

RECENT GULLY ACTIVITY ON MARS: CLUES FROM LATE-STAGE WATER FLOW IN GULLY SYSTEMS AND CHANNELS IN THE ANTARCTIC DRY VALLEYS. J.L. Dickson¹, J.W. Head¹, D.R. Marchant², G.A. Morgan¹, and J.S. Levy¹; ¹Dept. Geol. Sci., Brown Univ., Providence, RI 02912 USA (jdickson@brown.edu), ²Dept. Earth Sci., Boston Univ., Boston MA 02215 USA (marchant@bu.edu).

Introduction: One of the major surprises of the Mars Global Surveyor mission was the discovery of gullies, a class of unusually young features consisting of an alcove, a channel and a fan [1-2]. These features were interpreted to have originated through the flow of liquid water originating from groundwater discharge [1,2], although alternate interpretations have been presented [see 3]. Uncertainty as to the possibility of surface water flow under current martian conditions (below the triple point of H₂O) and evidence that conditions might have been more conducive to melting during higher obliquity conditions in the past, led to the idea that these features might be relict. Recent repeat observations of gullies, however, suggest that at least some gullies are currently active [4], and this has intensified the discussion concerning their formation mechanisms and age.

In order to look for changes since 2000 that might indicate the presence of fluid flow in gully channels, Malin et al. [4] repeatedly imaged thousands of gullies at hundreds of different sites; they ultimately found only two sites at which changes could be documented. These changes included the appearance of light-toned flows that formed at the two locations sometime between the two imaging sequences (8/99-2/04 and 12/01-5/05). On the wall of the crater at the Terra Sirenum site a distinct light-toned flow-like feature appeared in the channel. On the southern wall of a crater at Centauri Montes, light-toned material appears to have flowed down the slope. The two new deposits in each gully have similar apparent brightness, and relatively long, extended digitate distal and marginal branches; they occur on 20-30° slopes, have relatively low relief and divert around obstacles [4]. These characteristics suggest that the material moved slowly, thinned while moving, and branched easily [4]. Malin et al. [4] interpreted these characteristics to mean that the observed deposits were formed by flow of fluidized material through the gullies to their aprons by release of groundwater from underground aquifers “initiated and fed by collapse of an ice-impregnated rock dam creating a brief, low-volume debris flow initially charged with liquid but in which ongoing freezing at both the top and bottom surfaces, bed infiltration, and incorporation of slope sediment and debris increases viscosity, which inhibits downslope and runout motion” [4]. Because the light tone has lasted more than a martian year in an environment where water ice is un-

stable, Malin et al. [4] suggest that the brightness may reflect “replenishment of surface frost by exhalation, elutriation of fine-grained sediment, or precipitation of salts” [4]. Malin et al. [4] conclude that the water flowed on the surface of Mars during the last decade and that it was released from an underground aquifer source.

Terrestrial analogs to martian environments may provide insight into the processes operating on Mars, and the origin and evolution of gullies. Here we report on the results of ongoing field studies of gullies in the Antarctic Dry Valleys (ADV), a hyperarid, cold, polar desert analog for Mars [7]. We address the questions: What processes are responsible for gully formation? What processes are responsible for late-stage gully modification? How do ADV analogs help to evaluate and understand the evidence [4] for current gully activity on Mars?

Gullies in the ADV: Streams and gullies in the ADV form from the top-down melting of surface snow and ice due to enhanced seasonal solar insolation [7-8] and albedo-induced melting, in contrast to underground aquifer [1-2] or subsurface saline spring sources [5-6]. Observed sources for ADV streams and gullies include: 1) portions of cold-based glacier surfaces and fronts [8-9], and 2) annual and perennial snow banks and patches in alcoves and channels [7-8]. Many ADV gullies display the major geomorphic components of Mars gullies (alcove, channel, fan) and commonly occur on equator-facing slopes. Streams flow during austral summer, for less than 20% of the year, some only for a few days; they show considerable daily, intra-seasonal and inter-annual variation in flow behavior depending on insolation and air temperature [8]. About half of the stream channels observed in the ADV are currently active; many others date from earlier times [8] and thus may be in the waning stages of formation, or currently inactive. The range of stream, channel and gully morphologies observed in the different microenvironments in the ADV [7-8] suggests that some gullies are in the waning stages of their evolution; once a gully is formed it can remain active at a lower level as long as its topography can capture sufficient winter snow, and the summer temperatures are sufficiently high to cause melting of accumulated snow and ice.

Anatomy of Late Stage Activity in ADV Gully Channels from Melting of Winter Snowpack:

Analysis of gullies in the 2006-2007 austral summer field season [10-12] provided a basis to assess late stage gully activity and associated processes. On the equator-facing slopes of the South Fork of Upper Wright Valley (Fig. 1a-b), the bottom and sides of gully channels contained elongate accumulations of snow and ice up to 1-2 meters thick and a few meters to over 100 m long (Fig. 1c). Careful monitoring of these snow patches during November-January showed that they rapidly shrank due to sublimation and melting, breaking up into a series of smaller patches that ultimately disappeared. During sunny days, melting associated with these separated patches coincided with flow of water down the channels. Stream flow velocities were more rapid than flow advance rates due to the fact that as the surface flow advanced, it soaked into the ground creating the marginal and distal parts of the hyporheic zones (Fig. 2). Advance rates were clearly moderated by insolation and air temperature: clear, warm, calm days were characterized by more rapid advance, cloudy days by much less rapid advance, and mixed sunny/cloudy days by multiple stages of advance and retreat. When the sun was relatively low in the sky (evening and night) the melting decreased, the water flow began to retreat (soaking into the hyporheic zone) and the upper part of the water in the channel froze, forming a sheet of ice. Meltwater flowing through the hyporheic zone was sealed between the ice cement table and this surface ice during the night. When heating and melting resumed, the seal breached, and water advanced rapidly in the areas of the just previously formed hyporheic zone and then slowed again when reaching parts of the channel floor not yet wetted this season. This process was repeated daily until advancing flows from individual snow patches overtook another snow patch; at this point, due to encountering an established hyporheic zone, channel flow increased in velocity and flux, rapidly overtook the next advancing front, and caused an immediate increase in the advance rate. Maximum advance for one gully/channel system occurred on an almost continuously sunny day during which time at least six of the major snow patches were interconnected by flow. As the snowpacks gradually dissipated, there was not enough supply to yield continuous surface flow. Subsequently, remaining snowpack meltwater flowed through the subsurface, emerging at slope breaks down-channel (Fig. 3). Ultimately in some gullies/channels, melting and sublimation exhausted the supply of surface water contributions, and surface flow dwindled and ceased, with the upper few cm of the channel visibly drying. Excavation showed that the hyporheic zone was declining by surface evaporation, and subsurface drainage; the substrate in the hyporheic zone below the for-

merly active channels were damp down to the top of the ice table (about 15-25 cm), and in some cases the lower few cm were saturated with water flowing along the top of the ice table to create a distal zone of surface dampening.

Summary: 1) A wide range of gully activity occurs in the ADV and variations are seen in both space (microenvironments [7]) and time [8]. Less than half of the ADV gullies are currently active, and many of those, such as the ones described here, are active for only a short part of the austral summer and then only locally in parts of the gully. 2) Gully water-flow activity can extend well beyond the period of major topographic formation of the gully. 3) A major mechanism for the extended lifetime is topographic trapping of wind-blown snow in the austral winter and its heating and melting in the austral summer. 4) Gully water-flow activity can continue as long as snow is deposited there and seasonal conditions are conducive to the melting and flow of water (insolation-induced melting); the presence of low-albedo materials in the snowpack (wind-blown sand) can preferentially prolong this activity (albedo-induced melting). 5) Bright deposits can be produced in the gullies by formation of ice (channel floor and distal zone) and deposition of salts (edge of channel in the hyporheic zone); water flow continues under the ice cover.

Application to Mars and Recent Activity: 1) Activity was detected in only a small number of gullies on Mars (2 out of thousands studied [4]) over a multi-year period; the low level of current activity of the Mars gullies [4] suggests that many of them may be in later stages of evolution, subsequent to the main period of channel formation. 2) Deposits and activity in the two Mars examples are concentrated in the channel section of the gullies and in their distal regions (the bright digitate deposits) [4]; this is similar to the location and characteristics of the deposits formed in the ADV from melting of sequestered wind-blown snowpack, and water flow into the distal fan portion of the gully system. 3) The deposits on Mars are bright relative to their surroundings [4]; in the ADV cases studied, diurnal freezing of the channel formed bright ice, and variations in wetting and evaporation of the hyporheic zone deposits bright salts. 4) Recent gully activity on Mars occurs on crater interior walls [4]; gully presence and activity in the ADV is a function of microenvironment [7]. On the basis of these observations, we suggest that recent gully activity reported on Mars [4] may be due to late-stage activity caused by seasonal melting of windblown snow trapped and accumulated within the channel in the winter, similar to a mechanism suggested for gully formation as a whole [13].

References: [1] M. Malin and K. Edgett, *Science*, 288, 2330, 2000; [2] M Malin and K. Edgett, *JGR*, 106, 23429, 2001; [3] MEPAG SR-SAG, *Astrobiology*, 6, 677, 2006; [4] M. Malin et al., *Science*, 314, 1573, 2006; [5] J. Heldmann et al., *JGR*, 110, E05004, 2005; [6] J. Heldmann et al., *Arc.*, *Ant. Alpine Res.*, 37, 127, 2005; [7] D. Marchant and J. Head,

Icarus, in revision, 2007; [8] D. McKnight et al., *BioScience*, 49, 985, 1999; [9] A. Fountain et al., *BioScience*, 49, 961, 1999; [10] G. Morgan et al., *LPSC 38*, 1656, 2007; [11] J. Head et al., *LPSC 38*, 1617, 2007; [12] J. Levy et al., *LPSC 38*, 1728, 2007; [13] P. Christensen, *Nature*, 422, 45, 2003.

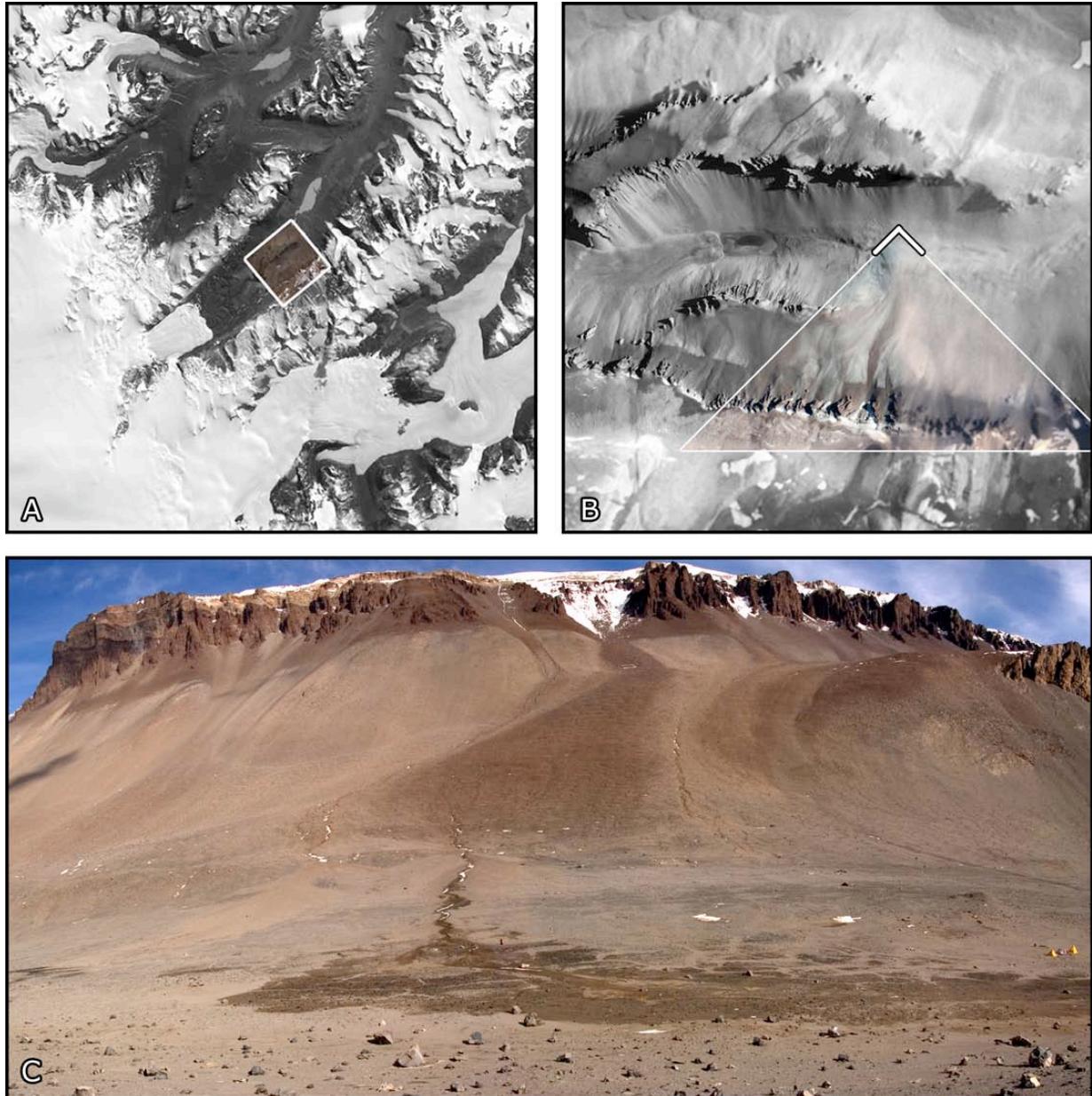


Figure 1. A) Landsat 7 orbital image of the Dry Valleys centered on Upper Wright valley. Central box is the context frame for B. B) Composite of Landsat 7 and IKONOS orbital image data of the South Fork of Wright Valley. The context triangle shows the viewing angle for C. C) Panoramic image of the southern wall of Wright Valley. The snow in the alcoves at the crest of the wall supply water for the gullies which trend downslope. In the winter, the small amount of snow that does fall in the valley is redistributed by wind and accumulates in local traps such as the alcoves and the gully channels themselves. The snow then melts in the summer to carve the observed channels and expand the hyperheic zone (See Fig. 2).

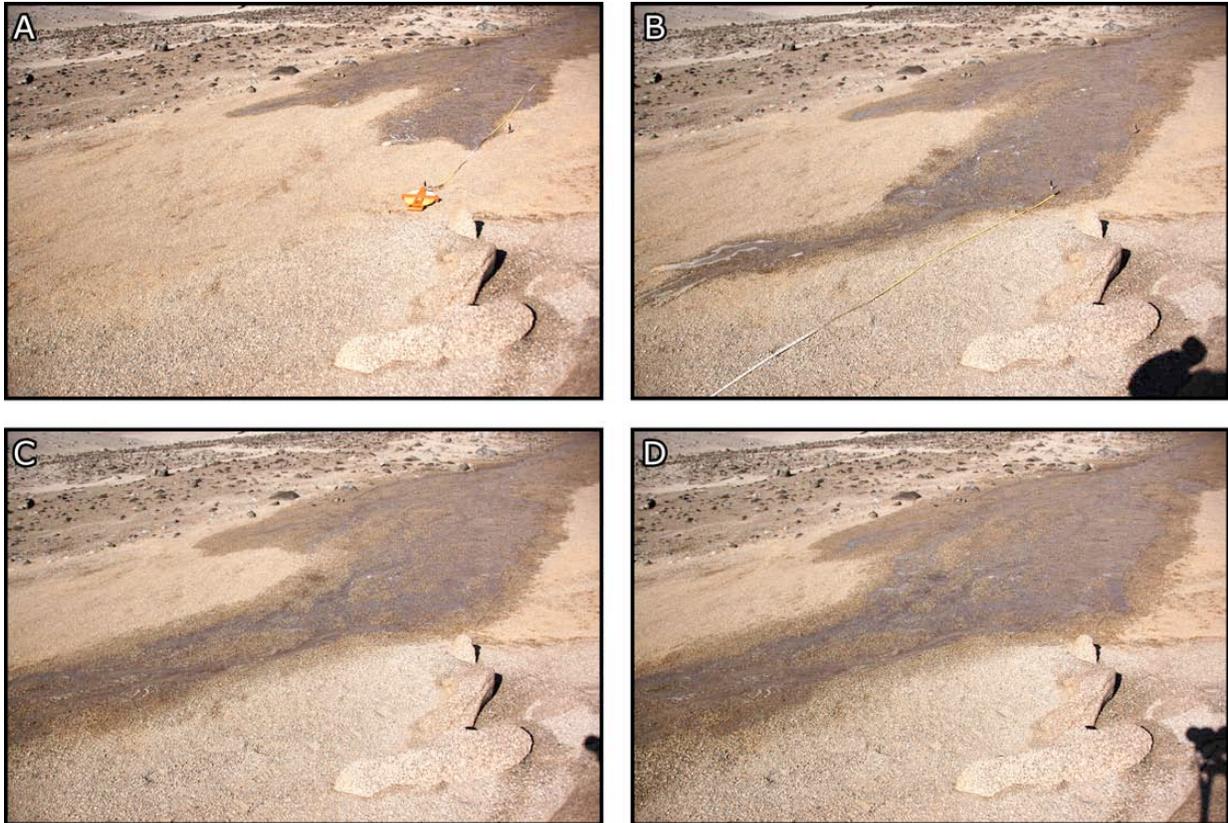


Figure 2. Time-lapse sequence of flow on the surface and through the subsurface, as shown by the expansion of the hyporheic zone in the near-subsurface. Each frame was taken 9 minutes apart.

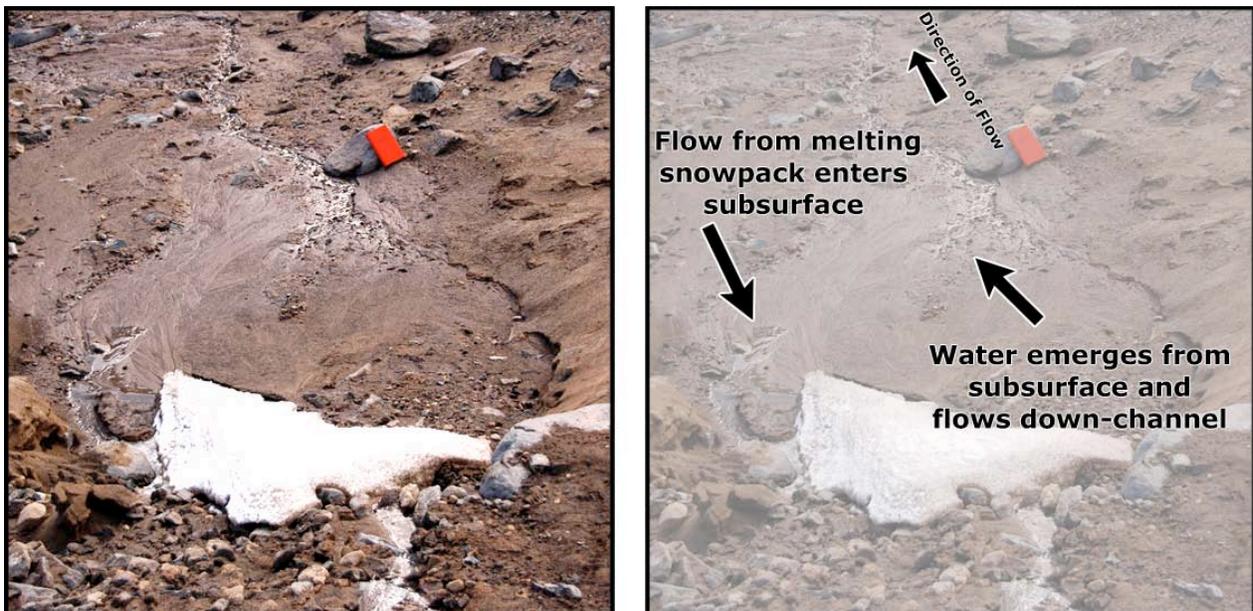


Figure 3. Down-channel view of flow through an Antarctic Dry Valley gully. Surface snowpacks melt and erode to yield surface flow (left). Flow persists on the surface for less than a meter before it migrates through the porous subsurface, emerging from beneath a group of small rocks less than a meter down-channel (center). This water then flows on the surface, later connecting with additional snowpacks.