GULLY FORMATION ON MARS: TESTING THE SNOWPACK HYPOTHESIS FROM ANALYSIS OF ANALOGS IN THE ANTARCTIC DRY VALLEYS. G. A. Morgan[1], J. W. Head[1], D. R. Marchant[2], J. L. Dickson[1], and J. S. Levy[1]; [1]Dept. Geol. Sci., Brown Univ., Providence, RI 02912 USA (gareth_morgan@brown.edu; james_head@brown.edu), [2]Dept. Earth Sci., Boston Univ., Boston MA 02215 USA (marchant@bu.edu).

Introduction: Gullies, a class of unusually young features on Mars consisting of an alcove, a channel and a fan, were initially interpreted to have originated through processes related to the presence of liquid water, primarily through groundwater discharge [1,2]; the current metastability of liquid water on the surface of Mars generated a host of alternative explanations for the gullies [see summary in 4], including H_2O flowing as a liquid in the current Mars environment [3,5]. This discussion has been intensified by recent observations interpreted to mean that gullies are currently active [6]. One interpretation of the source for the water thought to have formed the gullies on Mars is snow [7]; in this scenario, gullies "…form by melting of water-rich snow that has been transported from the poles to mid-latitudes during periods of high obliquity…" [7]. Among the main features of the model [7] are: 1) Snow is deposited at mid-latitudes during periods of high obliquity and melted at lower obliquity when mid-latitude temperatures increase; 2) Melting produces liquid water that is stable below an insulating layer of overlying snow; 3) Gullies form on snow-covered slopes (through meltwater erosion or due to meltwater seeping into loose slope materials and destabilizing them); 4) Snow patches remain today, protected from sublimation by a layer of desiccated dust or sediment; indeed melting might be occurring today in currently favorable snowpack locations [7].

Terrestrial analogs to martian environments may provide insight into whether snow might serve as a source of water for gully formation, and if so, what specific environments and processes are involved and whether they are likely to occur on Mars. In this analysis we report on the results of ongoing field studies in the Antarctic Dry Valleys (ADV), a hyperarid, cold polar desert analog for Mars [8]. We describe specific occurrences of annual and perennial snow accumulations serving as sources of water flowing in gullies in the ADV, and field analyses of the anatomy of associated gullies.

Streams and Gullies in the ADV: The Antarctic Dry Valleys, a polar desert environment in which sublimation exceeds precipitation, contain streams and gullies in certain microenvironments [11]; many ADV gullies contain alcoves, channels and fans and some flow into ice-covered lakes [12]. Gullies form from surface top-down melting of snow and ice due to enhanced seasonal solar insolation [8,12] and no deep subsurface (below the permafrost) groundwater springs have been reported. Major streams are fed by melting glaciers; meltwater forms at unique positions on some glacier fronts and surfaces related to seasonal insolation intensity and geometry [13] (insolation-induced melting). Melting can be enhanced by the lower albedo of some substrates (albedo-induced melting) [8]. Smaller streams and many gullies are fed by the melting of perennial and seasonal [10] snow pack deposits within the alcoves and channels. Gullies and streams commonly occur on equator-facing slopes. Analysis of ADV satellite images and aerial photographs led us to assess the nature and location of prominent gullies, their distribution as a function of ADV microenvironment, and their similarities to those on Mars [8,14]. On the basis of this, we undertook fieldwork in the ADV in the South Fork of Upper Wright Valley during the 2006-2007 austral summer and studied a series of gully systems along the southern wall of the South Fork of Wright Valley, just south of the Dais (Fig. 1) [9-11]; we report our observations and preliminary results here.

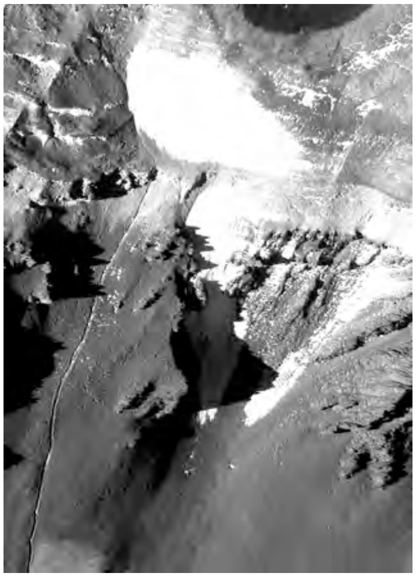

Fig. 1. Perennial and annual snow and ice deposits feeding gully systems in the ADV. Top: satellite view (snow patch is ~500 m wide); bottom: perspective view.

Gully Formational Processes: The northern edge of the Asgard Mountains at Upper Wright Valley contain a number of alcoves and alcove-like terraces and depressions along the margins of the valley (Fig. 1); many of these contain visible snow and ice and some are the source areas for gully systems. We report here on two of these gully systems. In the first, a patch of snow and underlying ice ~500 m wide occurs in a depression on a bench at the northern edge of the Asgard Mountains. A gully system begins at the edge of the snowpack (Fig. 1), about 1000 m above the valley floor, and extends downslope for over 2 km to the floor. Observations of aerial photos for multiple years show that at least the central portions of this snow/ice is perennial. By early December 2006, marginal parts had started to melt, and the channel was occupied by water actively flowing from the ice toward the scarp and cascading over the cliff; the stream was ice-covered in the mornings and became progressively less ice-covered during the day. Although the water in the upper part of the channel was cloudy, the sediment load was minimal and largely confined to bedload movement of sand-sized particles. Subsequent to the flow of water over the scarp, the water was lost in the coarse bouldery deposits on the steepest and most inaccessible parts of the cliff. In the intermediate parts of the slope, the channel cuts into slope colluvium, and displays many of the characteristics of martian gullies, including: v-shaped cross sections, levees and secondary channels [1]. In the more distal parts of the gully system toward the valley floor, the slope shallows and the steep colluvium gives way to a series of fans, which appear to be formed from sediment and reworked colluvium transported in the channel. In the mid to lower reaches of this gully system, water derived from melting of patches of wind-blown snow [10] form intermittent surface flows. Continual end-to end surface water flow in the channel and gully system was not observed in December 2006-early January 2007. There is also significant morphological evidence (in the form of lobe-shaped terraces on the channel floor) that the water supplied to the channel has contributed to its erosion through the mobilization of colluvium above the ice table to cause solifluction and debris slurries.

A second gully system is located less than 200 m to the west in a dark debris tongue (Ferrar Dolerite) extending from a snow and ice-filled alcove (Fig. 1), down to the valley floor; the channel part of the gully system is most prominent in the lower part of the tongue and in the valley below. Channel and water activity in the second gully system were clearly related to the melting of wind-blown snow [10] that had accumulated in the protective environment of the channels during austral winter. At no time in December 2006-early January 2007 was continuous surface flow observed from the alcove to the snowbank sources below. A significant amount of water transport took place in the colluvium both adjacent to the channel, and below it (in the hyporheic zone) along the top of the ice table [10,11]. Melting of snow patches sequestered in the channels was clearly driven by favorable insolation/air temperature conditions (insolation-induced melting). Albedo-induced melting at all scales also influenced water flow; 1) in individual snowbanks where sand had blown on top of the snow, and 2) in the second gully system, where lower-albedo dolerites clearly assisted production of snowmelt relative to other gullies.

Summary: 1) These ADV gullies form from the melting of annual/perennial surface snow and ice accumulations; 2) Surface water flow in ADV gullies and channels varies widely in occurrence and flux, based on local environments and albedo, and daily, intraseasonal and interannual variations in insolation; 3) Flow in gully channels can be maintained beyond the period of active channel carving by topographic trapping of windblown snow and its subsequent melting [see 10].

Application to Mars and Assessment of Snowpack Hypothesis: 1) These observations show that surface snow and ice deposits in a variety of microenvironments in the ADV serve as sources for water channels and morphologies associated with the formation and evolution of gully systems, even when mean annual snow accumulation is minimal [8]; 2) In contrast to the requirement for more ancient favorable conditions for Mars gully formation proposed by [7], these observations show that conditions for melting in the ADV can occur on an annual basis and can fluctuate over a wide range of time scales. Melting does not need to be restricted to a specific obliquity value as favorable insolation conditions could occur in a variety of microenvironments, on a variety of different time scales (e.g., day, season, year, etc.); 3) Water derived from the melting of snow banks can erode channels on slopes by a range of processes over similar time scales [10-11]; 4) The ADV examples show that complete snow cover [7] is not required; wind-blown snow in a region of extremely low annual precipitation is sufficient to form significant local snowpack accumulations [8-11] and snow is likely to form on Mars under a variety of conditions [e.g., 15-16]. We thus conclude that the formation and melting of snow provides a compelling interpretation for the formation of gully systems on Mars [7], particularly in light of the observations of gully-forming processes in the ADV [8-11].

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