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Debris Flows and Water Tracks in Continental Antarctica: Water as a geomorphic agent in a hyperarid polar desert

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Abstract

Most studies using Antarctica as a Mars analogue have focused on the McMurdo Dry Valleys, which are among the coldest and driest places on Earth. However, other ice-free areas in continental Antarctica also display landforms that can inform the study of the possible geomorphic impact of water in a polar desert. Here we present a new analogue site in the interior of the Transantarctic Mountains in Northern Victoria Land. Gullies show unambiguous evidence for debris flows, and water tracks act as shallow subsurface pathways of water on top of the permafrost tale. Both processes are driven by meltwater from glacier ice and snow in an environment which never experiences rainfall and in which the air temperatures probably never exceed 0°C.

1. Introduction

Gullies on Mars [1] may have formed by debris flows triggered by the melting of ice or snow [2,3], by dry granular flows [4-6], or by a combination thereof. Multi-year monitoring revealed present-day mass wasting at Martian gullies, most likely related to seasonal CO_2 activity [7] in environmental conditions that prohibit the stability of liquid water. It is debated, however, whether such "dry" processes can account for the full range of morphologic characteristics and the dimensions of the observed gully systems, or whether additional "wet" processes in the recent past and in a different climate may have been required. A better physical understanding of CO_2-related (flow) processes, which have no terrestrial analogues, is required to enable predicting the geomorphic potential of such flows to generate gullies.

The study of terrestrial debris flow processes and their erosive and depositional records can help exploring the parameter space of paleo-environments that may have been responsible for gully formation on Mars. Here we introduce a new analogue site in continental Antarctica that displays evidence for debris flows in a hyperarid polar desert. The site complements our previous analogue studies in Svalbard [8], where gullies and debris flows are morphologically very similar to Martian gullies [9]. In addition, it hosts water pathways that resemble water tracks observed elsewhere in Antarctica, which were suggested to be potential analogues for the so-called RSL (recurrent slope lineae [10]).

2. Study area

The study area is located in the Transantarctic Mountains of Northern Victoria Land at the De Goes Cliff in the southernmost part of the Morozumi Range (~71°49S, 162°00E; Fig. 1). The De Goes Cliff is a ~400 m-high, east-facing scarp oriented in NNW-SSE direction, and is composed of sediments (Beacon Supergroup) and sills (Ferrar Dolerite).

The study area is very remote from any research station, and the closest weather stations are either located more towards the interior of East Antarctica or more towards the coast, respectively. Therefore, it can be reasonably assumed that the environmental conditions at the study area range between those measured at these stations. While peak summertime temperatures exceed 0°C at coastal locations on a few days in the year, the inland stations never recorded temperatures >0°C. Summertime relative humidity is ~55% at the closest weather stations (meteorological data from www.climantartide.it).

3. Observations

The geomorphology of the ice-free surfaces in the study area is characterized by glacial drift deposits and ubiquitous thermal contraction cracks. The largest ice-free area is Boggs Valley in the Helliwell

Hills, a dry valley that measures about 5 × 2.5 km in size. Trenching showed that (in January 2016) relatively clear and bubble-free ice underlies most polygonally fractured terrain at a depth of 40 cm. Katabatic winds are common and mostly blowing northward along Rennick Glacier towards the coast.

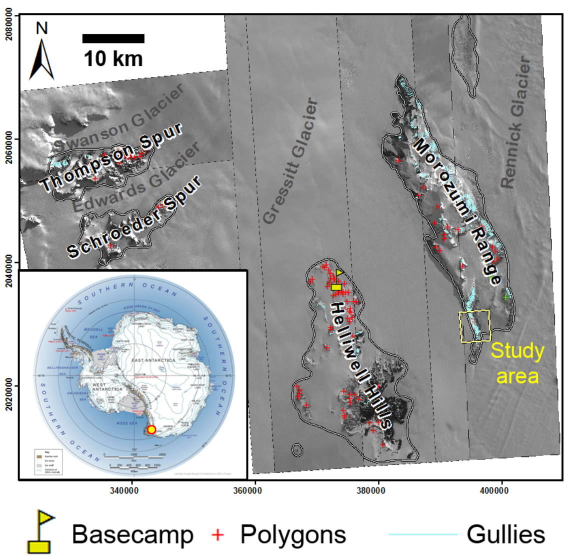

Figure 1: Location and context of study area.

3.1 Gullies.

"Gullies" (consisting from top to bottom of an erosional alcove, transport channel(s), and a depositional fan or apron, following the terminology used to describe them on Mars [1]) transect the entire height of the De Goes Cliff. Alcoves are cut into both igneous and sedimentary bedrock, followed by long and thin single-thread channels which continue across relatively small depositional fans down to the foot of the cliff. The channels are about 2 m wide and have levées that are up to 1 m wide and ~30 cm high. Debris flow tongues consist of mostly angular clasts with diameters of centimeters to decimeters. Meltwater from snow patches in the channels began to flow down the lower parts of some gullies in the early afternoon (~14:30). The length of the channel section with water flowing in it reached >13 m at 16:45, but for ~4-5 m the water only flowed in the subsurface and the surface remained completely dry. The discharge was estimated at <0.1 liter per second.

3.2 Subsurface pathways.

Immediately east of the gullies, some pathways for meltwater from snowbanks along the western margin of Rennick Glacier resemble fluvial channels in satellite images. Upon closer inspection, however, it becomes clear that these landforms do not transport flowing surface water. Instead, they represent only very shallow depressions (depth ~few cm), the surface of which is more or less wet (depending on the time since they were last active). Excavations show that the depth to ice-cemented, impermeable permafrost soil is ~40 cm. The irregular margin of the pathway (no erosion by flowing water) and the preservation of preexisting surface texture suggests that there is never any significant surface runoff in these depressions. Instead, they appear to be subsurface pathways for meltwater, just wetting the surface and darkening its albedo (analogous to *water tracks* in the McMurdo Dry Valleys [11] which, in turn, have been used as analogues to RSL [12]).

4. Discussion

We examined a new field site in Antarctica that shows landforms analogous to Martian gullies. Our observations highlight the potential of water-limited hyperarid polar deserts to generate sufficient meltwater to produce debris flows and water tracks. It appears possible that only very small amounts of water may be able to produce gullies on Mars, too. Further modeling should attempt to predict better estimates of melt rates under Martian climatic conditions that are only slightly different that those prevailing today.

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