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Reassessing the global gully distribution on Mars

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Abstract

Gullies on Mars are kilometer-scale erosion-deposition systems that resemble water-carved gullies on Earth [1]. Trends in their distribution and orientation with latitude have led many authors to associate these features with an exogenic climate trigger [e.g., 2]. There is a renewed debate [e.g., 3] about whether these features are caused by the sublimation of carbon dioxide ice or by melting of surface/near-surface ice – each of these formation mechanisms should produce different latitudinal trends. A new study of these features has resulted in a near complete global map [4], which allows us, here, to reassess their distribution and give a set of criteria which any model of gully-formation must explain.

1. Gullies and steep slopes

Gullies on Mars are found on sloping terrain, most commonly on impact crater walls, but also on mesas, valley-walls, central peaks, polar pit walls [e.g., 5]. Gullies are generally found to originate on slopes > 20° [6,7].

It is known that the frequency of steep slopes generally decreases towards the poles [8,9]. The general decrease of gully-density from the mid-latitudes to the poles is thought to be partly explained by the decrease in the number of steep slopes [6], however this has not been quantitatively assessed.

Here we reassess the distribution of gullies taking into account the presence or absence of steep slopes. Firstly, we compare the global gully-density map of Harrison et al. [4] with the frequency of slopes > 20° from the global MOLA gridded data over a 250 km-span (Fig. 2). Secondly we look in more detail at two study areas, one in Terra Cimmeria and one in Argyre Planitia.

2. Global trends

The boundary between frequent steep-slopes and infrequent steep-slopes on the slope-density map (Fig. 1) matches well with the drop-off in density of gullies in the southern hemisphere. Local minima in steep-slope-frequency are matched by local minima in gully-density (labelled A). One notable exception is the lack of gullies east of Hellas (labelled B), which cannot be explained by a lack of steep slopes. The equatorward extent of gullies is sometimes mediated by the steep-slope-frequency (labelled A), but in most cases is not – therefore spatial variations in this boundary need to be explained by another variable (possibly climate-related).

In the northern hemisphere gullies are less common, yet the low density of gullies is not entirely explained by a low frequency of steep slopes. Notable zones with low gully densities, but high frequency of steep slopes are labelled "B" on Fig. 1, including Phlegra Montes, Eastern Deuteronilus Mensae, western Ascuris Planum. The lack of gullies in all regions labelled "B" corresponds exactly to the locations of lobate debris aprons and viscous flow features mapped by Squyres [10].

The polar pit gullies located around the south pole of Mars are also somewhat anomalous as they do not have a high density of steep slopes. Previous work has found that these gullies have lower slopes than the global population [7] and may be formed solely by CO_2-processes [11].

3. Local trends

In our smaller-scale regional studies around Argyre Planitia and Terra Cimmeria, we mapped the gully-clusters as polygonal outlines [12] on 6 m/pix Context Camera (CTX) images. From this mapping we were able therefore to examine the distribution of gullies by only considering the MOLA pixels that had greater than 10° slope (Fig. 2), rather than simply density per area, as in previous studies. Both areas show important differences from the density shown in Fig. 1 and the southern hemisphere frequency distribution of Dickson and Head [13] based on data of [14] superposed on Fig. 2.

Firstly, for the Terra Cimmeria site there is no peak in gully-density at 37.5°S (as shown in Fig. 1 and [13]), rather gullies have an even distribution across the whole latitude band (therefore there is no steady decline in gully-forming potential towards the pole). Secondly, there is a distinct lack of gullies in the 27-42°S region in Argyre where gullies should be most common and indeed without considering the slopes are relatively dense in Fig.1.

4. Summary and Conclusions

From these analyses we conclude that any model of gully-formation would have to explain the following:

- The onset of gully-forming processes at ~30°N/S and the undulations in that boundary.
- The uniform density of gullies over the whole 30-55° latitude band in highland areas.
- Local paucity (e.g. N Argyre) and local hotspots of gully occurrence (e.g. E Terra Cimmeria).
- The trends in orientation of gullies with latitude reported in other works [4–6,14,15].

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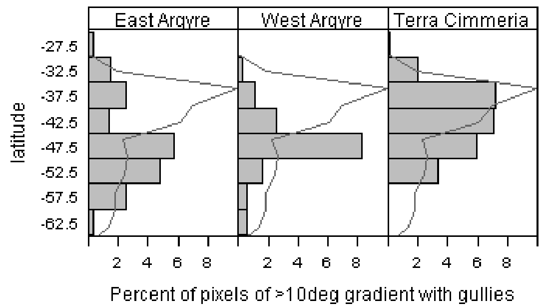

Figure 2: Latitudinal distribution of gullies on slopes >10° in the three study areas shown in Fig.1. In grey the normalized southern hemisphere frequency of gullies from [13], based on [14].

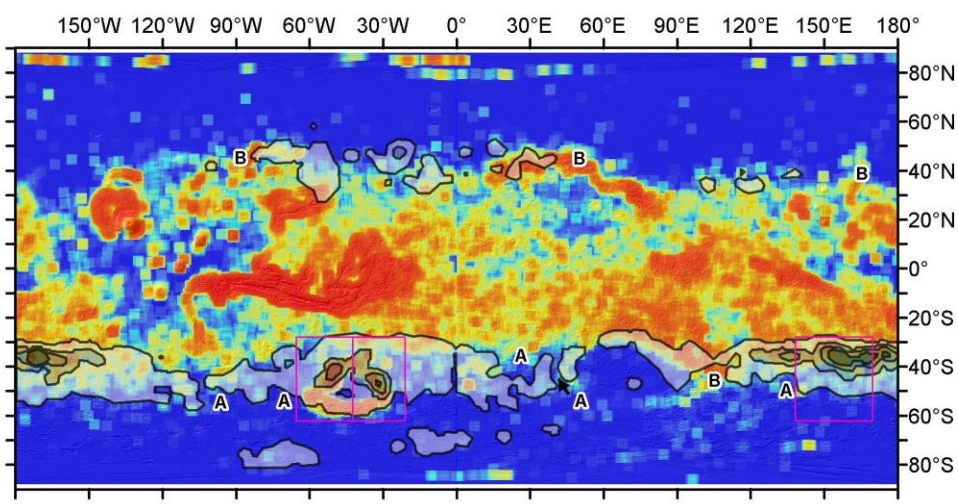

Figure 1: Map of density of steep slopes overlain by the gully-density map taken from [3], red indicates high density of steep slopes and blue indicates few steep slopes. Gully density increases with darker shades within the contours. Locations labelled “A” have low steep-slope density and low gully-density; those labelled “B” have a lack of gullies, yet a high steep-slope density. Areas outlined in pink are the locations of the regional study sites.