GULLY FORMATION ON THE NORTHWESTERN SLOPE OF PALIKIR CRATER, MARS. K. Luu[1,2], V. Gulick[1], N. Glines[1], [1]SETI Institute/NASA Ames Research Center, MS 239-20, Moffett Field, CA 94035. *Virginia.C.Gulick@nasa.gov*. *Natalie.Glines@nasa.gov*. [2]California State University, San Bernardino, 5500 University Parkway, San Bernardino, CA 92407. *Luuk300@coyote.csubs.edu* .

Introduction: Observation of relatively young gullies located along the impact crater walls on Mars has caused debate over what processes could have formed them, because current Martian atmospheric pressures and temperatures are often below conditions needed to stabilize water [1]. Proposed processes include water-rich debris flow [1], dry mass wasting [2], and fluvial activity from melted ice found in sediment [3]. The purpose of this study was to analyze the geomorphological features of the gullies to better understand the primary formation processes and the implications for possible paleoclimatic change.

Well-developed Martian gullies are comprised of an alcove, channel, and apron [1]. The alcove starts at the gully origin and is a carved depression that lies along the slope of the bedrock surface. The alcove connects to the main trunk of the gully, or the channel. The apron resides at the terminus of the channel and is composed of the deposited downstream material.

Palikir Crater, located within the basin of the larger Newton crater, is approximately 15 km in diameter and contains gullies incised into the crater rim. Gullies have formed on all interior crater slopes, except in an area on the southernmost slope [2]. The gullies on northern and eastern slopes have been previously studied, along with the RSL that are situated along the alcoves and upper tributaries on the eastern slopes [2,3]. Gullies on the western and southwestern slopes are currently being studied [7]. The northwest regions contain extensive, well-developed gully systems and will be the subject location of this case study.

We analyzed the gullies and used CRISM data to look for evidence of both hydrated minerals, which would suggest an abundance of water in the past Martian climate, as well as ice (both CO_2 and H_2O) for indications of more current hydration levels throughout the gully systems.

Method: We used HiRISE Digital Terrian Model (DTM) 039502_1380_039779_1380, stereo image ESP 039779_1380, and orthoimage 039502_1380 showing the West Palikir Crater rim. The DTM has a resolution of 1 meter/pixel.

Drainage delination. The gullies were deliniated using ArcGIS software. The DTM/orthoimages were viewed and mapped at full-resolution along tributary/channel pathways to produce a drainage diagram (Figure 1). The stereo anaglyph was used in conjunction as 3D visualization to validate depth perception not obvious in the orthoimage.

ENVI/MATLAB volume approximation and longitudinal profile. We used ENVI (Environmental Visual Imaging) software to draw approximately 100 transects perpendicular to the center stream lines of the gully. The spatial profile of each transect was used to determine the bank station elevation at each point and give us an approximate area of each cross section. The trapezoidal integral approximation function in MATLAB using the cross section areas to give us a minimum volume approximation and longitudinal profile.

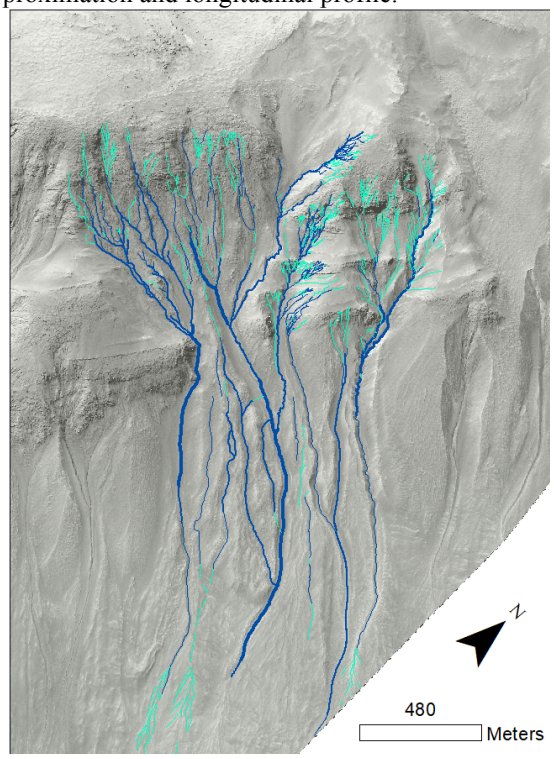

Figure 1. Drainage delineation of a complex gully system in northwest Palikir crater. Line weights indicate channel size, with lighter blue lines indicating fingertip tributaries. The DTM/Ortho image cuts off the aprons of the system.

CRISM CAT and mineralogy. We used the CRISM Analysis Tools in ENVI (CRISM CAT) to analyze the CRISM spectral data taken aboard the Mars Reconaissance Orbiter at 18 meters/pixel resolution. The analysis was performed on data package 000058F3 long wave length in the IR spectra. The data package covered the

northern rim of Palikir crater. We analyzed the data using a reference library of spectra and mineralogy filters [5].

Table 1. *Minimum volume approximation and alcove, channel slopes of gully A, the right most delineated gully (Figure1). Gully A data was taken from the ENVI method while ArcGIS was used for a mean slope estimate of the entire system.*

Gully (A) volume (ENVI)	4.6 x 10^6 m^3
Alcove (A) slope (ENVI)	17.2º
Channel (A) slope (ENVI)	11.8 º
Total slope of A (ENVI)	14.8 º
System mean slope (ArcGIS)	21.1 º

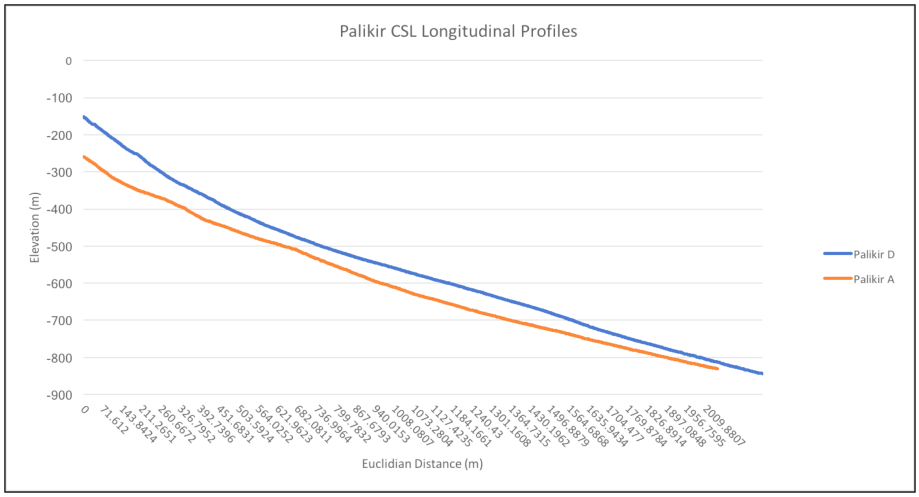

Figure 2. Longitudinal profile of Gully A (The rightmost gully) and Gully B, the left most gully deliniated in Figure 1. Approximate length of both gullies are 2 kilometers.

Discussion: The geomorphology of the gullies suggest water played a role in their formation. The drainage network from this gully is a highly integrated tributary system. Fingertip tributaries flow into intermediate tributaries which flow into the main trunk or channel of the gully (Figure 1). Integrated tributary systems are indicative of fluvial activity.

Another indication of fluvial activity is gullies eroding into bedrock. This is evident in Figure 1, where there is a horizontal layer of bedrock across the alcove of the system, but the bedrock line is discontinuous where the tributary channels cut through it. The longitudinal profile of gullies A and B both show a concave profile, further suggesting the material was removed from the surface as the gully was formed instead of deposited over the bedrock layer. This eliminates the possibility of a debris flow being the main formation mechanism of this gully, as it may need a linear or convex profile in the alcove/channel area to suggest debris was transported and deposited over the bedrock.

Cross-sections taken of the gully in ENVI show a V-shaped channel and thalwag, not a U-shaped valley indicative of glacial carving into the bedrock. Despite the global-scale ice below the Martian surface, glacial carving is most likely not the main formation mechanism of the gully system.

The slope of both the entire gully system and the alcove/channel slope of gully A are both less than the angle of repose for Mars Such low angle slopes do not allow gravity to become the main force in transporting debris and depositing it at the slope terminus that would be characteristic of a "dry" debris flow[7]. Complex gully systems at lower slopes in addition need water as a transport mechanism instead of gravity alone[7].

The complex morphology of the the gully system, including the integrated tributaries, incised channels, and concave profile suggest formation via a fluvial process. It is likely that multiple processes were involved in gully development, because, for example, terrestrial fluvial system also experience dry landslide activity. However, its main formation mechanism was most likely largely water based.

Notes on CRISM. Analyzing the spectral image yielded inconsistent spectra results for H_2O ice in the gully channels. The sample pixels that lit up after applying the RGB ice filters BD1435, BD1500_2, and ICER1_2 did not display a broad absorption feature at 1.5 microns. However, every pixel that indicated possible ice was not analyzed due to time constraints. The filter package for gypsum minerals likewise yielded inconclusive results for gypsum in the gully area due to lack of diagnostic absorptions features.

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