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An evolutionary scheme for morphological classification of Martian gullies

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Martian gullies are geologically recent small-scale features characterised by an alcove-channel-apron morphology associated on Earth with liquid water. Since their discovery by Malin and Edgett (1), several theories have been advanced to explain their formation. These typically emphasise either groundwater processes (1, 2) or melting of ground ice or snowpack (3). The former approach has been challenged on the basis of gullies observed on hills and central peaks, where aquifers are unlikely (4). Studies of gullied walls have been undertaken (5), but though morphological classifications of gullies have been proposed (1), they are largely descriptive. This study proposes an evolutionary classification scheme and a pilot study to determine its potential to address controversies in gully formation.

A morphological classification of gullies was developed, and four types identified:
Type I: V-shaped gullies in slope mantling material or scree (i.e. not cutting bedrock); no distinct alcoves.
Type II: Alcoves capped by a distinct and continuous stratum of rock.
Type III: Alcoves extending vertically upslope, without reaching top of slope.
Type IV: Alcoves reaching top of slope and cutting back into cliff.

The types form an evolutionary sequence: in particular, the sequence II-III-IV appears to represent the development of many Martian gullies. Moreover, we have found that average length increases from Type I to Type IV. Furthermore, the presence of small gullies (mostly I and II) in the mantling deposits filling larger alcoves suggests multiple stages of gully activity.

To test the classifications in practice, a sample of gullied slope sections imaged by MOC (Mars Orbital Camera) on Mars Global Surveyor at a resolution of 1-7 m/pixel were catalogued using ArcGIS software. 210 slope sections were covered, representing 1734 gullies across the southern mid-latitudes. Broad geographical coverage was obtained by working through MOC image numbers. For each slope section, the number of gullies, number of each type of gully, slope orientation, presence of mantling material, previous activity, and geographical setting (inner crater wall, outer crater wall, valley or channel, hill or mesa, central peak, other) was recorded in a GIS database.

The application of this classification scheme to a test dataset supported the theory of an evolutionary sequence, with the majority of uncertain classifications occurring between II/III and III/IV. The remainder were I/III uncertainties, suggesting that Type I represents an alternative first stage to Type II. Mantling material was ubiquitous: only five slope sections showed gullies with an apparent absence of mantling material.

The data were analysed by each of the recorded factors in turn. All types of gully were found in all contexts and orientations, with the exception that no Type IV gullies were found in hills contexts. Gully occurrence in different contexts was comparable to previous studies: the vast majority of gullied slopes were found on inner crater walls, valleys and hills/mesas. Hill/mesa contexts show high occurrence of Type I and low occurrence of Type II; valley contexts show the reverse. Interestingly, the hill/mesa distribution is not observed in central peak contexts.

While the majority of all types of gullies were oriented poleward, Types I and II displayed different preferred orientations: Type I gullies were preferentially found on W and SW-facing slopes, while Type II were more

commonly found on E and SE-facing slopes. 63% of gullies showed no evidence of previous cycles of activity ('new'). These gullies showed a strong overall poleward orientation (S, SW, SE), in contrast to those with evidence of previous activity, which were more evenly distributed. The proportion of 'old' gullies in hills contexts was extremely low (6%).

The use of a morphological classification reveals patterns in gully maturity and distribution which may have a bearing on the formation debate. Application of this to gullies in hill contexts also shows several peculiarities which, given their role as a stumbling block to the aquifer theory, merits further investigation.

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