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Landscape evolution in Martian mid-latitude regions: Insights from analogous periglacial landforms in Svalbard

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Abstract

Periglacial landforms on Spitsbergen (Svalbard, Norway) are morphologically similar to landforms on Mars that are likely related to the past and/or present existence of ice at or near the surface. Many of these landforms, such as gullies, debris flow fans, polygonal terrain, fractured mounds, and rock glacier-like features, are observed in close spatial proximity in mid-latitude craters on Mars. On Svalbard, analogous landforms occur in strikingly similar proximity, which makes them useful study cases to infer the spatial and chronological evolution of Martian cold-climate surface processes. The analysis of the morphological inventory of analogous landforms on Svalbard and Mars allows constraining the processes operating on Mars. Different qualitative scenarios of landscape evolution on Mars help to better understand the action of periglacial processes on Mars in the recent past.

1. Introduction

1.1 Background

Many young landforms on Mars were probably formed by exogenic processes and show a latitude-dependent geographic distribution. They include surface mantling, lobate debris aprons, lineated valley fill, and concentric crater fill, viscous flow features, gullies, and patterned ground. Collectively, these landforms might represent the surface records of Martian ice ages that were induced by astronomical forcing and associated climate changes.

Previous studies often considered just one of the features in isolation (e.g., gullies), without taking into account the geomorphologic context. 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. In particular, we focus on the pole-facing walls of impact craters, which are known to display various possible ice- and water-related landforms. Based on this comparison, we propose, in a qualitative sense, possible evolutionary scenarios which might help to understand the sequential formation of the Martian landforms into their present state.

1.2 Data and Methods

We investigate the morphology and topography of Martian landforms with image (HRSC, CTX, HiRISE) 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 of HRSC on Mars Express. Field work was performed on the Brøgger peninsula (W Spitsbergen) and in Adventdalen (central Spitsbergen) in summer 2008 and 2009.

2. Results

Despite significant differences in the climates of Mars and Svalbard, a suite of very analogous landforms has developed, though perhaps over enormously different timescales. Attempts to reconstruct paleo-climates on Mars have to take into account that different processes acting in different environments can produce similar results (equifinality). The integrated analysis of landscapes can reduce such ambiguities.

The landform inventory associated with pole-facing inner walls of impact craters in the Martian mid-latitudes suggests the geologically recent action of glacial and periglacial processes. Based on terrestrial analogue landforms in similarly close spatial proximity on Svalbard, three scenarios of sequential landscape evolution are presented for Mars: The “dry, “wet”, and “snow” scenarios, respectively. All scenarios start with initial snow fall and the deposition of a dusty snow pack, and they all end with recent gully and fan formation. These scenarios are qualitative in the sense that none of them is expected to exactly represent the real situation on Mars. In fact, the scenarios are not mutually exclusive, and mixed cases are very plausible. Dependent on latitude and insolation, some craters might have been shaped by the “dry” scenario (Fig. 1), while craters at other latitudes might have been shaped by the wet scenario. The different scenarios also have different implications for the interpretation of certain landforms. For example, fractured mounds are unlikely to be open-system pingos in the dry scenario, because the “dry” scenario does not involve liquid water in the subsurface, a prerequisite for the growth of hydraulic pingos.

3. Conclusions

The landscape evolution proposed here would be controlled by obliquity and/or orbital parameters such as eccentricity or the position of perihelion, and is therefore assumed to be cyclic. Several successive episodes of deposition and removal have already been suggested by previous authors. It is important to realize that the current Martian mid-latitude morphologies do not represent a stable situation over long periods. Instead, this is a dynamic landscape in constant, though perhaps very slow, transition, and patterns of sedimentation and erosion overprint each other repeatedly. Nevertheless, the associated rates for erosion (e.g., in the dry scenario) are likely to be very low, and not all traces of former ice ages are extinguished by later glaciations. Therefore, the spatial extent of former and more widespread glaciation can be identified by careful morphological analysis

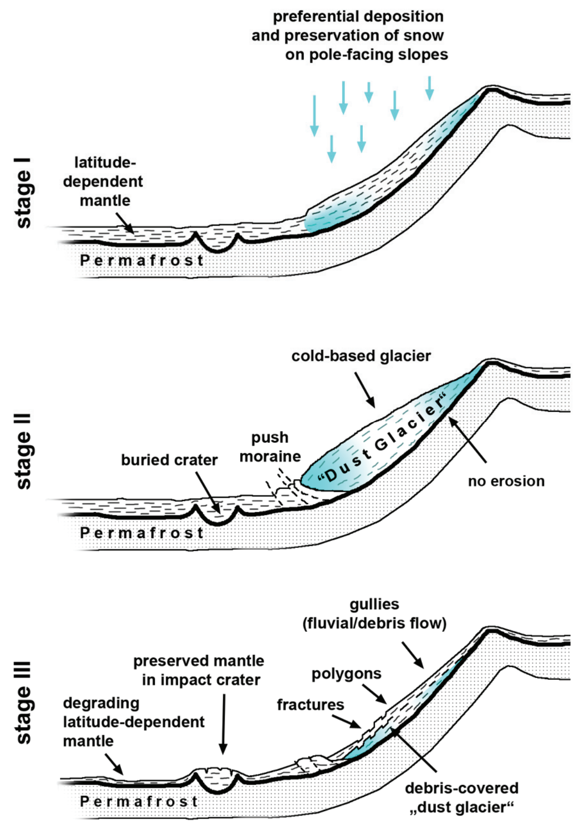

Figure 1: The “dry” scenario, one of three different qualitative scenarios for the sequential evolution of possible glacial and periglacial landforms in mid-latitude craters on Mars. Figure not drawn to scale, the pole is towards the left.

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