GULLY FORMATION ON MARS AND EARTH: THE TRANSITION FROM GLACIAL ACTIVITY TO GULLY DEPOSITIONAL PHASES. G. A. Morgan[1], J. W. Head[1], J. L. Dickson[1], D. R. Marchant[2], and J. S. Levy[3]. [1]Dept. Geological Sciences, Brown University, Providence RI 02912, [2]Dept. Geology, Boston University, Boston MA 02215, [3]Dept. Geology, Portland State University, Portland OR 97207 (gareth_morgan@brown.edu).

Introduction: The discovery of gullies on Mars [1,2] resulted in a wide variety of proposed candidate mechanisms for formation but ensuing analyses have shown very strong latitude and orientation dependencies on their distributions [3-6]. These constraints have been interpreted to require: 1) a volatile on or near the surface as a source of liquid water, and 2) insolation and slope orientation as important factors in the gully formation process [7]. Thus, recent studies have focused on two categories of interpretation for the source of the volatiles: 1) "breached groundwater aquifers" in which liquid water at shallow depth beneath the melting isotherm suddenly erupts, and 2) "surface/near surface melting" in which ice at the surface or within the uppermost layer of soil melts during optimal insolation conditions. Furthermore, a recent synthesis of gully observations [7] has shown that: 1) cold trapping of seasonal H_2O frost occurs at the alcove/channel level on contemporary Mars, 2) gullies are episodically active systems, 3) gullies preferentially form in the presence of deposits plausibly interpreted as remnants of the Late Amazonian emplacement of ice-rich material, and 4) gully channels frequently emanate from the crest of alcoves instead of the base, arguing against a groundwater model [7]. On the basis of these developments, recent attention has focused on mechanisms that involve the episodic melting of atmospherically emplaced snow and ice under spin-axis/orbital conditions characteristic of the last several million years [8-15]. A key question is the relationship of the presence and accumulation of recent snow and ice in association with gullies to adjacent deposits of potential glacial or ice age origin [12, 16-20]. What clues can we derive from examining the related ice-rich deposits about the nature and sources of water that appear to have played a key role in gully formation? In this analysis, we focus on an assessment of two specific examples on Mars (Fig. 1, 2,3) and a very similar feature in the North Fork of Upper Wright Valley in the Antarctic Dry Valleys (Fig. 4a,b).

Newton Crater: A young 10 km diameter crater on the eastern margins of Newton Crater shows stratigraphic relationships that represent multiple episodes of glacial advance and retreat. Gullies are nested in spatulate depressions, interpreted to be the beheaded portions of the remnant glacial deposits. The gullies form from surface melting of snow and ice following the final stages of glacial recession [12]. Furthermore, multiple phases of gullies can be seen, with earlier gully fans being deformed and later ones superposed. Seasonal water snow/ice deposits are observed in the vicinity of the gully alcoves. The presence of gullies as the latest stage event in the declining glacial environment, particularly in the former glacial snow and ice accumulation zone, further implicated surface snow and ice deposits as a possible source of water to form the gullies [12].

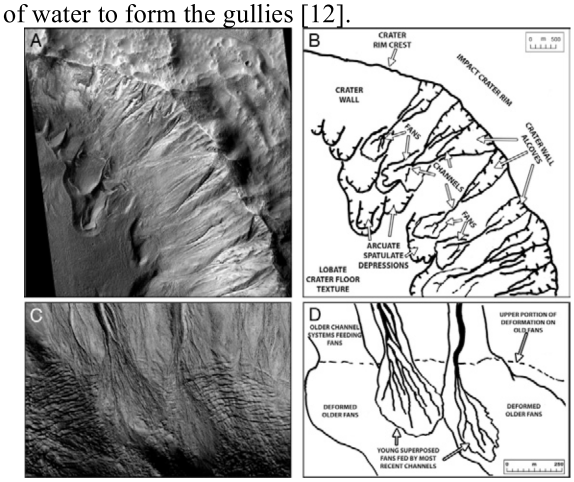

Fig. 1. Superposition of gullies on earlier glacial deposits [12].

Crater at 41°S, 156°E: In this crater (Fig. 2) a suite of gullies is observed with fans that superpose hollows bounded by arcuate ridges [7] of the type that others have interpreted to be of glacial origin [12, 17,19,20]. One alcove hosts what is interpreted to be [7] evidence for viscous flow of ice-rich material: an extended alcove contains material that is lineated downslope, similar to debris-covered glacial systems or possible rock glaciers on Earth. Thus, following large-scale glaciation, gully-forming processes appear to have involved ice-rich deposits at some time during their evolution in these cases.

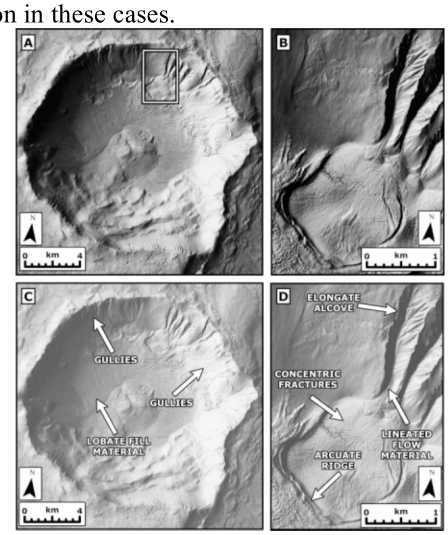

Fig. 2. Setting for ice-rich gully deposits [7].

North Fork of Upper Wright Valley: We have documented active gully formation in the nearby South Fork of Upper Wright Valley on equator-facing slopes, from top-down melting of annual and perennial snow, and descent of the melting isotherm through a dry permafrost layer to the top of the ice table [11]. On a pole-facing slope in North Fork, an example is seen of a very different gully setting, more similar to the subset of the Mars gully population described above (Figs. 1, 2). In this example (Fig. 3 right, Fig. 4), there are three major components: 1) Convex-Outward Ridge: An arcuate, convex outward, asymmetric ridge about 250 m wide, with its steep-side generally outward, forms a 500-600 m wide depression. The ridge is surfaced by abundant polygons and tan material derived from weathered granites outcropping adjacent to the dolerite sill in the cliffs above (in contrast to the interior lobes and the scree slopes derived largely from the darker dolerite units). The ridge is characterized by widespread polygons, and is breached on its south-southeastern side. 2) Dark lobes: A series of lobes, all containing polygons, emerges from the major alcove and descend downslope; one main lobe fills the upslope part of the depression, generally conforming to the shape of the depression. Polygons do not appear to show any deformation and no major flow-related ridges or structures have yet been observed. The dark lobes are similar in appearance to features in the Dry Valleys interpreted to be viscous flow features representing ice and meltwater-assisted downslope movement (gelifluction/solifluction lobes) [21]. These features are clearly stratigraphically younger than the depression they fill. 3) Gullies: Superposed on the dark lobes are at least two generations of gullies, with narrow channels forming in the upper reaches of the valley wall, emerging from the near-bottom of the alcove, and forming fans on top of the lobes. Snow clearly fills some of the gully channels (Fig. 4) strongly suggesting (as with the case in South Fork [11]) that melting of this snow is part of the water source for their erosional activity. Distal sediments occur at the base of the fans, obscuring the polygons on the adjacent lobe surface. In summary, three major phases are observed: 1) Glacial phase: Accumulation of snow and ice in the alcove and outward flow to form the convex-outward ridge; decrease in glacial conditions causes loss of ice and beheading; 2) Viscous flow phase: Accumulation of smaller amounts of snow and ice in alcove and formation of debris-rich viscous flow features; 3) Gully phase: Smaller amounts of very localized snow and ice melt under warmer climatic conditions to form superposed gully features. Note that the fixed geometry and orientation of the alcoves ensures that snow and ice accumulation will take place preferentially in the alcove, creating the three sequential phases reflecting climate change trends, and linking them all to surface accumulation of snow and ice and its fate under changing climatic conditions.

Summary: Terrestrial analogs in Mars-like environments [21] provide assistance in understanding the relationship of climate-related features associated with gullies on Mars and illustrate the common link to surface snow and ice deposition and melting under changing climatic conditions.

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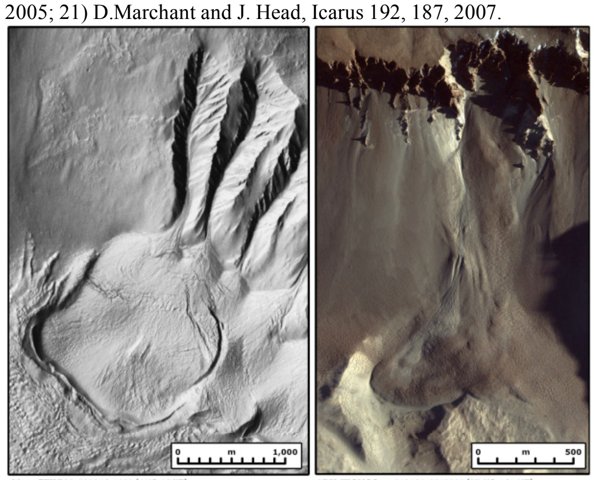

Fig. 3. Comparison of Mars example of arcuate ridge, depression filling, and gullies (left, see Fig. 2 [7]) and arcuate morainal ridge containing lobes and superposed gullies in the North Fork of Upper Wright Valley, Antarctic Dry Valleys.

Fig. 4. Detail of North Fork lobe at base of slope below alcove. Note the two superposed fans on the lobate deposit, nested in the depression formed by the convex outward ridge interpreted as a moraine.