MARS GULLY ANALOGS IN THE ANTARCTIC DRY VALLEYS: GEOLOGICAL SETTING AND PROCESSES. J. W. Head[1], D. R. Marchant[2], J. L. Dickson[1], J. S. Levy[1], and G. A. Morgan[1]; [1]Dept. Geol. Sci., Brown Univ., Providence, RI 02912 USA (james_head@rown.edu), [2]Dept. Earth Sci., Boston Univ., Boston MA 02215 USA (marchant@bu.edu).

Introduction: Malin and Edgett [1,2] initially described a class of young features on Mars that they termed gullies, consisting of an alcove, a channel and a fan. Restricted to middle and high latitude locations, these features were interpreted to have originated through processes related to the presence of liquid water (through groundwater discharge); the potential presence of liquid water on the surface of Mars currently or in the very recent geological past, when liquid water is metastable [3], generated a host of alternative explanations for the gullies [see summary in 4]. Detailed analysis of the conditions under which H_2O could flow as a liquid in the current Mars environment shows a range of conditions under which gully-forming activity is possible [3,5]. Recent observations of changes in gullies, interpreted to mean that a few gullies are currently active [6], have intensified this discussion. Terrestrial analogs to martian environments may provide insight into the processes operating on Mars. For example, the nature of perennial saline springs forming channels on Axel Heiberg Island in the Canadian High Arctic has been used to support the argument that martian gullies formed from subsurface groundwater springs [7]. In this analysis we report on the results of ongoing [8-11] field studies in the Antarctic Dry Valleys (ADV), a hyperarid polar desert analog for Mars [11].

Streams and Gullies in the ADV: The Antarctic Dry Valleys can be subdivided into three microenvironments, each of which has distinctive geomorphic characteristics [11]. The majority of the ADV surface is unconsolidated sediment (e.g., colluvium, till) modified by contraction-crack polygons. Ice-cemented permafrost occurs in most places throughout the ADV and is most commonly encountered at depths of 0-50 cm; above the permafrost table, a wet active layer is seen in the warmer coastal microenvironment zone, a dry "active" layer occurs in the intermediate zone, and in the stable upland zone soil temperatures generally fail to rise above 0^0C, preventing the formation of either wet or dry active layers [11]. Gullies and streams occur in the warmer and intermediate zones, commonly on north-facing slopes, and contain the major geomorphic components (alcove, channel, fan) seen on Mars (Fig. 1-2). Streams and channels vary in width from 1-30 m and can be up to 30 km in length [13]. Lack of pluvial activity and associated distributed runoff means that gully streams have little interaction with the broader landscape [11]. In contrast to the underground aquifer saline spring source in the Arctic Axel Heiberg region [7], streams and gullies in the ADV form from surface top-down melting of snow and ice due to enhanced summer solar insolation [11,13] (Figs. 1-2).

Water Sources: Specific sources for water feeding streams and gullies are due to the melting of surface and very near-surface snow and ice (Figs. 1-2); no deep subsurface springs (below the permafrost base or within the permafrost) have been reported. Because maximum precipitation in the ADV is less than ~10 cm of snow per year [11], other processes are required to concentrate

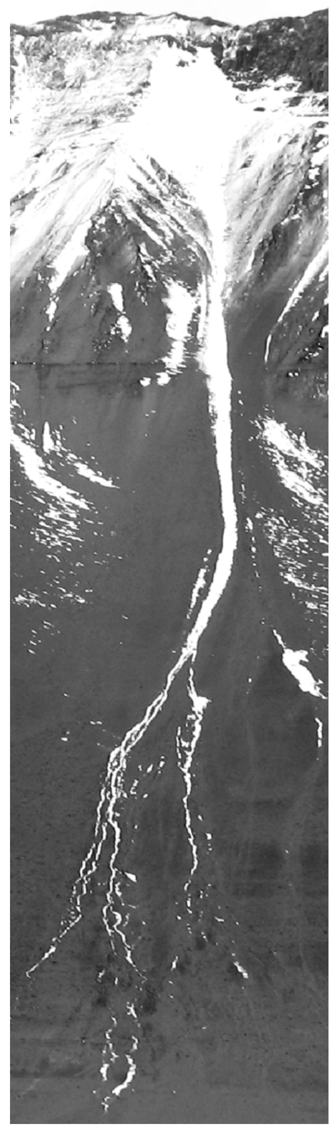

Fig. 1. Gully system in the ADV, consisting of alcove, channel and fan; wind-blown snow has collected in topographic traps (alcove, channels); summer melting causes flow and erosion/deposition.

sources for the meltwater that feeds gully streams; these primarily include glaciers and wind-blown snow accumulations in favorable topographic traps (Figs. 1-2) as follows: 1) surface portions of cold-based glaciers at unique positions related to seasonal insolation intensity and geometry [14] (insolation-induced melting), and 2) annual and perennial snow banks and patches within alcoves and channels [8-10,13]. Melting is enhanced by the lower albedo of some substrates (albedo-induced melting) [11].

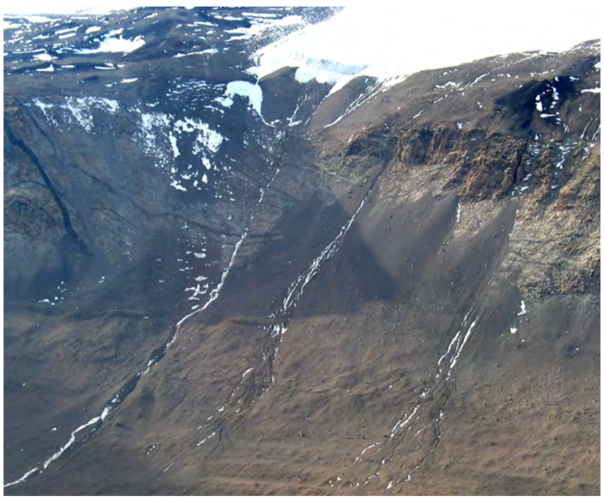

Fig. 2. Example gully systems in the ADV: Surface melting of the glacier at the top forms meltwater which carves the longest channel on the left; note alcoves and fans in two gullies on right and wind-blown snow trapped in all three gully channels.

The Hyporheic Zone: During periods of active channel flow, dark bands form along channel banks and in a broad zone distal to the active surface flow, the surface manifestation of a hyporheic zone (where channel water both enters and exits, altering the volume of water in the channel) [13]. Subsurface flow occurs along the top of the ice table [10]. Lack of a general groundwater system means that the hyporheic zone is very important for water storage, transport, and exchange, and activity can continue there after surface water flow in the channel has ceased [10].

Flow Duration: Streams flow during austral summer for less than 20% of the year, some only for a few days; streams show considerable daily, intra-seasonal and inter-annual variation in flow behavior depending on insolation and air temperature [13], and water supply [8-10]. About half of the stream channels observed in the ADV are currently active; this implies that many of the others date from earlier times [13] and thus may be in the waning stages of formation, or currently inactive.

Stages in Gully Evolution: The range of stream, channel and gully morphologies observed in the different microenvironments in the ADV [8-11,13] suggests that the gullies whose water sources are dominated by seasonal snow patches are in the waning stages of their formation; end-to-end flow of surface water and incision of the channel are clearly required to form the entire gully system (Fig. 1). Once the gully is formed, however, it can remain active at a lower level as long as its topography can capture sufficient snow, and summer temperatures are sufficiently high, to cause melting of the snow and ice [9] (Fig. 2, right). Hyporheic zone flow appears to dominate in the latest stages of gully evolution, and can continue beyond the termination of active surface flow.

Biology: Extreme conditions limit the presence of life in the ADV environment, but streams can be 'oases' of life. Diverse microbial communities are observed in many streams; cyanobacteria, chlorophytes, diatoms, nematodes, rotifers, tardigrades; algal communities grow as mats, can survive long periods (decades) of desiccation and extreme cold in a cryptobiotic state [13]. Abundant algal mats often exist even in those late-stage channels wetted only by annual snow patch melting [9].

Summary: 1) ADV gullies and streams form primarily from top-down melting of cold-based glacial ice and/or annual/perennial surface snow and ice accumulations [8-10] (Figs. 1-2). 2) Significant water transport and storage occurs in the hyporheic zone [13]. 3) Surface water flow in ADV gullies and streams varies widely in occurrence and flux, based on local microenvironments and daily, intra-seasonal and inter-annual variations in insolation [8-11,13]. 4) Between periods of melting and flow, channel water commonly freezes to produce a veneer of surface ice; salts are also deposited [9]. 5) Flow in channels can be maintained beyond the period of active channel carving by topographic trapping of windblown snow and its subsequent melting, producing local ice and sediment deposits in the gully system [9] (Fig. 2).

Application to Mars: These results suggest that on Mars: 1) Gully formation could have resulted from surface sources and top-down melting of annual/perennial snow and ice accumulation [9-10;12]; 2) Gully activity may persist well beyond the initial formation stage through melting of local, trapped snow accumulations within the gully [9]; 3) Melting of such accumulations could produce distal fresh deposits and represent late-stage evolution of the gully system, perhaps analogous to current activity recently reported [6,9] on Mars.

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