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## Comparison of the Morphology of Crater-Slopes with Gullies to those Without Gullies

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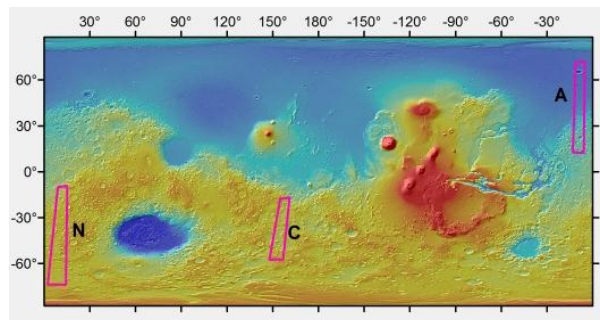
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**COMPARISON OF THE MORPHOLOGY OF CRATER-SLOPES WITH GULLIES TO THOSE WITHOUT GULLIES.** S. J. Conway<sup>1</sup>, N. Mangold<sup>1</sup>, M. R. Balme<sup>2</sup> and V. Ansan<sup>1</sup>, <sup>1</sup>LPGN, CNRS/Univ. Nantes, 44322 Nantes, France, <sup>2</sup>PSSRI, Open University, Milton Keynes, UK. susan.conway@univ-nantes.fr.

**Introduction:** Gullies were first noted in Mars Orbiter Camera images [1] and have since been found to be commonplace throughout the mid-latitudes on Mars [e.g. 2]. These features are often associated with the action of liquid water, either as unconcentrated water flow or debris flow [e.g., 3,4]. The fact that gullies are found predominantly in the mid-latitudes and have a pole-facing preference [2] points to a climatic influence on their formation.

We present a study of gullies in craters in the regions of Terra Cimmeria, Noachis Terra and Acidalia Planum (Fig. 1) using HRSC topographic data at 100 m/pix or better. We aim to determine if craters with gullies have a different morphology to those with no gullies.

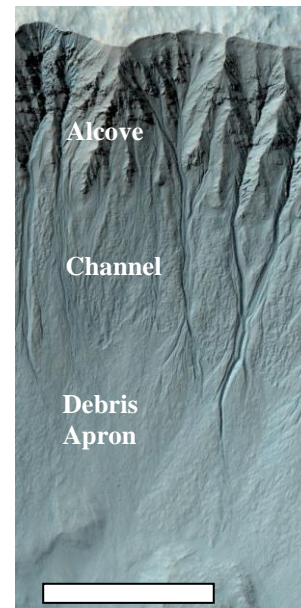


**Fig. 1.** Map showing the three study areas: A = Acidalia Planum, C = Terra Cimmeria and N = Noachis Terra.

**Approach:** Craters were mapped using the catalogue of [5] as a base. Each crater was then divided into four segments facing each of the cardinal directions. For each segment the topographic data were extracted and the distance of the pixels from the crater center calculated. These data were drawn as a profile and the average profile was calculated using a step-distance of 75 m. From this profile the maximum slope and curvature (the exponent of the best-fit power law) were calculated. A local sinusoidal projection was used for each area.

Gullies were mapped using all available HiRISE, MOC, CTX and HRSC images. Gullies were identified using the criteria of Malin et al. [1] as features having an alcove, channel and debris apron (Fig. 2). Clusters of gullies were mapped as polygons which encompassed all of the gullies. Using these polygons we calculated the percent of the crater wall covered by gullies for each of the segments.

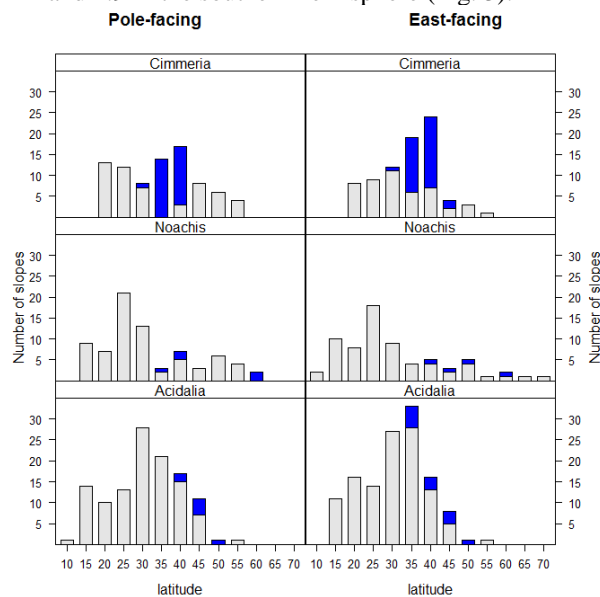
**Results:** We found more craters with gullies in Terra Cimmeria (78), than in Acidalia Planum (24) or Noachis Terra (9). As found by previous workers we found that gullies were concentrated around 40° latitude and had a predominantly pole-facing preference. E-facing gullies were found to be nearly as common as pole-facing ones. For a given latitude band, in a given orientation we found that gullies tend to be found on craters with the steepest slopes and those with the greatest curvature. When curvature is plotted against slope there is no relationship. The mean slope of craters containing gullies is 21° and the mean curvature is 3.0. We also find a weak positive relationship between percent gully coverage per sector (gully density) and slope. If compared to the population as a whole there is no specific morphological characteristic that separates crater walls with gullies and those without. These observations suggest that gullies require the prerequisites of steep slopes and higher curvature to form in craters.



**Fig. 2.** An example gully, scale bar is 500 m, HiRISE image PSP\_005985\_1455, credit NASA/JPL/U of A.

Assuming this to be the case, we examined the spatial distribution of all craters having slopes and curvatures which exceed the first quartile of the slope and curvature distributions for craters with gullies, namely a slope of 18° and a curvature of 1.9. The results are shown in Fig.2 for pole-facing and E-facing slopes. For Terra Cimmeria it shows that almost all slopes that

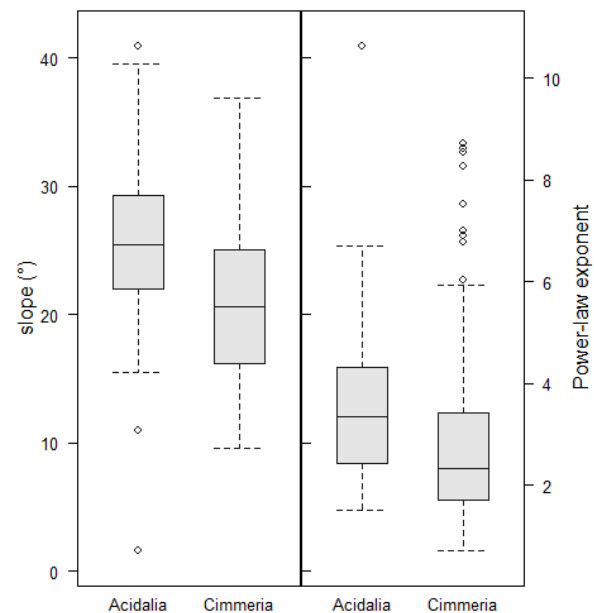
could have gullies, do have gullies in the 35-40° latitude bands. For Noachis Terra, there are few slopes that meet these criteria at latitudes > 35° and some of those that do host gullies. This explains the very low number of gullied slopes found in this area. This agrees with the results of Reiss et al. [6] who found gullies on steep slopes in Hale crater, but not on the shallower slopes of the neighboring Bond crater. However, for Acidalia Terra there are many steep, concave slopes, but only 10-20% of them are occupied by gullies. Looking more carefully at this region we find that gullies are found on steeper and more concave slopes than for the southern hemisphere areas. The average slope is 26° in Acidalia and the curvature is 3.6 compared to 21° and 2.9 in the southern hemisphere (Fig. 3).



**Fig. 2.** Barcharts of the number of crater walls with slope > 18° and curvature > 1.9, with blue being those with gullies. Note: Cimmeria and Noachis are in the southern hemisphere and Acidalia is in the northern hemisphere.

**Discussion and Conclusion:** The fact that gullies seem to be found only on steeper slopes and more concave slopes for a given latitude and orientation suggests a threshold process for their formation. This could be a threshold related to the triggering of the mass wasting forming the gullies, such as is found on Earth for debris flows [e.g., 7]. However, this might be expected to be the same globally. If we assume a climatic control on gully formation [e.g., 3] this could be a threshold associated with accumulation of material or melting of that material. Given the difference of behavior between the northern and southern hemisphere in our study, but also the more muted morphology in the north as noted by other authors [e.g. 8], gully formation has progressed differently in the two hemispheres.

Such a difference could be related to the difference of elevation between the two hemispheres. However, the higher local pressure in the north should make liquid water more stable, but this is where the gullies are less developed. Alternatively, the difference may arise from the relative lack of seasonal CO<sub>2</sub> frost in the north and its associated stabilizing effect on water ice. It has been suggested that CO<sub>2</sub> frost should be deposited on pole-facing slopes in winter in the southern hemisphere, particularly at high obliquity. This CO<sub>2</sub> would have protected any groundice/snow from sublimation [3] leading to more water ice being subsequently available for melting in summer. In the northern hemisphere, where this effect is limited, there would be less water ice and hence a reduced amount of melt.



**Fig. 3.** Boxplots showing the slope and curvature distribution in the northern hemisphere (Acidalia) vs. the southern hemisphere (Cimmeria). Data from Noachis are not shown as there are too few datapoints. The horizontal bar is the mean, the box defines the quartiles, the whiskers the range and the circles the outliers.

**References:** [1] Malin M. C. and Edgett K. S. (2000) *Science*, 288, 2330-2335. [2] Balme M. R. et al. (2006) *JGR*, 111, doi:10.1029/2005JE002607. [3] Costard F. et al. (2002) *Science*, 295, 110-113. [4] Heldmann J. L. et al. (2005) *JGR*, 110, doi:10.1029/2004JE002261. [5] Salamuniccar G. et al. (2011) *PSS*, 59, 111-131. [6] Reiss et al. (2009) *PSS*, 57, 958-974. [7] Godt J. W. and Coe J. A. (2007) *Geomorphology*, 84, 80-97. [8] Bridges N. T. and Lackner C. N. (2006) *JGR*, 111, 09014.