UNDERSTANDING EQUATORIAL GULLY EROSION ON MARS: A CASE STUDY ON KRUPAC CRATER.

Emma R. Rogers[1], Virginia C. Gulick[2], Natalie H. Glines[2]. [1]SETI Institute REU (roger269@purdue.edu), [2]SETI Institute/NASA Ames.

Introduction: Gullies on Mars are typically defined by an eroded alcove, an incised channel, and a downslope depositional apron. The junction between the channel and the apron where the gully system transitions from eroding a channel to depositing sediment in the apron is known as the apex. Gully systems have been extensively studied in the middle latitudes of Mars, where most gullies are located. However, gullies in the high latitudes and especially in the equatorial regions have not undergone detailed morphologic and morphometric analysis. Detailed 3D analysis of gully morphologies is essential as it provides insight to different gully forming processes, clues to past environmental conditions, and comparisons to previously studied middle and high latitude gullies.

We studied Krupac Crater, located just below the equator (7.79°S, 86.01°E), south of Amenthes Planum. Krupac is ~10 km in diameter, and contains numerous gully systems on its north, east, and south slopes. Gullies are poorly developed on the southern slope, but are well developed and extensive on the northern and eastern slopes. Eastern gullies are long with few tributaries, while Northern gullies are shorter and form complex tributary networks. The western slope has minimal gully development and does not have a HiRISE image, and so is not considered in this study.

Methods: We examined a HiRISE stereo image, anaglyph, and Digital Terrain Model (DTM) of Krupac Crater to measure and map the gully systems in ArcMap. Drainage networks were mapped in detail using HiRISE imagery (Fig. 1). In addition to delineating all the individual channels that comprise each gully network, we also outlined the associated aprons and alcoves, and the source region for each gully system. These network maps were used for characterizing drainage systems, including determining stream order [1] and network magnitude [2].

We analyzed four prominent gully systems within Krupac, which are located on the northern and eastern crater slopes (Gullies 8, 33, 48, and 74)(Fig. 1).

Following the method described in Gulick et al. [3], we used ENVI to generate transects across both the apron and along the deepest part of the gully (thalweg), which forms the center streamline (CSL) from source to terminus (Fig. 2). Using elevation data from the DTM, we generated longitudinal profiles that show incision into bedrock at the alcove and upper channel regions and deposition of material in the apron (Fig. 3). With these

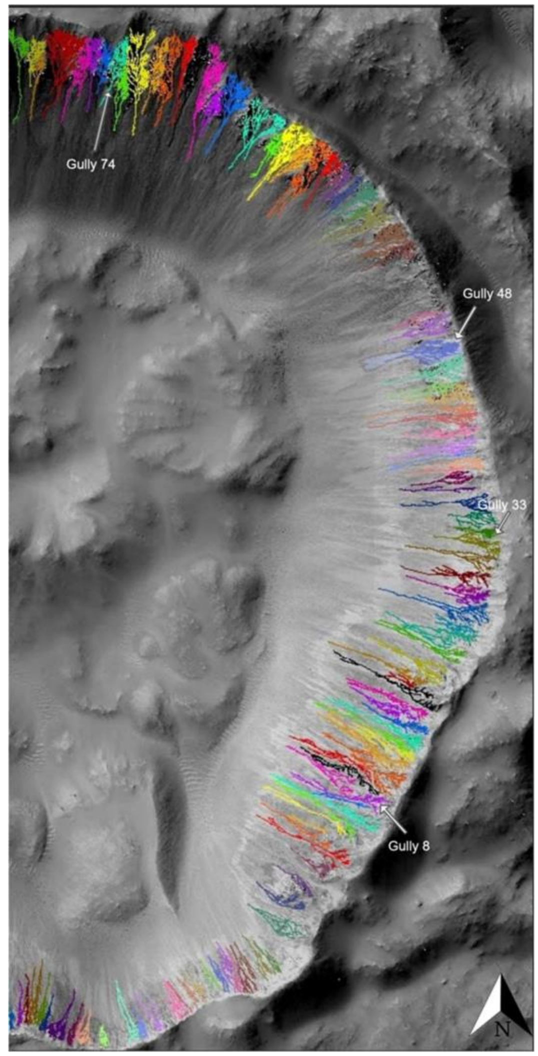

Figure 1: HiRISE image of Krupac crater. Individual gully networks mapped in different colors. The most prominent gullies analyzed are labeled with arrows. HiRISE DTM ESP_036209_ 1720_IRB_A_01_ORTHO

profiles, we calculated alcove, channel, apex, apron, and overall slopes as well as gully and apron volumes. The CSL or longitudinal profile can yield important information such as the degree of profile concavity, which provides clues to the dominate processes involved in gully formation.

We recorded bank stations marking the highest elevations within the drainage basin along the margin of each gully transect, and the lowest points of each transect along the apron margins. These bank stations provide an accurate outline of the extent

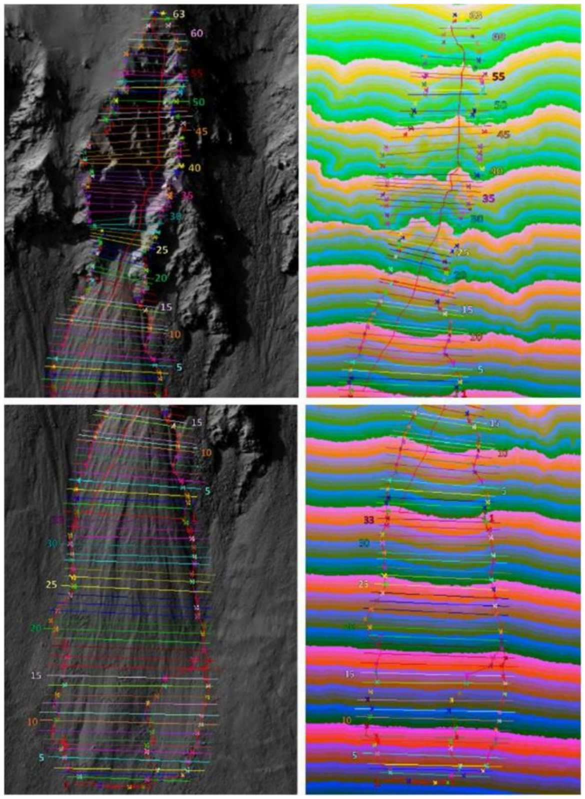

Figure 2: images of Krupac gully 74 showing the transect method. a) HiRISE image under gully transects 1-63 defined by the CSL. b) DTM elevation colored image with same transects as part a c) HiRISE image under apron transects 1-33 as well as gully transects 1-15. d) DTM elevation colored image with same transects as part c.

of the gully system and information to determine the eroded gully and depositional apron volumes. We also used surface temperature (T) and pressure (P) data from Mars Global Surveyor's Thermal Emission Spectrometer (TES) and Mars Odyssey's Thermal Emission Imaging Spectrometer (THEMIS) to compare the stability of H_2O and CO_2 phases at these sites.

Results: Using the Strahler stream order method, the four main gullies yielded fairly low values of 3 for gully 8, and 4 for gullies 33, 48, and 74. However, using the Shreve stream order method gave high network magnitudes for the northern and northeastern gullies 48 and 74, with magnitudes of 58 and 47, respectively. The Shreve stream order method gave lower network magnitudes for gullies 8 and 33 on the eastern side of the crater, with magnitudes of 12 and 16.

Gully system transects were mostly U-shaped and the longitudinal profiles showed that the CSL were mostly straight, with little to no concavity or convexity. Additionally, the slopes on all four gully systems were steep. Alcove slopes ranged from about ~34-36˚, while apex slopes ranged from ~30-34˚. TES P ranged from 3.7 – 4.7 mbar, while THEMIS and TES T, range from 165 – 293 K, placing the range of conditions in` Krupac Crater to be below the triple point of water, and beyond the stability region for CO_2 ice. Conclusions: Since the Shreve stream order system is an indication of drainage basin size and the degree of tributary network integration, the high network magnitudes associated with gullies 48 and 74 indicate possible aqueous or volatile assistance at some point in time during the formation of these gully systems.

However, all four gully systems had relatively straight longitudinal profiles and U-shaped cross-sections suggesting that the gullies were formed predominantly by dry flow processes. Dry flow processes are further supported by steep alcove slopes that are above the angle of repose (~33°), where gravitational forces are sufficient to move loose sediment downslope and transport them to the apron region as the apex slopes are well above 22°. TES and THEMIS T and THEMIS P ranges indicate that H_2O ice is presently stable seasonally in Krupac Crater, while liquid H_2O and CO_2 ice are not, indicating that fluvial or CO_2 ice sublimation processes do not contribute to gully or sediment flow activity within the crater during the present day.

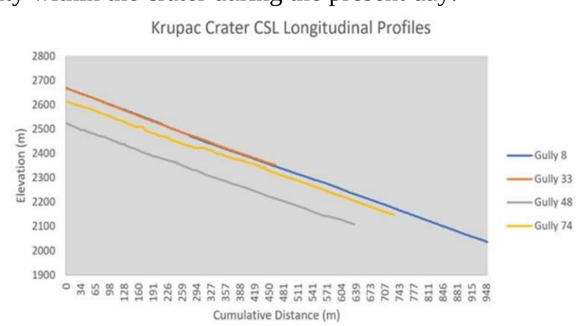

Figure 3: Krupac Crater gully profiles show nearly straight from source regions to terminus.

However, these results seem to indicate that in the recent past (last 10^5 year obliquity cycle), Krupac could possibly have been in a T and P range that initially supported liquid flow to form the integrated tributary networks, but that most of the subsequent formation and modification of the Krupac gullies are dominated by dry gravitational flows.

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References: [1] Strahler, 1952, GSA Bull. 63:1117-1142. [2]. Shreve, 1966, J. Geol., 17-37. [3] Gulick et al 2019, GSL, http://dx.doi.org/10.1144/SP 467.17