

Comparison of small lunar landslides and martian gullies

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Abstract

Some lunar crater-wall landslides strongly resemble martian gullies, despite the lack of geologically active water on the Moon today or in the past. The lunar features indicate that alcove–channel–apron morphology, attributed on Mars to seepage of liquid water, can also form via a dry landslide mechanism. Therefore a more stringent test than just an alcove–channel–apron morphology is necessary to differentiate dry landslides from water carved gullies.

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1. Introduction

Malin and Edgett (2000) report the observation of martian gullies on steep terrain and suggest that they formed by liquid water drainage in the recent past. Numerous authors build on this hypothesis, including Mellon and Phillips (2001), Christensen (2003), Hartmann et al. (2003), Heldmann and Mellon (2004), Márquez et al. (2005), and Balme et al. (2006). If the Malin and Edgett (2000) hypothesis is correct, then liquid water on the surface of Mars produced fluvial landforms within the past 0.3 to 3 Myr (Reiss et al., 2004). Also, water-formed gullies support the idea of a long-term hydrological cycle on Mars (Baker et al., 1991). In addition to the geologic and hydrologic implications of the water hypothesis, near surface water reservoirs would be valuable resources for future martian explorers and colonists, and would increase the possibility of extant native life on Mars.

The primary inconsistency of the water hypothesis is that liquid water is unstable at most martian surface locations under the present climatic conditions (Ingersoll et al., 1971). Haberle et al. (2001) find five geographic locations where water is stable on Mars for tens of days per year, but determine that those regions do not correlate with the distribution of gullies presented by Malin and Edgett (2000). To explain the presence of liquid

water at the surface of Mars in recent times, some authors propose highly concentrated brine solutions (Knauth et al., 2000; Haberle et al., 2001; Burt and Knauth, 2003), while others suggest geothermally heated subsurface aquifers (Mellon and Phillips, 2001).

To address these inconsistencies, Treiman (2003, 2005) proposes that the martian gullies formed via avalanches of fine granular material without liquid water. The Moon is a reasonable place to test this hypothesis. The lunar surface is blanketed in fine granular material (regolith) (Jaffe, 1966). Samples returned from the *Apollo* missions are uniformly anhydrous, indicating that lunar rocks formed in a water-poor environment, and the absence of secondary hydrated minerals implies no liquid water has been geologically active at any time since the rocks formed (Lunar SPET, 1969). In this paper I present lunar analogs for the Malin and Edgett (2000) martian gullies.

2. Lunar data

The highest resolution lunar data are still the *Lunar Orbiter* high resolution photographs, which resolve objects 1–2 m in extent. Comparisons of the same regions in both *Lunar Orbiter* and *Apollo* panoramic camera photographs show that the *Apollo* photographs have significantly poorer resolution. Of even lower resolution are the images from the camera, AMIE, on *Smart-1* (45 m/pixel) and *Clementine*'s Ultraviolet/Visible

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Camera (125 m/pixel). These data cannot reveal meter scale alcove–channel–apron features.

The *Lunar Orbiter* photographs are of poor quality by today's standards. The spacecraft and instruments, which flew in 1966–1967, were constructed with technology from that era. The photographs were taken with a film camera. An on-board automated system developed the exposed film, scanned it into strips, and transmitted the result back to Earth as analog data. Back on Earth, photographic prints of the strips were hand-mosaicked into frames. As a result, the data contain anomalies such as processing defects (i.e., bubbles), striping, missing and duplicated data, and saturation. This analog processing results in uncertain photometric and geographic calibration that restricts quantitative analysis.

Because *Lunar Orbiter* data was to support *Apollo* landing site selection, the photography targets were frequently flat areas, rather than slopes where gully-like landslides might occur. Of the 1075 high resolution *Lunar Orbiter* images, only 29 show steep slopes. Three of those images show alcove–channel–apron features: II-112-H1 (Figs. 2 and 3), V-119-M (Fig. 4), and V-070-H2 (Fig. 5). Nine slopes have features that might be gullies, but resolution or lighting render identification uncertain. The remaining 17 steep slopes appear featureless.

The lack of additional examples is not surprising given the few high resolution lunar photograph of slopes currently available. Gullies were not identified on Mars until MOC returned many high quality, high resolution images. The *Lunar Reconnaissance Orbiter Camera* will return high quality images at 0.5 m/pixel that will allow a thorough survey of the Moon's gully-like features.

3. Comparison of martian and lunar features

Malin and Edgett (2000) identify martian gullies using three morphologic characteristics: alcoves, channels, and deposition aprons. The alcove, which begins at or below the top of the slope, is a concave depression at the head of the gully. Martian alcoves have widely varying morphologies (broad, narrow, complex). The channels are incised into the cliff, rather than being albedo features. The deposition aprons at the bottom of the cliff resemble terrestrial alluvial fans. The alcove–channel–apron morphology persists as the primary criterion for gully identification (Hartmann et al., 2003; Heldmann and Mellon, 2004; Márquez et al., 2005; Balme et al., 2006). Fig. 1 illustrates alcove–channel–apron gullies on the walls of a large channel on Mars. The image is from the Mars Orbiter Camera (MOC) number M03/02290, and is located at 29.71° S, 38.99° E. Mellon and Phillips (2001) present this image as an example of martian gullies.

I identify several lunar landslide features that are close analogs for the martian gullies. All of the lunar examples are found on crater slopes. The slope in Figs. 2 and 3 is located on the Moon at 12.1° W, 3.4° N. The slope in Fig. 4 is located on the Moon at 47.4° W, 23.2° N. The slope in Fig. 5 is located on the Moon at 27.4° E, 12.2° N, near the edge of Mare Tranquillitatis, near Mare Serenitatis.

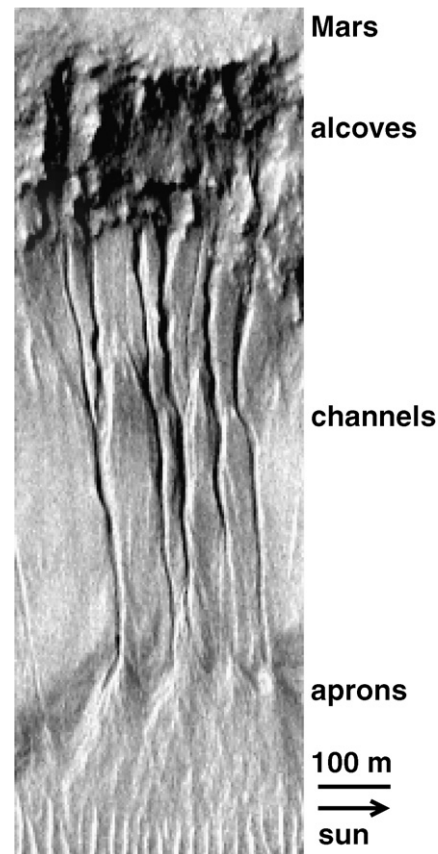


Fig. 1. Image of martian gullies; subframe of Mars Orbiter Camera (MOC) image M03/02290. The scene is illuminated from the left. These gullies exemplify the characteristic alcove–channel–apron morphology attributed to liquid water formation on Mars (Mellon and Phillips, 2001).

The lunar landslides in Figs. 2 and 3 exhibit well defined lengthened alcoves as described by Malin and Edgett (2000), similar to the leftmost martian alcove in Fig. 1. The rightmost alcove of Fig. 5 is a bit wider, similar to Figs. 3a, 7, and 9c of Malin and Edgett (2000). The martian and lunar alcoves are similar in scale and morphology. The alcoves narrow toward their bases, from which incised channels emanate. Neither the channel in Fig. 4 nor the leftmost channel in Fig. 5 has pronounced alcoves; rather, the alcoves are similar to the abbreviated alcoves illustrated in Fig. 3f of Malin and Edgett (2000).

All of the lunar examples (Figs. 2–5) show incised channels. In Figs. 2–4 the Sun illuminates the scene from the left. The channels are dark (shadowed) on the left side and bright (illuminated) on the right side. The channels in Fig. 5 are more subtle, partly because the channels are illuminated more directly from above, providing less topographic information via shadows. The Sun illuminates the scene from the right in this photograph. The channels are identified by a brighter left side and a darker right side.

Deposition aprons are also visible in the lunar analogs. The channels stop partway down the slope and debris aprons flow from their bases. Figs. 2 and 3 show the aprons illuminated on the left and shadowed on the right. In Fig. 4 the apron is less well defined than the steep sided channel. The rightmost channels of Fig. 5 is illuminated on the right and shadowed

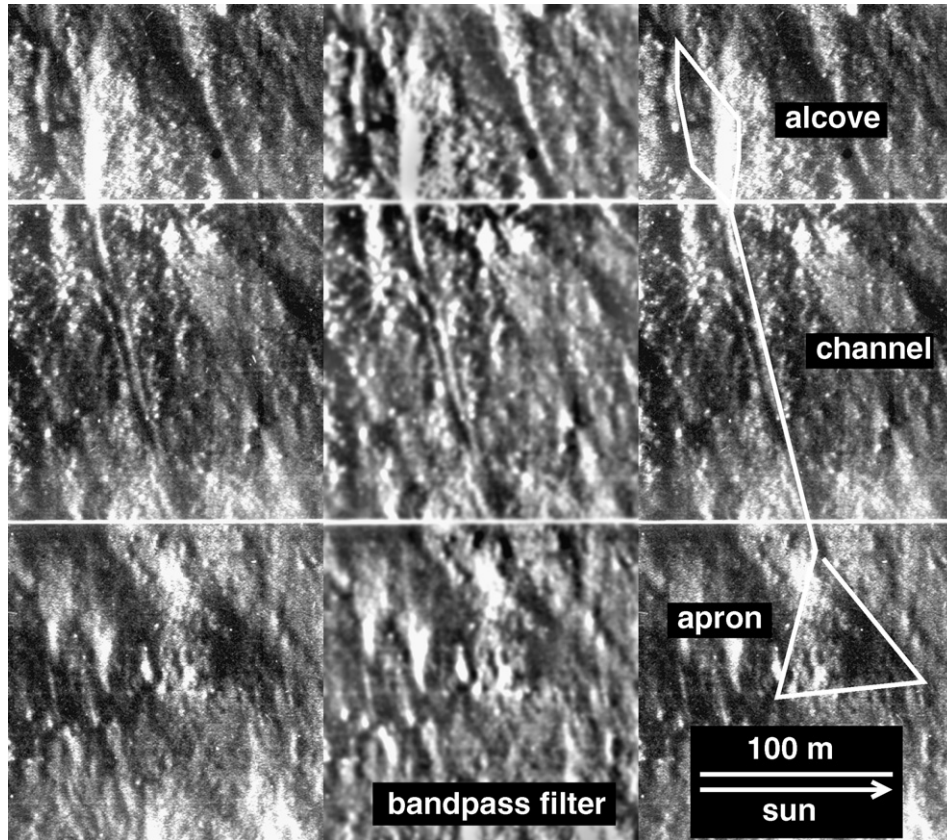


Fig. 2. A lunar landslide feature repeated three times. This photograph is a subframe of *Lunar Orbiter II* photograph 112-H1. The scene is illuminated from the left. (Left) The raw (scanned) photograph, adjusted for brightness and contrast. (Center) The photograph after using a bandpass filter to enhance the channel. (Right) The raw photograph repeated with annotations. This lunar landslide feature has the same characteristic alcove–channel–apron structure as the martian gullies, whose formation has been attributed to liquid water. The horizontal white stripes are a result of processing of the *Lunar Orbiter* photographic print strips.

on the left. The left channel may branch out into a triangular apron, but there are no obvious shadows from this apron. A processing bubble and strip seam also interfere with apron identification.

4. Discussion

Gullies are morphologically distinct from slope streaks, which are present both on Mars (Sullivan et al., 2001) and the Moon (Howard, 1973). Slope streaks are narrow, fan-shaped, dark streaks, not topographic channels. They trend straight down the slope ignoring impediments and gradually fan out downslope. The lunar channels are not slope streaks. Although brightness values in photographs can be due to either albedo or topography, the two can be differentiated by observing an area of uniform slope with respect to the Sun. In these lunar craters, the wall facing the Sun is uniformly illuminated and shows little brightness variation, indicating little albedo variation on the crater slopes. Furthermore, all the landslide features were observed on crater walls near the crater's terminator, where low Sun angle provides exaggerated shadows, enhancing the observation of topography. The topographic gullies on these crater slopes are probably not confined to the areas of low Sun angle. Similar features may well continue around the crater wall, but due to the increasing Sun angle, the shading differences quickly

become much more subtle. More gully features may be observable with high resolution images taken with better illumination or using greater dynamic range.

In all the lunar examples the channels proceed downslope linearly. Many martian gullies are quite similar (Fig. 1) but others show anastomosing channels and tributary and distributary systems (Edgett et al., 2003). With the limited lunar data available, it is impossible to say that the more complex channels are not present on the Moon, only that they have not yet been detected. *Lunar Reconnaissance Orbiter* data will provide more lunar data with which to determine whether the more complex features are unique to Mars, and perhaps water-formed, or whether they too can be formed as a result of dry mass movement on the Moon. Nevertheless, the fact that linear gully-like features are observed on the Moon indicates that mass wasting may play a more significant role in martian gully formation than has previously been recognized.

Another difference between the lunar and martian features is the channels' topographic expression. The martian gully channels have sharp margins, whereas the lunar channels have rounded edges. This difference may be the result of the greater age of the lunar features, as evidenced by small impact craters visible along the lunar slopes. Thus, it is reasonable to expect that the lunar features will be somewhat degraded compared to the young, pristine martian ones. Small or micro-meteorite

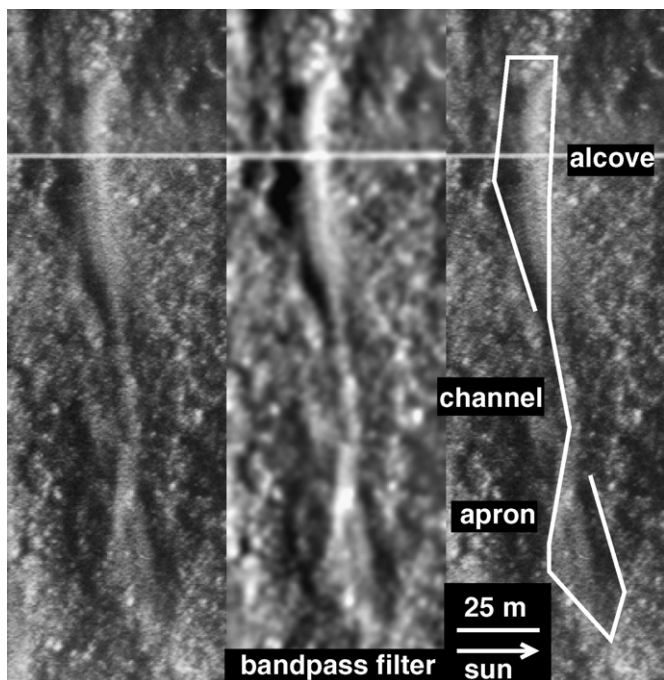


Fig. 3. A lunar landslide feature repeated three times. This photograph is another subframe of *Lunar Orbiter II* photograph 112-H1. The scene is illuminated from the left. (Left) The raw (scanned) photograph, adjusted for brightness and contrast. (Center) The photograph after using a bandpass filter to enhance the channel. (Right) The raw photograph repeated with annotations. This lunar landslide feature also has the characteristic alcove–channel–apron structure of the martian gullies, whose formation has been attributed to liquid water. The horizontal white stripe is a result of processing of the *Lunar Orbiter* photographic print strips.

impact degradation could smooth the sharp channel edges observed on Mars to what is observed in the lunar photograph.

The lunar features are identical in spatial to the martian features (compare scale bars in Figs. 1–5). The lunar alcoves and aprons have similar morphology to those on Mars, and the lunar channels are topographic, as are the martian ones. Thus it is possible to form alcove–channel–apron features without liquid water, as seen on the Moon, and so alcove–channel–apron morphology alone is insufficient to determine the mode of origin of gully-like features on Mars.

5. Dry landslide formation

Treiman (2003) proposes that the martian gullies formed by avalanches of fine granular material without liquid water. He suggests that the gullies are a case of landslides larger than slope streaks (Sullivan et al., 2001) but smaller than large-scale landslides such as those in Valles Marineris (Lucchitta, 1979). He presents the Earth analog of “climax” snow avalanches. On Mars, wind-deposited fines may persist for some time in an unstable configuration until a slide is initiated by a local perturbation of the deposit. On the Moon, fines would not be deposited by the wind (there is no atmosphere) but rather by impact ejecta from micrometeorites, small nearby craters, or large distant craters—the mechanism which forms the lunar regolith. Heldmann and Mellon (2004) argue against the dry flow hy-

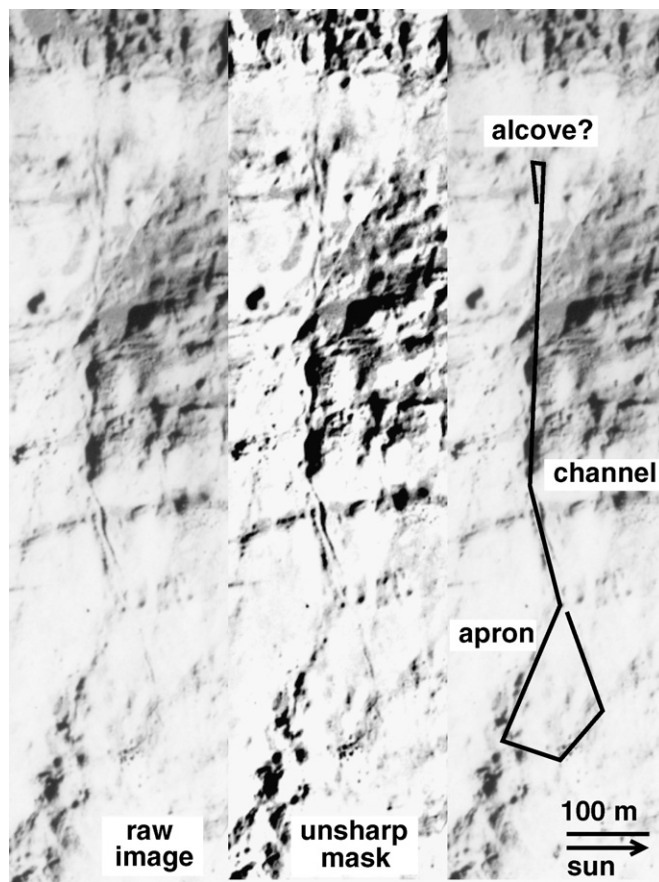


Fig. 4. Another lunar landslide feature repeated three times. This photograph is a subframe of *Lunar Orbiter V* photograph 199-M. The scene is illuminated from the left. (Left) The raw (scanned) photograph, adjusted for brightness and contrast. (Center) The photograph after using an unsharp mask to enhance the channel. (Right) The raw photograph repeated with annotations. This lunar landslide feature exhibits a clear channel and apron, perhaps originating from a small alcove above. The diagonal stripe is a result of processing of the *Lunar Orbiter* photographic print strips.

pothesis on the basis of martian global wind patterns; however, wind does not appear to be essential for gully formation since the Moon has no wind.

In corroboration of the dry flow hypothesis, Shinbrot et al. (2004) show experimentally that flows of dry granules exhibit features similar to those seen on Mars. They experiment with low density, hollow ceramic beads with diameters from 4 to 90 μm and successfully reproduce the alcoves, channels, and aprons of typical martian gullies on centimeter scales, without the action of liquid water.

6. Conclusion

I identify five lunar features with alcove–channel–apron morphology similar to that of martian gullies. Because of the paucity of lunar water, these observations indicate that dry landslides can create alcove–channel–apron morphology on a planetary scale and does not require liquid water.

Does the existence of lunar “gullies” mean that the martian gullies were not formed by liquid water? Not necessarily. After all, the martian gullies also resemble terrestrial gullies formed

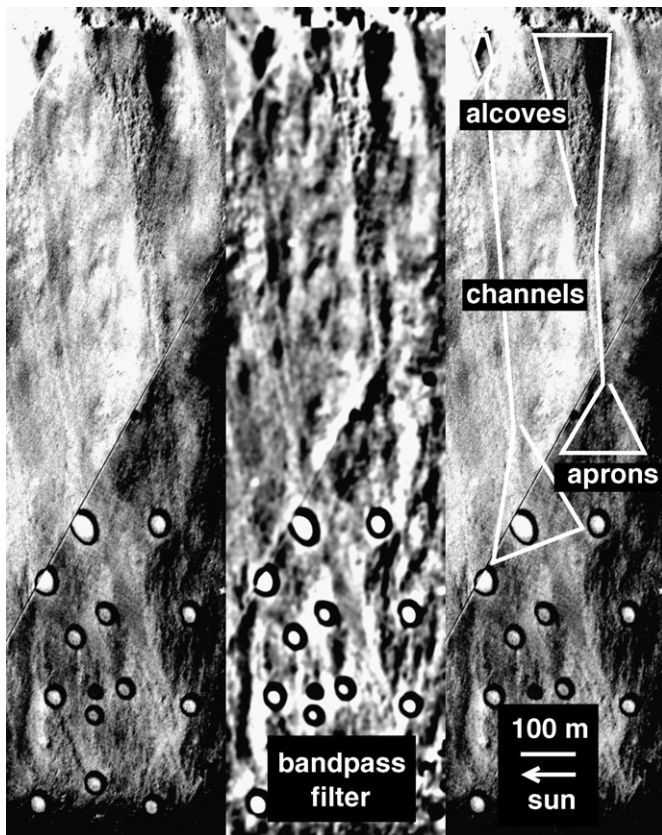


Fig. 5. Lunar landslides in Crater Dawes, repeated three times. The photograph is a subframe of *Lunar Orbiter V* photograph 70-H2. The scene is illuminated from the right, though at a higher angle than the previous examples, making feature identification difficult. Nevertheless, alcoves, channels, and aprons are present, as in the previous examples. (Left) The original (scanned) photograph, adjusted for brightness and contrast. (Center) The photograph passed through a bandpass filter to enhance the channels. (Right) The raw photograph repeated with annotations. The circular blobs are defects from the spacecraft's on-board processing of the photographic film. The diagonal stripes are a result of processing of the *Lunar Orbiter* photographic print strips.

by liquid water (Hartmann et al., 2003). Nevertheless, the dry landslide mechanism for formation of the martian gullies cannot be ruled out on the basis of the alcove–channel–apron morphology alone, as has been done previously in the literature.

Formation of martian gullies by liquid water would indicate that Mars has recently produced liquid water at its surface in sufficient quantities to produce fluvial landforms. Although this idea is tantalizing, I argue that we cannot yet say with confidence whether near surface water is, or was recently, present on Mars based on alcove–channel–apron morphology alone.

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