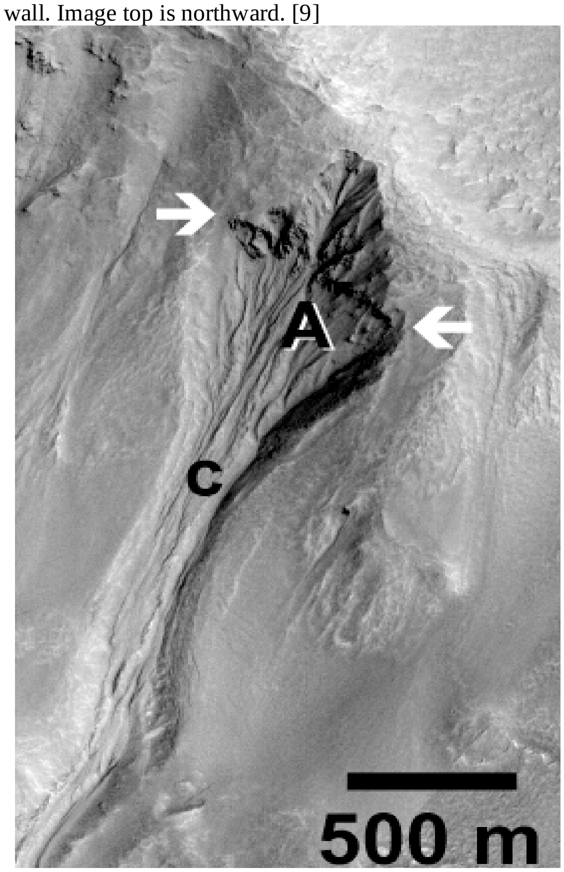
GROWTH OF GULLY ALCOVES (MARS): IMPLICATIONS FOR INTERPRETING GULLY MORPHOLOGY AND ORIGINS. A.H. Treiman, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058 <treiman#lpi.usra.edu>.

As they form, alcoves of Martian gullies can grow uphill and sideways as debris slumps into them and is carried away in the gully flow; this process is clear in laboratory flows of dry granular materials and in large snow avalanches. This mechanism, with observations of Martian gully alcoves, implies that: the top of a gully's alcove need not be the source of the flow (e.g., an alcove that tops at a cliff need not have started at the cliff); the base of a gully's alcove need not be at the source of flow; that the initiation point of a gully flow can be hidden, and that slope angles of surfaces within a gully alcove have little significance.

Gullies and Alcoves: Gullies are common on walls of impact craters, chasms, and pits, may represent recent outbursts of liquid water from Mars' subsurface [1-6] or near-surface [7], and so are potential targets for astrobiology exploration [8]. A typical gully includes an alcove, a channel, and a deposit (Fig. 1). The alcove is a fan-shaped (theatre-shaped) depression high on a slope, and is a source of debris. Downhill, the alcove narrows to its base, a channel through which the debris flows. Further downhill, the channel debouches into a fan- or cone-shaped mound of debris.

Fig. 1. Gully on crater wall, Cimmeria, MOC E10-04348. **A** is alcove, **C** is channel, arrows mark resistant layer in wall. Image top is northward. [9]



Alcove Growth: It is generally agreed that alcoves can grow by propagating uphill and sideways, as debris at the edges of the alcove are destabilized, slump into the alcove, and flow away [1,2,4,6,10]: "Undermining and collapse of a region … would promote headward extension of an alcove …" [1a]. This growth of alcoves is a general phenomenon of slope failures, and is seen in wet debris avalanches on Earth [6], laboratory experiments on dry granular media [11], and snow avalanches [12].

Because an alcove can grow uphill, its top (or headwall) need not be where the gully flow started. Fig. 1 shows a clear example of this in the alcove above the resistant layer, marked by arrows, which has its base at a gap in the resistant layer. This shape suggests that debris flowed from above the resistant layer through the gap, permitting the alcove depression to grow upward across and above the resistant layer. Similarly, Fig. 2 shows many alcoves that extend uphill through gaps in resistant layers (**a**, **b**, **c** on Fig. 2). These alcoves in the upper reaches of the slope widen upwards above resistant rock layer **b**, can narrow upwards at each resistant layer (as at **c**), and can terminate at these layers (as under '**a**' and '**b**', and just left of '**c**'). Here, it is possible that the main portions of the gully flows (and alcoves) started at major resistant layers, but it is equally reasonable that the gullies started far downslope, and that their alcoves grew up-

Fig 2. Gullies on pit wall, Noachis, MOC E10-03724. **A** is an alcove, **C** is a channel, **D** is a deposit fan. Resistant rock layers marked as **a**, **b**, **c**. Plains at image top (northwest). [9]

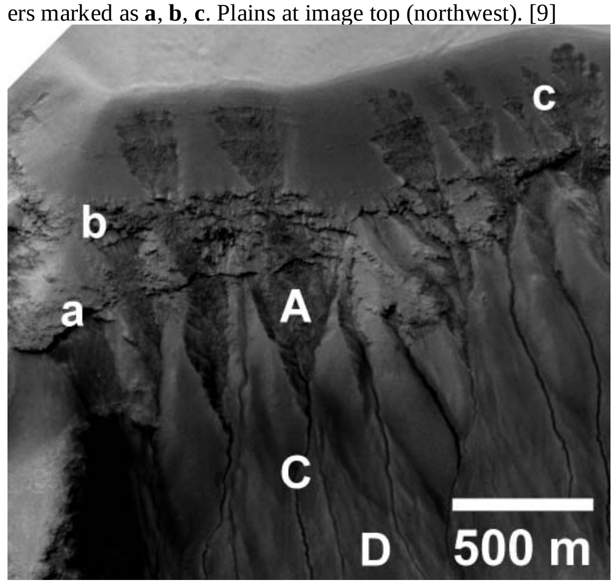
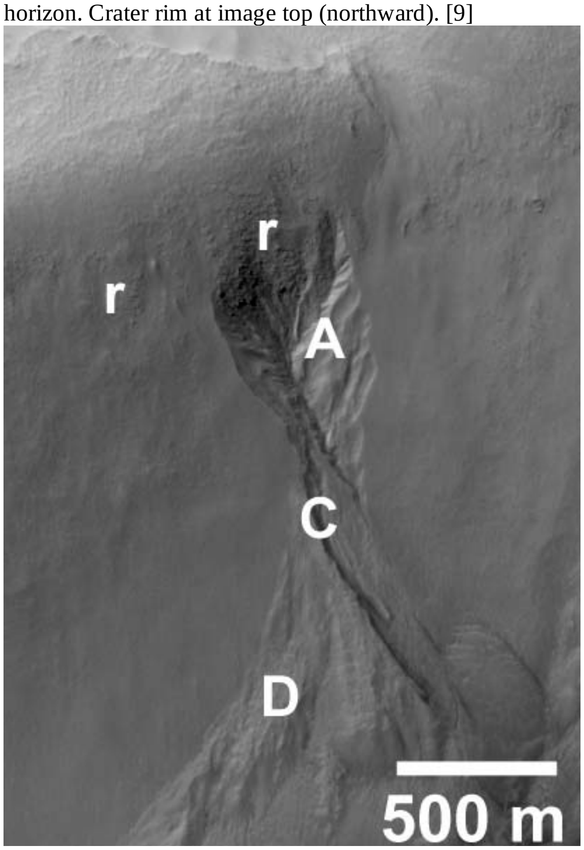


Fig. 3. Gully on crater wall, Cimmeria, MOC R15-00513. **A** is alcove, **C** is channel, **D** is deposit fan. 'r' marks rubbly horizon. Crater rim at image top (northward). [9]



ward to where they appear now.

Alcove Top: If a gully's alcove grows upwards, why would it stop growing? Several factors can be responsible, including changes in: slope angle, availability of debris, or the physical properties of debris (e.g., a rocky cliff). (1) If the alcove grows on a convex-upward surface, the slope may become too shallow for debris to slump, and alcove growth would stop. Figure 1 shows an extreme example of this, where the alcove extends to the crater rim. At the rim, the slope is zero, so debris there will not flow. Other alcoves that terminate at crater rims or flat plains are shown in Figs. 1a, 2c, & 5d of [13] and 3a of [10]. (2) Upwards growth of an alcove will cease where there is no debris to slump and flow. Fig. 3 shows an alcove that terminates uphill at a rubbly horizon, recognized by the visible large boulders and thus the lack of covering finer debris. Similar alcoves that terminate for lack of debris are shown in Fig. 9a of [13] and Figs 3c, 3f, 5, & 9c of [1]. An extreme and important case is where a growing alcove impinges on massive bedrock or a cliff, e.g.: Fig.1; at **'a'** in Fig. 2; Fig. 3e and 5a of [1]; and Figs. 1 of [4,5]. (3) Alcove growth would also stop if the physical properties of the debris changed upslope (e.g., cementetation, grain size, water content).

Alcove Base: The base of an alcove, where the alcove depression narrows to a single channel, has been suggested as a logical initiation point for a gully-forming flow (i.e., elevation at which water left the subsurface) [3,14]. However, it can be difficult to tell just where the 'base' of an alcove is when a gully has multiple channels of finite width (Fig. 1,3). Also, as a gully alcove enlarges sideways, its apparent base migrates downslope [11]. Thus, the observed 'base' of an alcove need not be where the 'base' was when the gully flow started.

Gully Initiation: Because a gully alcove can enlarge upward and sideways from its start point, the initiation point of the gully avalanche is somewhere in the gully's alcove or channel. In both areas, the land surface can heavily modified by erosion and deposition by the gully flow. Thus, the initiation point of a gully can be disguised and any genetic characteristics be erased.

Alcove Slope: The slopes of land surfaces in gully alcoves have been used to distinguish among various theories of gully origins [14]. However, surface types within alcoves are so varied that a single mechanism or implication seems unlikely. Slope surfaces within alcoves can include: bedrock (e.g., Fig. 2), which can hold slopes in excess of the angle of repose; rubbly slopes (Fig. 3), presumably at the angle of repose; erosional channels (Fig. 1), at or below the angle of repose; and ungullied fill material (e.g., Fig. 1 of [13], Fig. 2 of [7]), at or below the angle of repose. With such a range of landforms in gully alcoves, it is not surprising that slopes are so variable.

Discussion: Recognition that gully alcoves can grow by enlarging uphill and sideways, though seemingly trivial, has important implications.

(1) Uphill and sideways growth of alcoves can occur in both wet and dry debris [6,11], and so it does not attest to the presence or absence of water.

(2) Uphill propagation of an alcove can occur after, and upslope from, initiation of the alcove and gully. So, alcove growth need not depend on how the alcove/gully started – they are independent processes. An initial disruption on a slope that initiates alcove growth could form in many ways: seep or eruption of volatiles [1-6,10], meteoroid impact, rock avalanche, wind erosion, etc. Once formed, the initial depression will be erased or extensively modified as the alcove grows and debris flows downhill [11].

(3) Termination of an alcove's growth, and thus the character of its top edge, may depend on the slope and debris available – not on how the gully/alcove started. Alcoves that terminate into rubbly or gentle slopes (Fig. 3) have propagated upwards until they ran out of material or gravitational (slope) energy to continue the flow. Alcoves that terminate at resistant or raised lay-

ers (**c** on Fig. 2) are isolated from potentially mobile debris farther up the slope.

(4) Finally, alcoves that terminate uphill at cliffs or resistant layers (Figs. 1, 2) can form by upward propagation alone. If an alcove begins on a slope below a cliff, it will propagate upwards toward the cliff. The cliff will block propagation of the alcove because (nearly by definition) the cliff will not be covered in debris that could slump into the alcove. Thus, gullies with alcoves beneath cliffs need not have formed by fluid escaping from underground at the cliff [1-6,10]. Upward and outward growth of gully alcoves does not disprove the presence of water or CO_2 in the genesis of gullies, but does provide mechanistic 'volatile-neutral' explanations for many features of gully alcoves.

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