THE EFFECT OF VARYING ANNUAL SNOW ACCUMULATION ON GULLY FORMATION IN ANARCTICA: COMPARISONS BETWEEN 'WET' AND 'DRY' SEASONS AND IMPLICATIONS FOR GULLY FORMATION ON MARS.

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Introduction: The discovery of gullies on Mars attracted significant attention because of the apparent role of liquid water in their formation and because of their very youthful nature [1,2]. They were initially interpreted to be the result of groundwater discharge [1-3], though further considerations regarding the current metastability of liquid water on the surface of Mars generated alternative explanations, including atmospherically deposited sources of water [4-7]. Recent modeling work has demonstrated that snowfall [8] and the melting of such deposits [4,5,9] is possible in the regions where gullies are located under periods of higher obliquity. This has provided support for the snowmelt model of gully formation [4-6,9].

The utilization of terrestrial analogs provides an essential natural laboratory for testing the snowmelt model as a viable means of gully formation. In this analysis we report on results obtained from field studies within the McMurdo Dry Valleys of Antarctica (ADV), a hyper-arid polar desert that has long been held as one of the most Mars-like of terrestrial analogs [10-12] (Fig. 1). Within this environment, precipitation only falls as snow and so the availability of liquid water is restricted to meltwater generated by the solar heating of ice and snow deposits.

In order to best constrain the Martian conditions we concentrated our efforts within the most elevated (and hence driest) portion of the intermediate microclimate zone [12] situated within the South Fork (SF) region of upper Wright Valley. This region marks the most inland extent of active fluvial features within the ADV and is most analogous to Mars during Amazonian periods of high obliquity in terms of precipitation and max T values [12] (Fig.1). Unlike other gullied regions of the ADV, there are no significant adjacent glacial systems to supply meltwater, and so the most significant ice deposits are snowbanks that more closely resemble the deposits predicted to form on Mars during its recent history [4-6,9]. We found that there is significant inter-annual variability in the abundance of snow for gully generation. However, even in years with minimal snowfall, windblown snow can be concentrated in suitable geomorphic traps.

2006-07: The 'Wet' Year. The majority of the larger gullies studied in SF in 2006-7 exhibited fluvial activity associated with snowmelt from within two geomorphic traps:

Alcoves. The northern edge of the Asgard Mountains in SF contains a number of alcoves along the margins of the valley. The upper slopes of the range dip in excess of 30° and exhibit cross-sectional profiles that are similar to crater walls into which the majority of martian gullies are carved. Many of the alcoves contain surface snow/ice that partially melts, providing a seasonal source of water to the gully systems. Observations of aerial photos for multiple years show that the majority of snow/ice in alcoves is perennial. During storm events low lying clouds hug alcove walls and preferentially deposit snow on them, building up snow deposits over multiple years. By early Dec 2006, marginal parts of one examined snowbank had started to melt, and the gully channel below it was occupied by flowing water during peak daily insolation.

Ephemeral Windblown Snow in Channels. In the mid to lower reaches of these gully systems, water is derived from melting of ephemeral patches of windblown snow in channels (Fig.2). Despite the low amount of annual precipitation, strong winds are capable of transporting snow and concentrating it within geomorphic traps, such as gully channels that are transverse to dominant wind flow. In late November, some of the lower channels were almost completely filled with snow. During November to January the snow banks shrank and eventually disappeared due to a combination of sublimation and melting. Melting was clearly modulated by insolation and air temperature, restricting peak meltwater generation to cloud free conditions, when the sun was at its highest point in the sky. In-channel surface flow was only achieved after a sufficient volume of meltwater had soaked into the active layer to permit runoff across a hyporheic zone; the formation of a hyporheic zone advanced both laterally and downstream, always well ahead of eventual surface flows (Fig. 2).

Surface runoff eroded inner braided channels (10s of cm –1 m wide) within the sediments lining the floors of the gully channels. Throughout the period of activity, small-scale fluvial features consistent with features observable in HiRISE images of martian gullies [13] developed, including terraces several centimeters deep that were cut into channel floors (Fig.2), and which formed islands (longitudinal bars) of elevated debris. Gravitational slumps consisting of small boulders (>1 m long) within a sand grained sized matrix were actively observed to form along channel walls; these slumps appear related to the development of tension cracks within adjacent colluvium, causing blocks of wetted colluvium to slide into the channel. In the more distal parts of the gully systems, the slopes of valley walls shallow, and steep colluvium gives way to depositional fans formed form sediment transported in gully channels.

2008-09. The 'Dry' Year: No snowbanks were observed in any of the gully channels at our arrival on Dec 3rd, and the alcove snowbanks were significantly reduced in size. The consequence of the reduced snow distribution was that meltwater production was limited to the alcoves, where evidence for sheet flow and limited channel flow was seen in the form of regelation ice found only directly downslope of alcove snowbanks. No evidence for recent fluvial activity/erosion was observed in the lower sections of the gullies (such as soil darkening due to hyporheic zone development and small scale braided channels; Fig. 2), despite temperatures high enough to permit surface melting and runoff (Fig 1). Many of the channels active in 2006-7 were highly subdued (Fig. 2), which is most likely the result of partial infill with windblown sands. Wind speeds in SF were as high as 16 ms^{-1} over the last two years, and small aeolian ripples (λ ~30 cm) had formed in previously active channels.

We found no evidence to suggest that either 1) deep subsurface groundwater springs (below the permafrost) or 2) melting at the surface of the ice table were a potential source for fluvial activity during either season. The correlation between fluvial activity and volume of snow at the start of the two seasons further demonstrates the dependence of snowmelt for fluvial activity to occur. However, despite the lack of fluvial activity, slump blocks still modified channel walls.

Application to Mars: Our findings demonstrate that fluvial activity and erosion can occur in a hyper-arid desert environment as the result of the influence of direct solar insolation on windblown snow deposits that have been concentrated in topographical hollows (i.e. alcoves and channels). The sensitivity of gully activity to snow volume demonstrates the importance of snow accumulation, in addition to temperatures permitting melt generation, in determining the location of gully activity. Hence melting conditions alone cannot form gullies; sufficient surface snow and ice accumulation is also a requirement [4-6]. On Mars this is likely to be determined not only by the latitude dependence of precipitation [8], but also by localized factors which determine where snow is able to accumulate prior to the onset of melting (e.g. such as under the conditions expressed in Fig. 1), and therefore aspect is important.

Finally the higher wind strengths in SF relative to Mars [14] provides insight into the degradational processes that are likely to have occurred between periods in which the martian gullies are active; this can both subdue channel morphology through erosional processes and infill gully features with depositional landforms (Fig. 2). This has the potential to make the interpretation of gully formation more difficult (i.e. whether activity is in the form of incision from fluvial runoff or high sediment slurry flows, or a combination of the two).

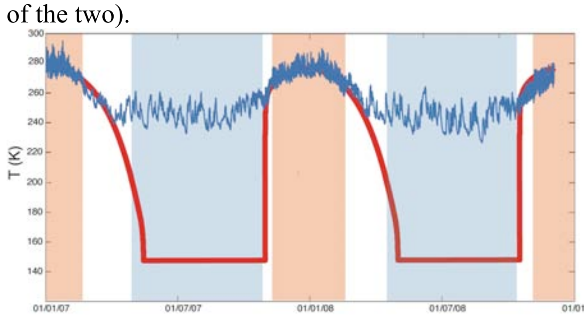

Fig 1. Ground T recorded at top of gully fan in SF between the two field seasons (blue line) compared against equivalent seasons for a martian southern hemisphere, pole-facing slope at 35° obliquity (red line). Pink represents period of melting conditions (T>273 K) on both planets, blue represents periods of surface ice stability (T<200K) for Mars, i.e. when snow accumulation can occur. Mars model generated by LDM, Paris 1D model.

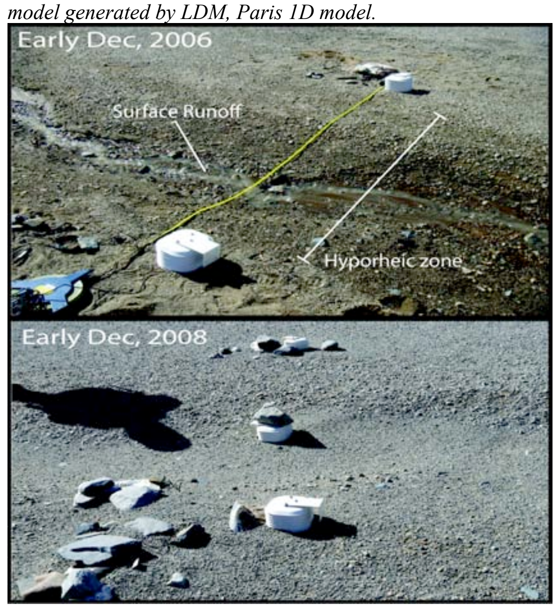

Fig 2. Difference in fluvial activity between the two field seasons as a result of the lack of snow in 2008 relative to 2006.

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