TESTING A DEBRIS FLOW SOURCE AREA AND INITIATION HYPOTHESIS FOR SIMPLE 'CLASSIC' MARTIAN GULLIES. N. L. Lanza[1,2], G. Meyer[1], H. Newsom[2], R. Wiens[3], and C. Okubo[4], [1]Earth and Planetary Sciences, MSC03 2050, 1 University of New Mexico, Albuquerque, NM 87131 (nlanza@unm.edu), [2]Institute of Meteoritics, University of New Mexico, Albuquerque, NM, [3]Los Alamos National Laboratory, Los Alamos, NM, [4]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ.

Introduction: On Earth, gullies indicate the presence of liquid water. Terrestrial gullies form by a number of different mechanisms, most notably through runoff-dominated surface erosion and infiltration-triggered slip [1]. However, the temperature-pressure environment on Mars today does not allow for liquid water precipitation, nor is liquid water stable on the surface for any significant time periods. Thus, the presence of geologically modern gullies on the martian surface presents an interesting problem.

Here, we examine characteristics of terrestrial flow features and compare these to martian gullies. We find that many martian gullies share many key characteristics with debris flow erosional and depositional features. If martian gullies are formed by a debris flow mechanism, and liquid water causes initiation of of the flow by melting of a near-surface layer that broadly underlies slopes (causing saturation, increased pore pressure, and decreased shear strength), then gully head locations should exhibit the same contributing area-slope relationship found for terrestrial debris flow [2]. We are currently examining gullies in a limited study area with well-defined channel heads, limited evidence for multiple flows (e.g. small fans below the gullies) and relatively simple associated alcove regions. Initial results are forthcoming. If a consisitent area-slope relationship is found for these martian gullies, it will provide strong evidence for gully formation as the result of saturation of surface materials by a liquid generated by melting of a near-surface layer.

Why debris flow?: There are several mechanisms of formation for gullies on Earth, and clues about the initiation mechanism can be found in the morphology of the final form. Malin and Edgett [3] identified three main components of gullies: an alcove, a channel, and a debris apron. On Earth, the alcove-channel-apron morphology is often associated with debris flows [4, 5]. The major evidence for debris flow is the presence of a well-defined, leveed channel [5]. An alcove near the top of the channel is also expected, resulting from the loss of material during flow initiation, and may continue to develop over numerous successive events. A debris apron or fan may also occur near the bottom of the slope when debris flow materials cease to flow. In terrestrial debris flows, the formation of the channel is due primarily to scouring of the slope as the debris flow moves past and acquires more slope material [6]. Both Costard et al. [7] and Mangold et al. [8] have also noted the resemblance of feature associated with martian gullies to terrestrial debris flow features.

A debris flow begins as a slide of rigid material, which occurs when the material becomes saturated. This material surges downslope in response to gravity, and more than one surge may occur during a single event. Debris flows can have peak velocities of 10 m/s [9] and can flow distances in the kilometer range [10]. Observations of debris flows show that the material appears to become fluid as it flows along the slope, and becomes rigid again as it is deposited [9]. It has commonly been thought that the solid and liquid fractions of the flow act as one fluid material. Pierson and Costa [11] examined the rheologic response of different sediment-water mixtures, and determined that debris flow is a non-Newtonian fluid that exhibits plastic flow behavior. Iverson [9], however, points out that it is difficult to explain the behavior of debris flow with a single rheology. Instead, he suggests that the interaction between the solid and fluid components leads to the observed behavior, which points to an ever-changing rheology as the flow develops.

It is important to note that the name 'gully' indicates a steep-walled incised channel, but does not imply a specific flow process that caused the erosion. On Earth, gullying is an erosional process that often results from surface runoff produced by precipitation [12]. Debris flow is a mass wasting process that may also cause gully erosion.

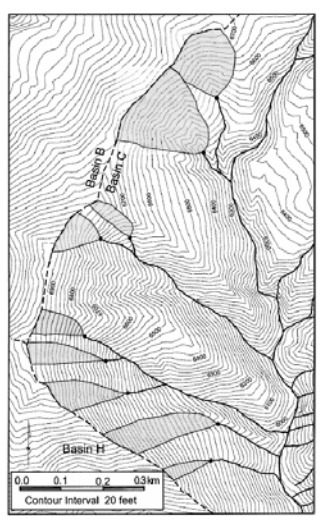

Figure 1. Example of mapping upslope contributing areas to debris flows initiation locations. Solid circles mark initiation locations, and black lines are the flow paths. Shaded polygons denote the contributing area. From Cannon, et al. [1].

The topographic signature of debris flow: Montgomery and Dietrich [2] examined the starting locations of channels in relation to the slopes above the channel, and found a relationship between the drainage area and the slope gradient, with slope decreasing as the drainage area increases. The drainage area is an area above the channel head that focuses shallow subsurface throughflow liquid into slope concavities. On Earth, this liquid is often surface runoff from rainfall. On Mars it is much more likely to be from a subsurface source. However, in both cases liquid is likely to move downslope through the regolith as throughflow. [2] suggest that channels will begin at the first point downslope where there is a large enough source area to support them, i.e. failure occurs at the point on the slope where the slope materials are saturated to a critical depth (and thus a critical pore pressure to induce failure), which requires a minimum amount of water from upslope.

The source area is defined as the region from the top of the drainage divide downslope to the point of initiation at the top of the channel (Figure 1) [1, 2]. The area-slope relationship described by [2] is the relationship between the source area and the gradient of that slope area. As the slope becomes steeper, failure presumably becomes more likely given the increase in shear stress. In addition, throughflow is also concentrated more quickly on steep slopes. This idea is seen in theoretical calculations by Montgomery and Foufoula-Georgiou [13], which show that smaller source areas are needed to initiate channels on steeper slopes. Figure 2 shows the relationship between contributing area and slope for 84 debris flows at Storm King Mountain, CO.

It should be possible to measure this area-slope relationship on Mars using image and topography data sets. If the area-slope relationship holds for martian gullies that have distinct channel heads and are not complicated by many subsequent dry mass failures above the oversteepened channel head, it will point to a liquid agent of formation and potentially a debris flow mechanism.

Implications: If the area-source relationship holds for martian gullies, then the source region of liquid is likely to be distributed broadly over slopes in the near-surface regolith. Past work suggests that liquid water is the most likely agent of formation due to the temperature-pressure environment on Mars. Proposed sources of water include near-surface ice [7], snowmelt [14], and aquifers [15, 16, 17]. While ice may be deposited at and stable in the near-surface at the gully locations at higher obliquities, models do not predict either its abundance or long-term presence today (e.g. [18]). In addition, it is unclear how water from snowmelt would be stable long enough to saturate the slope material. However, both near-surface ice and snowmelt remain good candidates for saturation of slope materials given that they operate at the surface. Aquifers are much less likely to cause saturation distributed broadly over slopes near the surface due to the fact that they are predicted to be stable at greater depths from the surface and discharge along discrete, low-permeability horizons or at footslopes [17]. Regardless, if the gullies are found to be recent debris flows on Mars, this will necessitate a reevaluation of the current models of water stability at the surface.

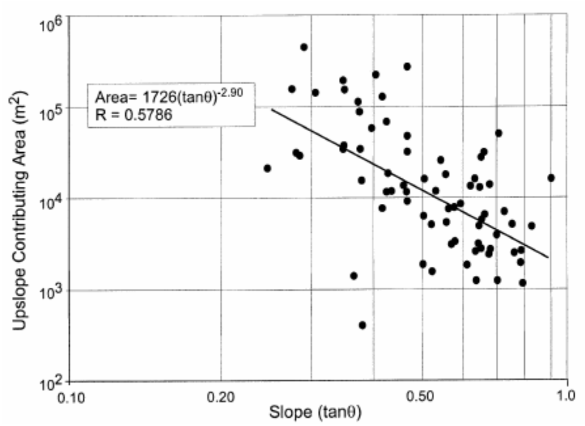

Figure 2. Upslope contributing area as a function of its average gradient. From Cannon et al. [1].

References: [1] Cannon, S.H. et al. (2001) *Geomorph.* 39, 171-188. [2] Montgomery, D.R. and Dietrich, W.E. (1988) *Nature* 336, 232-234.[3] Malin, M.C. and Edgett, K.S. (2000) *Science* 288, 2330-2335. [4] Johnson, A.M. and Rodine, J.R. (1984) in *Slope Instability* eds. Brundson, D. and Prior, D.B., New York: Wiley. [5] Hungr, O. et al. (2001) *Env.& Eng. Geo.* VII, 3, 221-238. [6] Stock, J.D. and Dietrich, W.E. (2006) Geo. Soc. Am. Bull. 118, 9/10, 1125-1148. [7] Costard, F. et al. (2002) *Science* 295, 110-113. [8] Mangold et al. (2003) *J. Geophys. Res.* 108, E4, 5027. [9] Iverson, R.M. (1997) *Rev. Geophys.* 35, 3, 245-296. [10] Malet, J.P. et al. (2005) *Geomorph.* 66, 215-235. [11] Pierson, T.C. and Costa, J.E. (1987) *Geol. Soc. Am., Rev. Eng. Geo*. VII, 1-12. [12] Ritter, D.F. et al. (2002) *Process Geomorphology*, 4th Ed. New York: McGraw Hill. [13] Montgomery, D.R. and Foufoula-Gergiou, E. (1993) *Water Resour. Res*. 29, 12, 3925-3934. [14] Christensen, P.R. (2003) *Nature* 422, 46-48. [15] Mellon, M.T. and Phillips, R.J. (2001) *J. Geophys. Res*. 106, E10, 23165. [16] Gilmore, M.S. and Phillips, E.L. (2002) *Geology* 30, 12, 1107-1110. [17] Heldmann, J.L. and Mellon, M.T. (2004) *Icarus* 168, 285-304. [18] Kossacki, K.J. and Markiewicz, W.J. (2004) *Icarus* 171, 272-283.