MARTIAN SLOPE STREAKS AND GULLIES: ORIGINS AS DRY GRANULAR FLOWS. A.H. Treiman[1] and M.Y. Louge[2], [1]Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058 <treiman@lpi.usra.edu>, [2]Sibley Shool of Mechanical and Aerospace Engineering, Cornell University, Ithaca NY 14835 <MYL3@cornell.edu>.

Streaks and gullies (Figs 1,2) are common on Martian slopes, and are geologically young; slope streaks have formed during the last few years of Mars Global Surveyor imaging. Both slope streaks [1] and gullies [2] involve flow of granular material, but it is not clear whether liquid water (or another suspending agent) was involved. The possibility that liquid water was involved makes gullies and slope streaks important for understanding Mars' recent climate and for the hope of extant life near its surface.

Here, we show that significant features of slope streaks and gullies are consistent with dry flows of granular material. Liquid water may not be required.

Granular Flows: Recent progress in the theory of granular flows has allowed good quantitative predictions of their behavior [3-5]. The crucial advance was recognition that inelastic collisions and enduring frictional contacts must be included in energy and momentum balances in the flows. These theoretical models [3,4] have replicated well the behaviors of steady granular flows or avalanches on rigid surfaces: slope angles for flow, flow thicknesses, flow rates, and dynamic behaviors (like upward moving waves [3]).

Once initiated, granular avalanches propagate by at least two mechanisms [5-7]. Avalanches propagate only downhill on a shallower or less oversteepened slope, covered with a thinner layer of mobile grains. These avalanches develop a triangular plan form, opening downward at a constant angle Ψ [5-8,1]. The angle Ψ increases with slope steepness and oversteepening, to a point at which another mechanism begins. On steeper and more oversteepened slopes, and those with thick layers of mobile grains, avalanches propagate uphill and excavate deeply into the slope [6,7].

If a flow contains grains of different sizes, they can become segregated [9-11]. In unconfined flows over rough surfaces, larger grains rise to the flow tops by several mechanisms including sieving and squeeze expulsion [9,12]. Flow tops move faster than bases, thus transporting larger grains to the flow front and edges, where they tend to remain [10,12,14]. The abundance of larger particles at a flow's front can cause instability if the larger particles are rougher than the smaller. A retardation in the flow front would then attract larger particles, which would retard that point more, and split the flow front into fingers [10].

Slope Streaks: Slope streaks (Fig. 1) are commonly interpreted as granular flows [1], avalanches of thin layers of bright, wind-deposited dust exposing

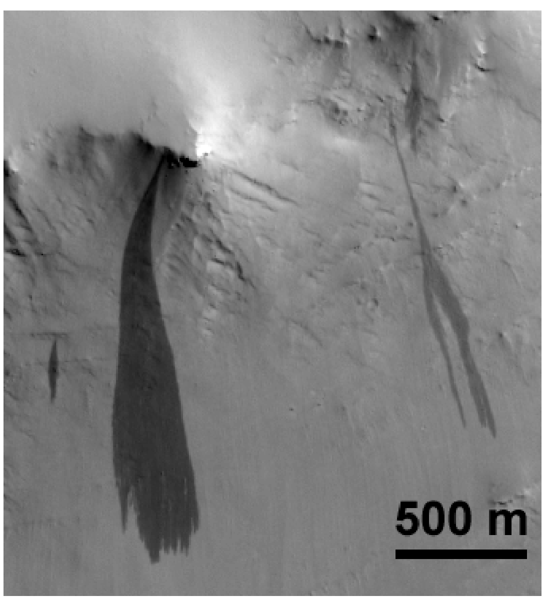

Figure 1. Typical slope streaks, Arabia (MOC M04-02746) [1]. Streaks start at topographic irregularities and spread downhill. Note fingering at toe of left streak.

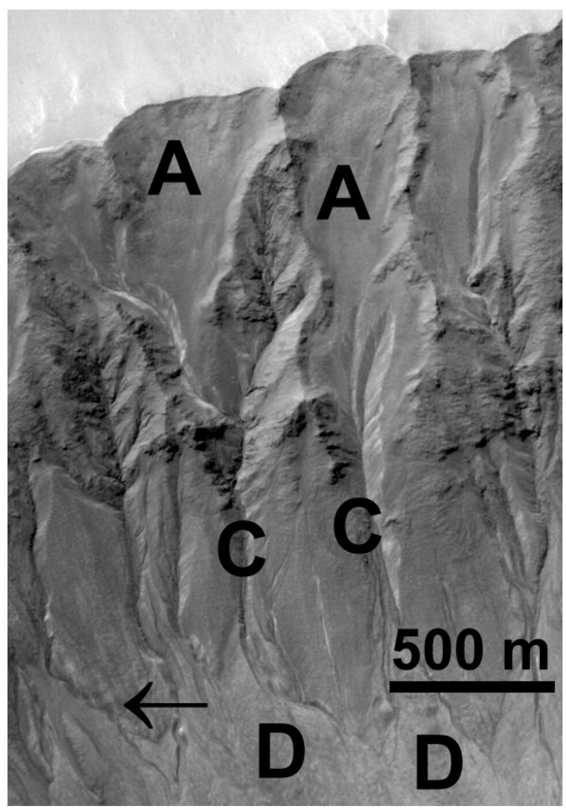

Figure 2. Typical gullies, Gorgonium Chaos (MOC M14-01830) [19]. A = alcove, C = channel, D = depositional cone/fan. Arrow points to sinuous channel.

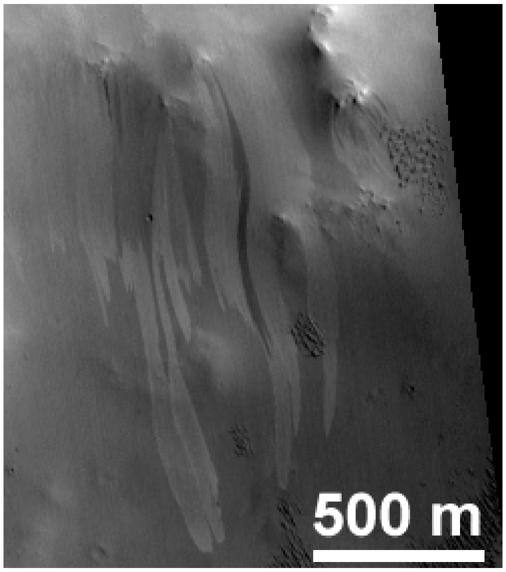

Figure 3. Slope streaks, Arabia (MOC M03-07572 [1]). Note variety of color contrasts, especially streaks at bottom of image with bright borders and darker cores.

darker sand or rock beneath. Slope streaks also have been interpreted as granular solids dispersed in water, solids suspended in vapor, or water alone [15-18].

As noted by Sullivan et al., the slope streaks correspond well to the triangular avalanches of Daerr and Douady [6,7], with respect to thinness, initiation at a point, propagation only downhill, propagation with a characteristic opening angle, and variation of the opening angle with slope character (right side, Fig. 1). Commonly, slope streaks have scalloped lower edges (left side, Fig. 1), which are similar to fingering instabilities [10] that arise in avalanches of mixed grains.

The color contrasts of slope streaks may also be explained if the streaks are avalanches of mixed grains – different size grains having different colors. For a typical slope streak (Fig. 1) darker coarser grains would rise to the flow tops over smaller brighter grains. Similarly, atypical slope streaks with darker cores and brighter margins (Fig. 3) could represent avalanches of larger brighter rougher grains and smaller darker smoother grains.

Gullies: Martian gully landforms (Fig. 2) represent debris flows or massive avalanches. They typically consist of: an alcove near the top of a slope; a depressed channel (straight or sinuous) beneath the alcove; raised levees commonly bordering the channels; and a fan- or cone-shaped mound beneath the channel, representing material that flowed down the channel [2,19,20]. Most workers have emphasized the importance of liquid water in gully formation, but have differed over the source(s) of the water [2,21-24]. Other workers have called on granular solids suspended in dense gas [25,26].

The geomorphology and geology of gullies is also consistent with formation as dry granular flows [20]. Gullies' alcoves may correspond to the heads of upward-propagating avalanches in the experiments of [6,7]. Leveed channels are reported in laboratory flows of dry particulates [27], and naturally in dry pumice flows [13,14]. Sinuous channels are known in dry pumice flows [13,14], but have not (to our knowledge) been produced in the lab or explained by theory.

Discussion: Many features of Martian slope streaks and gully landforms are similar to those produced in lab experiments on dry granular flows, and/or explicable by theories of dry granular flows. In particular, slope streaks and gullies correspond closely to the two avalanche modes described by Daerr and Douady [6,7], triangular and upward-propagating respectively. These correspondences suggest that slope streaks and gullies may both be dry granular flows – separate manifestations of the abundance of dry granular materials at the Martian surface. Our observations do not preclude liquid water in these Martian flows, but suggest that it may be unnecessary.

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