Geomorphological Analysis of Gullies Along Western Slopes of Palikir Crater

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Gully Analyses Indicate Potential Fluvial Formation Mechanisms in Palikir Crater

Gullies are erosional slope features characterized by their alcove, channel, and debris apron. Many mechanisms have been theorized for their creation:

- Fluvial and/or debris flow processes
  - Surface snowpack melting during high obliquity
  - Release of subsurface liquid brine water under pressure
- Seasonal carbon dioxide frost and defrosting activity
- Dry granular mass wasting flows resulting from destabilization of regolith due to gravity on steep slopes

However, gully morphology on the eastern slopes of Palikir Crater appear most consistent with a formation by fluvial processes according to some previous studies [12, 5]. To constrain potential formation mechanisms, we used a HiRISE DTM (Digital Terrain Model) (see Fig. 1) generated from stereo image pairs and its corresponding orthoimage to analyze gully morphology and morphometry on the western slopes of Palikir Crater.

Key Question

How can gully morphology and morphometry provide evidence of past water activity in Palikir Crater?

Methodology

ENVI Transect Method: (Fig.1) Cross-sectional transects generated in ENVI (Environment for Visualizing Images) are created to determine the volume of gully material removed. Data was then entered into a Python script developed by our team, giving us gully and apron volumes.

- Missing gully volumes were calculated as:

$$\frac{Total\ Gully\ Volume - Total\ Apron\ Volume}{Total\ Gully\ Volume} x100$$

- Using center streamlines (CSLs) of the gully's thalweg, further measurements were taken:
  - ***Concavity Profiles:*** Normalized longitudinal gully profiles
  - ***Slopes:*** Average slopes and apex slopes determine if the system was created by a fluidized or non-fluidized dry granular flow [7]
  - ***Gully Lengths***: Describes degree of erosion
  - ***Sinuosity expressed as:***

$$S = \frac{L1}{L0}$$

L1=channel length
L0=straight line distance top to bottom

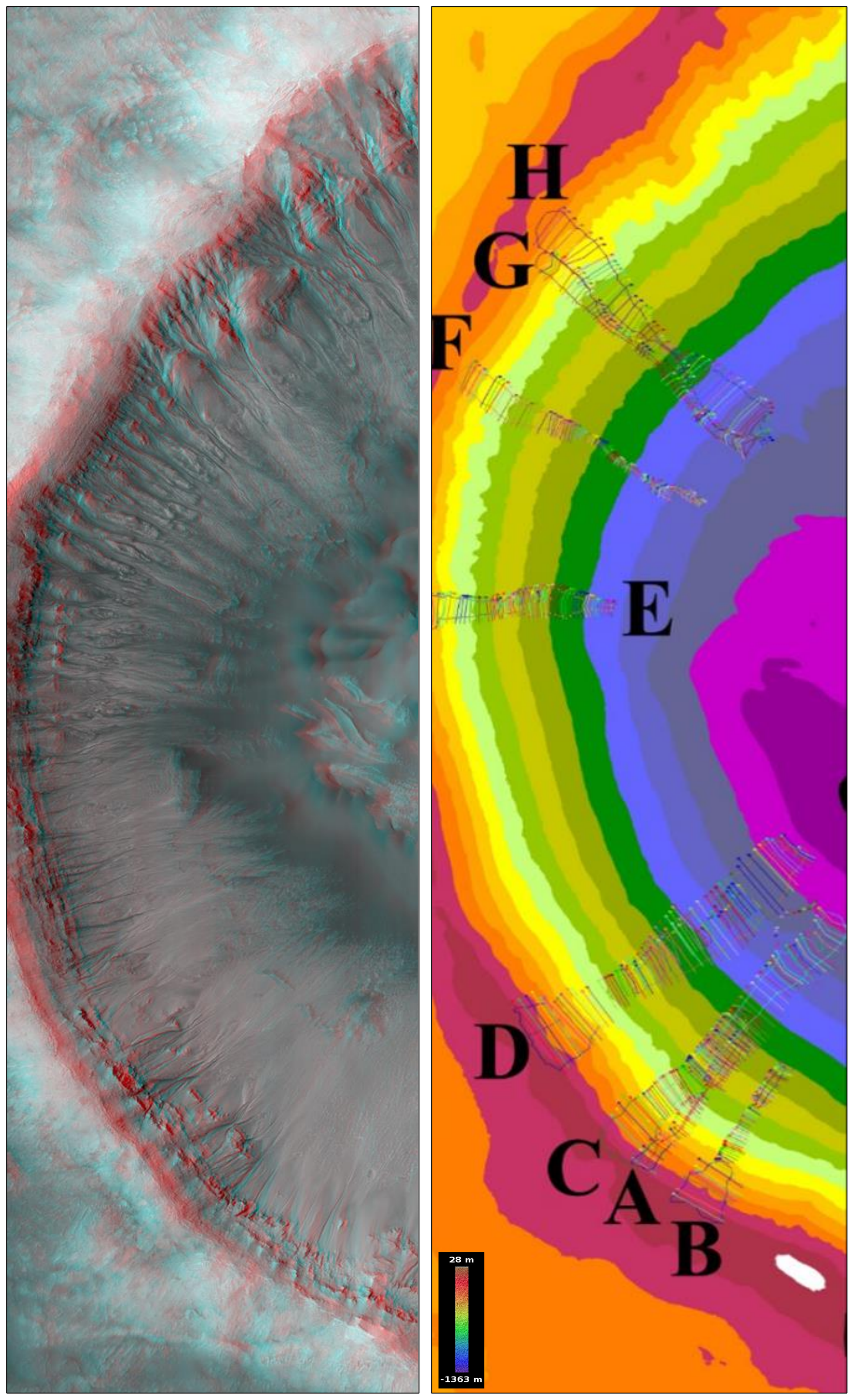

Fig. 1: Left shows an anaglyph (red-blue images generated using two HiRISE stereo pairs) of W. Palikir located at 202.142E,-41.735N. Right shows DTM, (DTEEC_039502_1380_039779_1380_A01) of W. Palikir with gullies A-H loaded in ENVI, scale of. North is up.

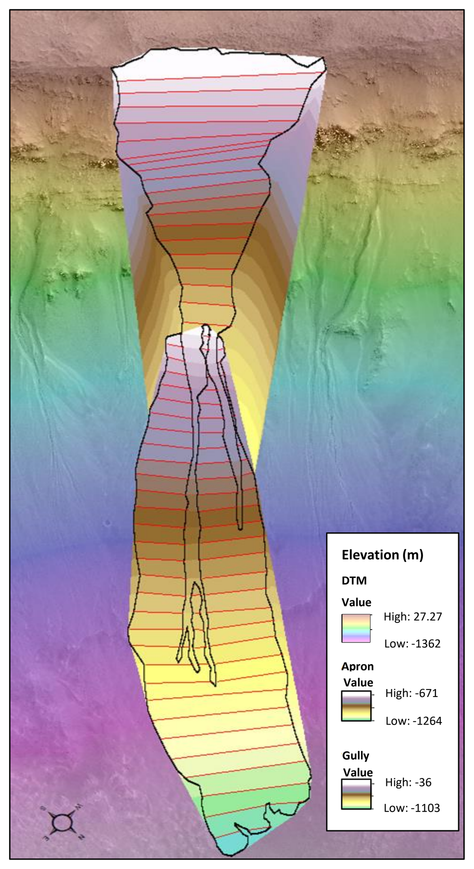

Fig. 2: Gully D loaded in ArcMap

ArcMap Method:

This fast alternative method utilizes TIN (triangulated irregular network) tools to create a cap over the eroded area of the gully and underneath the apron to simulate the pre-erosional/pre-depositional terrain.

Further ArcMap Measurements:

- ***Drainage Maps:*** Mapped tributaries, distributaries, and delineated drainage basins (Fig. 5).
- ***Drainage Density:*** *The sum total length of gullies over the drainage basin area. A measure of drainage integration*
- ***Stream Order and Magnitude:*** Using the Strahler stream ordering method, streams were assigned a numeric order to its links allowing characterization of streams based on their order. Stream magnitudes are equal to the total number of first order streams (exterior links) [11].

Results and Discussion

Volumes:

- Gully volume averages were $3.09x10^6m$ and $4.04x10^6m$ for ENVI and ArcMap respectively. The average apron volumes were an order of magnitude smaller of $7.73x10^5m$ and $2.14x10^5m$ for ENVI and ArcMap respectively.
- Missing gully volumes ranged between 83.3% - 99.9% in ArcMap and 17.2% - 99.6% in ENVI.
- Results likely represent a volatile component such as liquid water in gully formation [5].

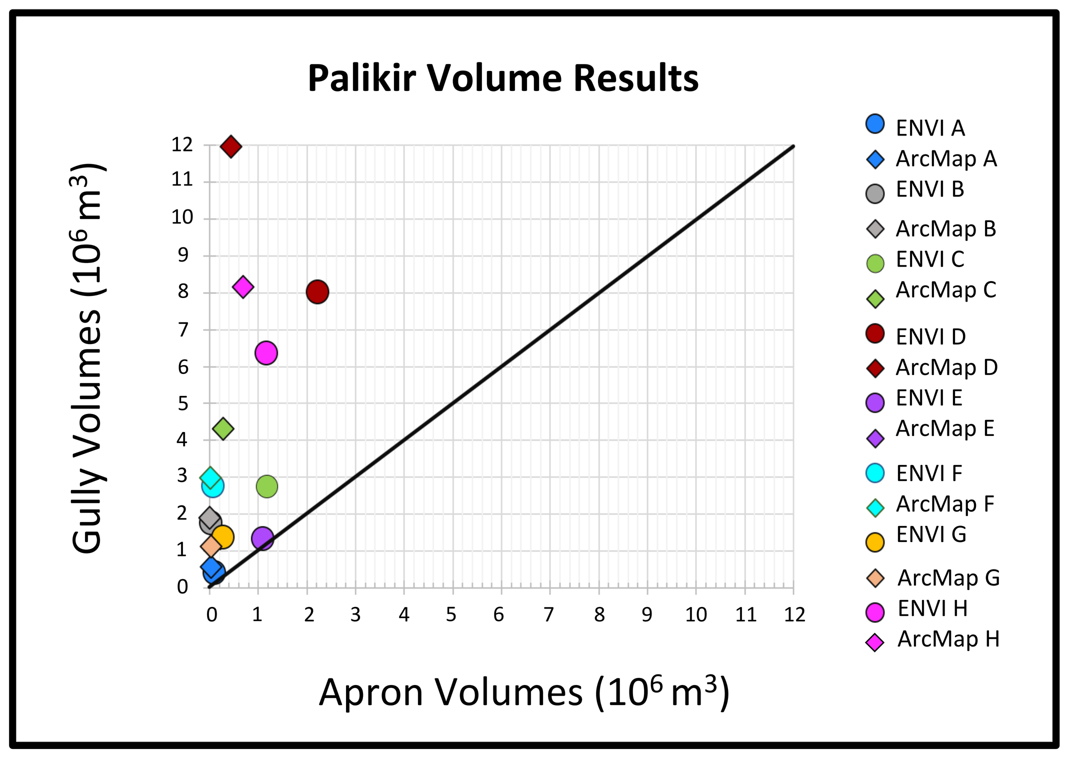

Fig. 3: Comparison of gully and apron volumes using ENVI and ArcMap. Gullies that have volumes larger than their aprons lie above the trend line.

Sinuosity and Gully Lengths:

- Lengths range from 1,069 to 2,843*m*. Longer lengths correlate to higher degree of erosion due to liquid flow [3].
- Sinuosity values ranged from 1.07 to 1.11. Liquid water-bearing flows exhibit similar sinuous characteristics [4].

Slopes:

- Average slopes were 25.65°, 19.97°, and 12.88° for the alcove, gully, and apron, respectively.
- Values are below the angle of repose of ~34° under Martian gravity meaning dry flows were less likely to carve these gullies [2].
- Apex slopes averaged at 14.24° falling below 21° where a dry granular flow typically deposits [7].

Concavity Profiles:

- Concave profiles (Fig. 4) generally indicate a fluvial dominated gully system, while convex or straight profiles indicate debris flow dominated or dry flow dominated gully systems, respectively [6].

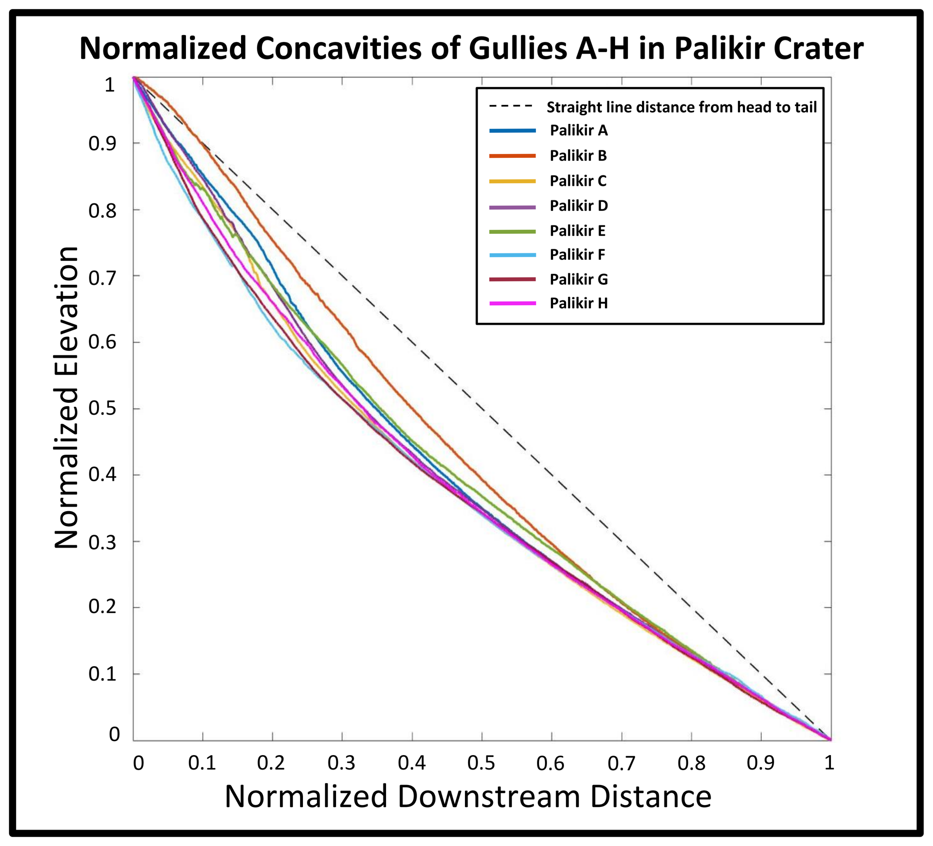

Fig. 4: Concavity profiles of gullies A – H.

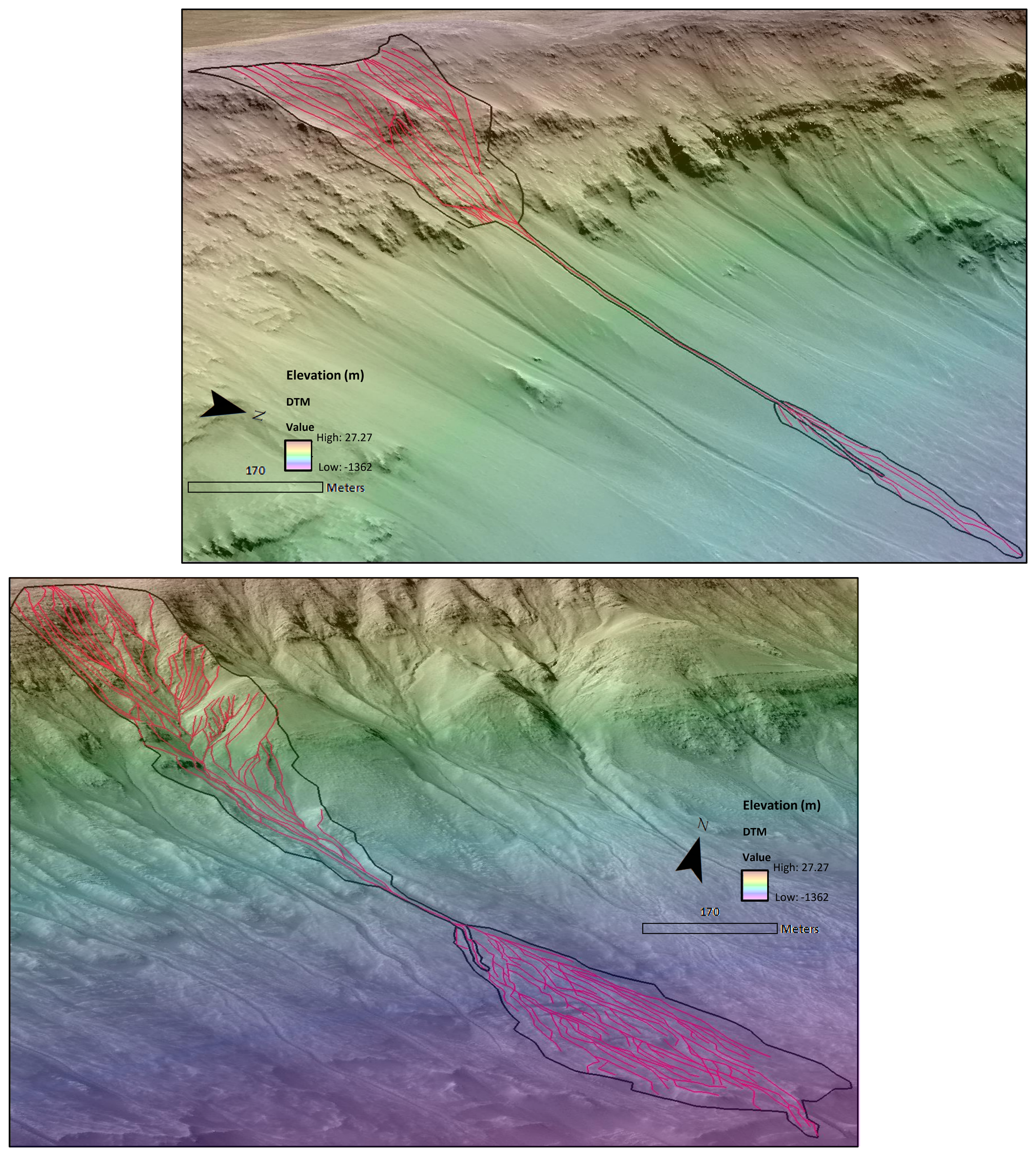

Fig. 5: Drainage maps of gully B (top) on the S. slope and gully H (bottom) on the N. slope of Palikir.

Drainage Densities:

- Table 1 shows stream orders and magnitudes gradually increasing toward the northern rim.
  - Better developed gullies with increased discharge or similar, but prolonged discharge along with a more complex stream network could account for higher values.
- Drainage Densities were calculated as:

$$D = \frac{\sum L}{A}$$

L=Total Length of Basin Streams
A=Basin Area

- Averaging around $0.03m^{-1}$, drainage densities were relatively low when compared to other Martian values of $0.004–0.122km^{-1}$[8].
  - Short lived erosional processes may explain such low values [8].

Table 1: *W. Palikir Gully Morphometric Parameters.*

Gully	Drainage Density (m^{-1})	Stream Order	Stream Magnitude
A	0.0205	2	3
B	0.0324	4	18
C	0.0231	3	12
D	0.0139	3	13
E	0.0396	4	34
F	0.0225	4	15
G	0.0594	3	9
H	0.0381	4	50

Implications for Fluvial Gully Origins

As with previous studies from our team, our results are consistent with other Martian gully systems in terms of fluvial origins [5].

- Enhanced erosion along N. crater slopes may result from a higher volume of frost or ice accumulating in shadowed areas from the sun.
- Subsequent melting can cause increased discharge or a longer period of gully formation in certain areas of the crater [1][2][3].
- Potential location, time, and climate dependent fluidization mechanism [7].
- Current Palikir gully activity may be a result of multiple processes with primary formation from fluvial processes [5].

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