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SMALL-SCALE MORPHOLOGIC PROPERTIES OF MARTIAN GULLIES: INSIGHTS FROM ANALYSIS OF HIRISE IMAGES.

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Introduction: The discovery of abundant, geologically recent gullies on Mars in Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) images [1] has led to numerous studies examining potential mechanisms for recent fluid or fluid-rich surface processes [e.g., 1-2]. The process or processes involved in Martian gully formation provide important insights into Martian geologic and volatile history. New gully deposits have been found in comparison of MOC images acquired over the extent of the MGS mission [3], leading to consideration of contemporary fluid activity. Gullies appear to be the youngest features in most locations [4], serving as evidence of geologically recent surface flow and erosive processes [5].

Detailed analyses of Mars Reconnaissance Orbiter HiRISE images provide new insights into gully characteristics and formation processes. The purpose of this project is to document the small-scale morphologies of Martian gully systems in order to explore the potential diversity of gully formation processes and to determine if small-scale gully morphology can be used to distinguish between the various mechanisms proposed on the basis of larger-scale characteristics. The initial focus of this work has been on examination of boulder distributions and upslope initiation points.

Background: As described by Gulick et al. [6], based on HiRISE image analysis, gullies exhibit a wide range of morphologies, sizes, and geologic settings. Multiple episodes of fluid flow causing erosion and the formation of gullies have taken place, explaining the broad range of features observed [7]. Martian gullies have a characteristic set of components. Gullies can be divided into an alcove at the top of the slope, one or more channels extending downslope, and debris fan at the base [1, 8]. Gullies tend to be concentrated in groups on the walls of craters, pits, and canyons. Although a cluster can differ greatly from an adjacent cluster [6], intra-cluster gullies tend to have similar morphologies.

Methods: Geomorphologic analyses were facilitated by use of Geographic Information Systems (GIS) to correlate and analyze datasets. Over 40 HiRISE images (~1 meter/pixel) containing at least one grouping of gullies were imported into a GIS database with a THEMIS IR image mosaic (230 meters/pixel) and MOLA DEM (~128 pixels/degree) for geographic reference and topographic analyses. Gully features were qualitatively characterized and descriptions compiled, including information on boulder distributions, sinuosity ratio, dimensions of gully system components (length and widths of alcoves, channels, and debris aprons), types of initiation points, evidence for multiple episodes of activity, and other general qualitative observations.

Results: Multiple stages of gully formation are clearly present in the population examined upon detailed analysis of over 40 HiRISE images. Gully systems exhibit different stages of development, with both simple, immature and complex, well-developed morphologies evident. Mature gullies tend to be well-developed with deeply incised and often sinuous channels, frequently terminating in heavily braided fans. In contrast, immature gullies are small, subtle features, visible only as poorly developed alcoves and/or channels. Different stages of maturity are intermixed within individual, isolated groupings of gullies (Figure 1).

Figure 1. HiRISE subimage PSP_2514_1420 contains a gully cluster with different levels of maturity. Image centered at 37.9°S, 217.9°E; 0.25 meters/pixel. Image credit: NASA/JPL/University of Arizona

The resolution of HiRISE images allows detailed characterization of the upper reaches of gully systems and provides information on potential gully initiation processes. There are two primary features interpreted here as gully initiation morphologies: small hollows at the tops of the slopes with debris deposited immediately below (Figure 2) and discrete "pinholes" with a single channel or streak extending down the slope below (Figure 3). Based on multiple exposures of these morphologies, the pinhole morphology can evolve into an alcove with maturity, or the alcove can form just below the pinhole. These two distinct styles of gully formation suggest a diversity in early stage gully morphology, which may be still recognizable in the more complex morphologies of mature gully systems.

Figure 2. HiRISE subimage PSP_003287_1115 shows gully initiation as small hollows that may enlarge to form well-developed alcoves with maturity. Image centered at 68.3°S, 1.2°E; 0.50 meters/pixel. Image credit: NASA/JPL/University of Arizona

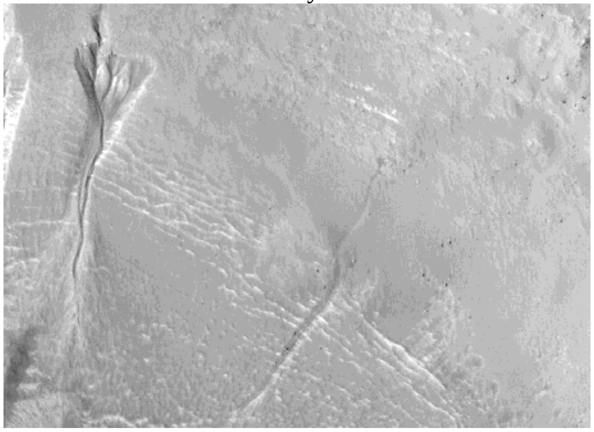

Figure 3. HiRISE subimage PSP_004176_1405 shows "pinhole" initiation, with a simple, narrow channel extending from a discrete pinhole. Image centered at 39.4°S, 202.7°E; 0.25 meters/pixel. Image credit: NASA/JPL/University of Arizona

HiRISE images allow the occurrence of boulders associated with gully systems to be examined. Boulders tend to be concentrated in alcoves compared to the rest of the gully and the surrounding hillslope. Although boulder abundance in gullies and on the surrounding slopes differs, concentrations tend to decrease downslope (heaviest concentration generally in alcove, then channel, then hillslope, then least on the apron). More mature gullies tend to contain a greater concentration of boulders in the alcove than less mature gullies. Boulder concentrations range from hillslopes that are heavily covered with boulders to those with few boulders, but the overall downslope trend is consistent.

Discussion: The distribution of boulders in association with gullies offers insights into transport processes. Several processes could account for the decreasing downslope distribution. Boulders could be moved downslope in early stages of formation by rockfalls or debris flows and preferentially buried downslope as gullies mature and deposit finer grained sediment. Because multiple stages of gully formation are evident in the images, widespread burial of large boulders in the distal regions of gully systems seems unlikely for the population of features observed thus far. Observations of gully alcoves and the associated hillslopes show evidence for rockfalls and the movement of individual boulders downslope. The concentrations of boulders decreasing down-gully and the greater boulder concentration in the gullies than on the surrounding hillslopes [9] are consistent with rockfalls originating in the alcoves as the primary emplacement mechanims for the boulders. Alternatively, the boulder distribution could be a result of debris flows with a progressive decrease in the ability to support clasts downslope. Erosion within the alcove could be fluvial in nature, facilitated by freeze-thaw, and/or the result of other erosive processes.

HiRISE images have allowed new observations and interpretations of Martian gully systems. Multiple stages of gully formation and the corresponding morphologic diversity are clearly evident. The presence of different early-stage gully morphologies indicates that different initiation mechanisms may operate on Mars. The boulder distributions indicate that alcoves erode actively and contribute rocks in a predictable manner to the adjacent hillslopes. Future research will extend these analyses and further explore the small-scale morphologies of Martian gullies.

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