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Morphometry of Alluvial Fans in a Polar Desert (Svalbard, Norway): Implications for Interpreting Martian Fans

E. Hauber (1), F. Preusker (1), F. Trauthan (1), D. Reiss (2), M. Zanetti (2), R. Jaumann (1), H. Hiesinger (2), and the Svalbard SPLAM Team

(1) DLR, Institute of Planetary Research, Berlin, Germany (Ernst.Hauber@dlr.de), (2) University Münster, Germany

Alluvial fan-like landforms have been identified on Mars [e.g., 1-3]. Alluvial fans contain information on several controlling factors (tectonism, climate, lithology/geology), and therefore the investigation of possible Martian fans can reveal information about the planet‘s climate. In lieu of direct observations of active depositional processes on Martian fans, comparisons with terrestrial analogues can constrain models of Martian fan formation derived from remote sensing data. Since present-day Mars is cold and dry, alluvial fans formed in cold deserts should be considered as useful analogues. The probably closest climatic analogue to Mars on Earth are the Antarctic Dry Valleys [5], but polar deserts can also be found in the Arctic. We report on our field work in summer 2008 and a simultaneous flight campaign with an airborne version (HRSC-AX) of the High Resolution Stereo Camera (HRSC) onboard Mars Express [6]. The results are compared with measurements of Martian fans, based on HRSC DEM.

Our study area is in Svalbard near Longyearbyen (78°13’0"N, 15°38’0"E), around mountains of Mesozoic layered sandstones and shales) on the northern side of Adventfjorden. Climate data are available from the nearby Longyearbyen airport (just a few km from the study area). The present climate is arctic [7], with low mean annual air temperatures and very low precipitation, mostly as snow.

Stereo images acquired in July 2008 (at the end of the snow melting season) were processed to orthoimages with a spatial resolution of 20 cm/pixel, and corresponding Digital Elevation Models (DEM) with a grid spacing of 50 cm/pixel. Simultaneous field measurements focused on channels and levees (widths, depths, heights), which were determined at vertical increments of 10 m, together with the local slope.

Alluvial fans in the study area are present on slopes of all orientations. They typically coalesce into bajadas. Basically all alluvial fans in the study area are characterized by sinuous channels, many of which display well-developed lateral levees, and debris tongues. Boulder-sized (>1 m) rocks are present, but rare. Where a vertical section of the fan can be observed (typically at the toe, where braided rivers cut the fans), it appears poorly sorted. Following the reasoning of, e.g., [8,9], we conclude that the fans in our study area are dominated by debris flows. However, fluvial processes might also have been involved, and the complex interplay between fluvial incision and debris flows on alluvial fans is well known also from fans in different climatic environments [e.g., 10].

Topographic profiles along 55 fans were measured in HRSC-AX DEM. Fan length ranges between 80 m and about 800 m, with heights between 9 and 140 m (from apex to toe). The profiles of the Svalbard fans can be approximated very well with a power law function. Overall gradients vary between 0.11 and 0.43, with a peak at 0.18-0.2. Several measures have been suggested to quantify the concavity of river and fan profiles [e.g., 1, 11]. We use a simple method, which was suggested by Langbein [12] and is still widely used [e.g., 9, 13,14]. The Langbein-concavity of the fan profiles shows a continous range between 0 and 0.53.

The topography of Martian fan-like features [2,3] is studied on the basis of DEM derived from HRSC stereo data [15,16], with a grid spacing of 50-100 m. An example of a profile along a Martian fan in Holden crater exhibits a Langbein-concavity of 0.194 and a gradient of 0.069. While the concavity falls in the range observed on

Svalbard, the gradient is less. Another major difference is the fan dimension, with the fan in Holden Crater being much larger. We also produced a HRSC DEM of Mojave Crater on Mars, which displays a number of fans with dimensions similar to those on Svalbard [3], and discuss the relationship between local slopes and fans in Mojave Crater.

Alluvial fans form by one or a combination of the following mechanisms: avulsing channelized rivers, sheet flows, and debris flows [17]. Previous studies comparing Martian and terrestrial fans have examined the usefulness of the concavity of along-fan profiles to discriminate between fluvially-dominated fans (concave-upward profiles) and debris flow-dominated fans (linear profiles) [1,2]. Morphological observations suggest that Svalbard fans are heavily affected by debris flows. However, their profiles show a continuum between more or less linear profiles and distinct concave-upward profiles, independent of orientation (which possibly controls snow accumulation and melting, and therefore depositional processes). We conclude that morphometric measures alone do not enable an unambiguous interpretation of processes acting on alluvial fans. Instead, complementary morphologic studies using high-resolution images seem to be required to discriminate between debris flows and fluvial activity on Mars, e.g., can we identify levees or debris tongues in HiRISE images? Their resolution is roughly 30 cm/px and should enable it. Even then, quantifiying the respective role of different depositional processes might be hard to achieve.

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