Figure 4B).

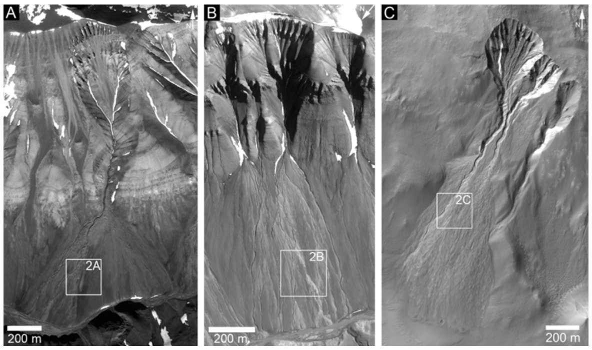

Figure 1. Examples of typical gullies on Svalbard (A and B) and Mars (C). A and B: HRSC-AX images at 78.29°N, 15.76°E (A) and 78.23°N, 17.06°E (B), both 20 cm/pxl. C: HiRISE image PSP_006888_1410 at 38.5°S and 319.8°E, 25 cm/pxl. White boxes show the locations of Figures 2A-C.

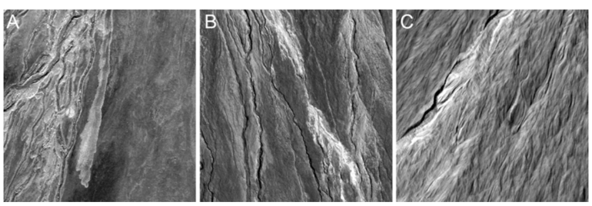

Figure 2. Examples of gully fan textures. A: Debris flow dominated gully fan on Svalbard with levéed channels, several lobate deposits, and a debris tongue (HRSC-AX, 20 cm/pxl). B: Fluvially dominated gully fan on Svalbard. Channels show mainly no levées, but several small fan-like deposits occur (HRSC-AX, 20 cm/pxl). C: Gully fan on Mars (HiRISE image PSP_006888_1410, 25 cm/pxl). All images have a width of 200 m.

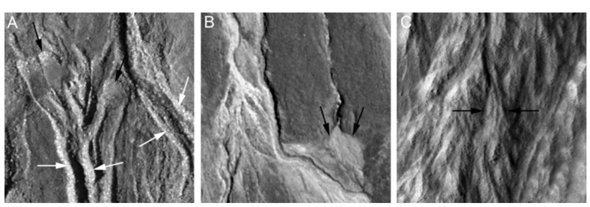

Figure 5. Examples of typical channels incised into gully fans from Svalbard (A and B) and Mars (C). All images have a width of 70 m. (A) Channels are accompanied by levées (white arrows) and terminate in lobe fronts (black arrows), typical for debris flow processes. Flow direction is to the top of image (HRSC-AX, 20 cm/pxl at 78.18°N and 15.78°E). (B) Most channels of the fluvial dominated gully fan show no levées. Some channels terminate in small fan deposits (black arrow) (HRSC-AX, 20 cm/pxl at 78.24°S and 17.04°E). (C) On Mars the channels are incised into the gully fans, showing no levees. They often terminate in small triangular shaped fans, typical for fluvial processes. A small fan deposit is indicated by black arrows. Flow direction is to south (HiRISE image PSP_002884_1395, 25 cm/pxl at 40.4°S and 196.9°E).

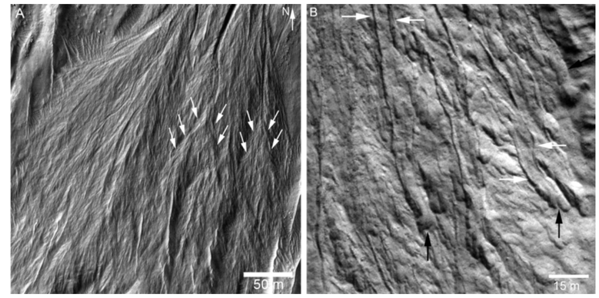

Figure 4. Morphology of Martian gully fans. (A) Typical Martian gully fan built up by small fans due to a large number of subsequent flow events. Two small fans at the termini of the two most pristine channels are indicated by white arrows for better visibility (HiRISE image PSP_001792_1425, 25 cm/pxl at 37.2°S and 128.6°E). (B) Martian gully fan built up by several debris flow events. Debris flow lobes (black arrows) and levées (white arrows) on the gully fan. (HiRISE image PSP_006822_1440, 25 cm/pxl at 35.7°S and 322.3°E).

Discussion: Morphological details of the of gully fans from Svalbard obtained by high resolution imagery and field work revealed that nearly all are heavily affected by debris flow processes. Although there are some gully fans on Svalbard, which are predominately formed by fluvial processes, debris flow features are not completely absent on these fans. The gully fans on Mars show surface textures indicating that they are formed predominately by fluvial processes (stream flows and/or hyperconcentrated flows) with a relatively high water content. Neither levéed channels nor lobate deposits were observed in the majority of cases. The typical Martian gully fan morphology are consistent with the deposition of small overlapping fans by multiple fluvial flow events. Morphologic evidence for clear contribution of debris flow processes in the formation of gullies on Mars is rare and found only locally. In addition to the observed fan built up by debris flows in Figure 4B, clear evidence for debris flow processes in gully formation on Mars has been found so far only in two other regions by [15] in the southern hemisphere and by [16] in the northern hemisphere. Another known example for debris flow processes are gullies on Martian dunes [17, 18].

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