MARTIAN SLOPE STREAKS AND GULLIES: ORIGINS AS DRY GRANULAR FLOWS.

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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].

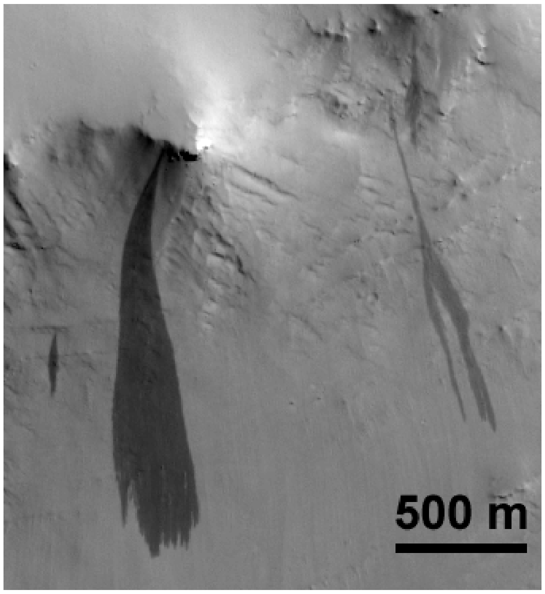

Figure 1. Typical slope streaks, Arabia (MOC M04-02746) [1]. Streaks start at topographic irregularities and spread downhill. Note fingering at toe of left streak.

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

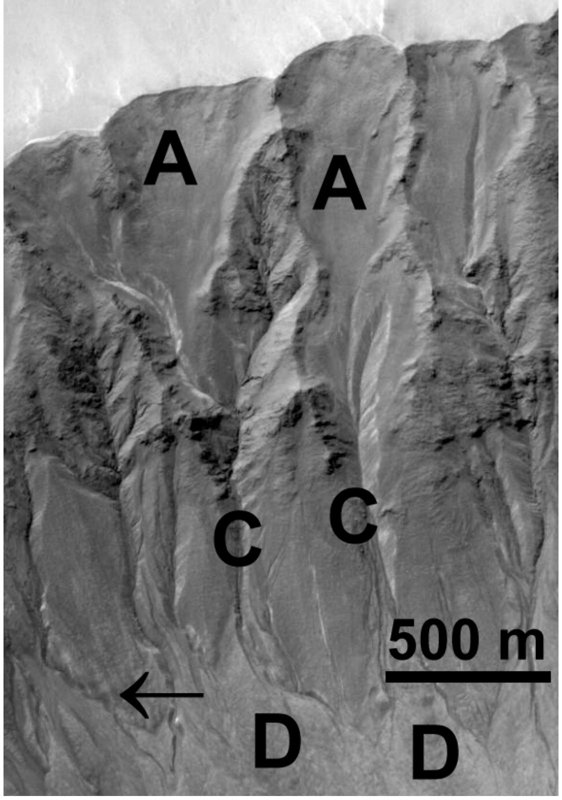

Figure 2. Typical gullies, Gorgonium Chaos (MOC M14-01830) [19]. A = alcove, C = channel, D = depositional cone/fan. Arrow points to sinuous channel.

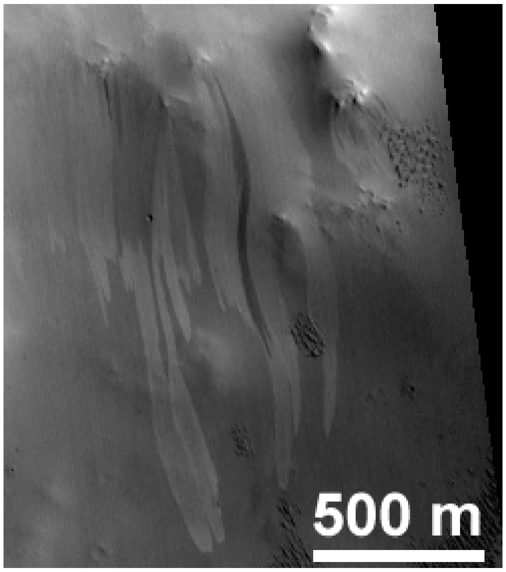

Figure 3. Slope streaks, Arabia (MOC M03-07572 [1]). Note variety of color contrasts, especially streaks at bottom of image with bright borders and darker cores.

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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Wednesday, March 17, 2004
MARS: GULLIES, FLUIDS, AND ROCKS
8:30 a.m. Salon B

Chairs: P. Lee
R. A. Yingst

8:30 a.m. Heldmann J. L. * Mellon M. T.
Gullies on Mars and Constraints Imposed by Mars Global Surveyor Data **[#1355]**
Mars Global Surveyor spacecraft data has been analyzed to uncover trends in the dimensional and physical properties of the martian gullies and their surrounding terrain. This data is used to test the validity of several proposed gully formation mechanisms.

8:45 a.m. Lee P. * Cockell C. S. McKay C. P.
Gullies on Mars: Origin by Snow and Ice Melting and Potential for Life Based on Possible Analogs from Devon Island, High Arctic **[#2122]**
Gullies on Devon Island, High Arctic, which form by melting of transient surface ice and snow covers and offer morphologic and contextual analogs for gullies reported on Mars are reported to display enhancements in biological activity in contrast to surrounding polar desert terrain.

9:00 a.m. Ishii T. * Sasaki S.
Formation of Recent Martian Gullies by Avalanches of CO_2 *Frost* **[#1556]**
The formation mechanism of gullies by avalanches of CO_2 frost can explain the distribution, orientation and morphologic features of gullies. We calculate CO_2 frost thickness on each slopes orientation and confirm a possibility of CO_2 avalanches.

9:15 a.m. Treiman A. H. * Louge M. Y.
Martian Slope Streaks and Gullies: Origins as Dry Granular Flows **[#1323]**
Streaks and gullies on Martian slopes have been interpreted as water-bearing flows. Water is not necessary. Nearly all features of slope streaks and gullies are known in, and consistent with theories of, flows of dry granular materials.

9:30 a.m. Gilmore M. S. * Goldenson N.
Depths and Geologic Setting of Northern Hemisphere Gullies (and Comparison to Their Southern Counterparts) **[#1884]**
Northern gullies correspond to cliff-formers ~250 m below the surface.

9:45 a.m. Kargel J. S. * Marion G. M.
Mars as a Salt-, Acid-, and Gas-Hydrate World **[#1965]**
Gas hydrates, acid hydrates, and salt hydrates probably are abundant on Mars and may constitute a large fraction of the crust. Some of these phase assemblages melt/freeze at very low temperatures. Surface ponds/marshes of acid brines may be stable.

10:00 a.m. BREAK

10:15 a.m. Bullock M. A. * Moore J. M. Mellon M. T.
Composition of Simulated Martian Brines and Implications for the Origin of Martian Salts **[#1722]**
We report on laboratory experiments that have produced dilute brines under controlled conditions meant to simulate past and present Mars. Brines formed under a present-day Mars-like atmosphere have elemental abundances similar to those found in martian fines.

10:30 a.m. Sears D. W. G. * Chittenden J. Moore S. R. Meier A. Kareev M. Farmer C. B.
Evaporation Rates of Brine on Mars **[#2159]**
The evaporation rate for brine on Mars has been determined under Martian conditions, with and without advection.

10:45 a.m. Komatsu G. * Rossi A. P. Di Lorenzo S.
Hydrogeology of the Valles Marineris-Chaotic Terrain Transition Zone, Mars **[#1197]**
The Valles Marineris-chaotic terrain transition zone on Mars is rich in landforms indicative of past water and volcanic activities. Complex interactions of such activities are represented by features at Gangis Chasma and its surroundings.

11:00 a.m. Kieffer S. W. * Brown K. L. Simmons S. F. Watson A.
Measured Fluid Flow in an Active H_2O-CO_2 Geothermal Well as an Analog to Fluid Flow in Fractures on Mars: Preliminary Report **[#1856]**
A PTQ-probe was inserted into a flowing H_2O-CO_2 geothermal well 1300 m in depth. The well was was flowing under (variable) production conditions. The spinner data (Q) have been converted to velocities, and a preliminary model for the flow is presented.

11:15 a.m. Heslop E. E. M. Viles H. A. * Bourke M. C.
Understanding Rock Breakdown on Earth and Mars: Geomorphological Concepts and Facet Mapping Methods **[#1445]**
We review recent conceptual improvements in understanding rock breakdown on Earth that might be usefully applied to boulder morphologies on Mars. We outline a new field technique (facet mapping) and report on a pilot data set from the hyper-arid Atacama Desert.

11:30 a.m. Yingst R. A. * Biederman K. L. Monhead A. M. Haldemann A. F. C. Kowalczyk M. R.
Classification and Distribution of Mars Pathfinder Rocks Using Quantitative Morphologic Indices **[#1272]**
Rock morphologies can be assessed quantitatively and compared with spectral data to classify rock surface types at the MPF landing site. Here we report on the creation of a database of morphologic indices calculated for the Rock Garden region.

11:45 a.m. Keszthelyi L. * Burr D. M. Herkenhoff K. Gaddis L.
Systematic Rock Classification in a Data-poor Environment: Application to Mars **[#1663]**
We propose a technique for classifying rocks on Mars when the process used by field geologists on Earth fails due to a dearth of observations.