GEOMORPHIC ANALYSIS OF INTEGRATED GULLY SYSTEMS ON MARS. Virginia C. Gulick[1,2], Natalie H. Glines[1,2], Patrick M. Freeman[1,2], Paige Morkner[1], Carly Narlesky[3], Sean Corrigan[4]. [1]NASA Ames Research Center, Moffett Field, CA 94035, [2]SETI Institute, Mountain View, CA, [3]MBK Engineers, Sacramento, CA; [4]Colgate University. Virginia.C.Gulick@nasa.gov.

Introduction: The formation of gullies during Mars' more recent geological history has remained an active topic of debate for nearly the past decade and a half. Several global studies have provided information on their distribution and have inspired numerous hypotheses to explain gully formation (for a recent review see [1]). However, the variety of gully morphologies present on the surface of Mars has led many to conclude that gullies likely formed by multiple processes. Therefore to better understand the relative importance of various gully formation and modification processes, we have been conducting detailed morphologic and morphometric studies of gullies in a variety of environmental settings on Mars using HiRISE images and DTMs. Here we present some of our results from our research of several integrated gully sites as well as two dune gully systems.

Drainage Maps: Using HiRISE and CTX images, we produced detailed drainage maps of gullies on the slopes of Corozal crater (Fig.1a), Moni crater (Fig. 1b) (located along the southern floor of Kaiser crater), and Palikir Crater (Fig.2a)(located on the floor of Newton crater), on the central peak of Lyot crater (Fig. 2b, 3b), a gully system on the central peak of Hale crater (Fig. 3a), and one on the western rim of Hale crater, on the western wall of Sisyphi Cavi, in addition to the large Matara dune gully, and a gully located on the Kaiser dunes for comparison.

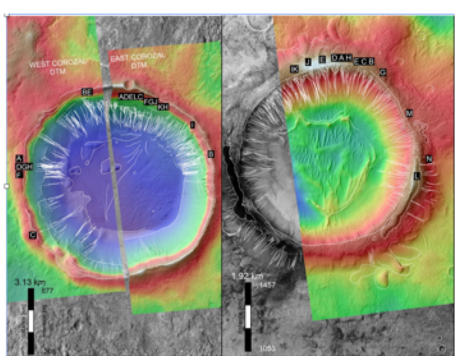


Figure 1: Detailed drainage maps of gully systems on the slopes of Corozal (left) and Moni (right) Craters. HiRISE DTMs overlayed onto drainage maps. Letters indicate individual gully systems studied with HiRSE DTMs.

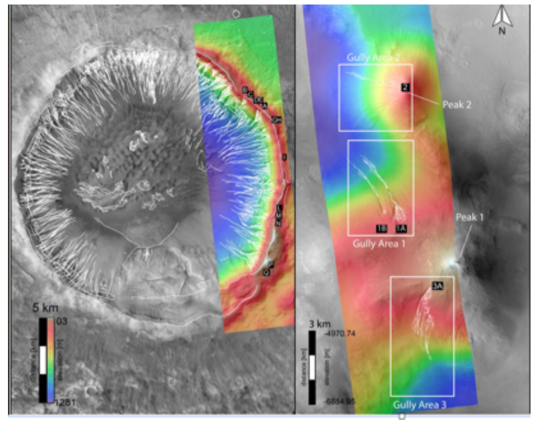


Figure 2: Detailed drainage maps of gully systems on Paliker crater (left) and on the central peak of Lyot crater (right).

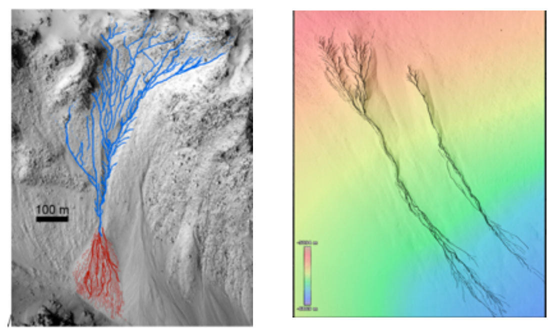


Figure 3: Examples of integrated gully systems on the central peaks of Hale (left) and Lyot (right) craters as mapped using HiRISE images. See Corrigan et al. LPSC 2017 for details on Hale gully system. Close up of gully area one of Lyot central peak in Figure 2.

The resulting drainage maps reveal that the gully systems on the crater slopes and on the central peaks form complex, highly integrated, tributary systems in the source regions, incised channels in the mid-sections and channels with levees on the aprons when viewed close up at HiRISE resolution (~25cm/px). Such morphology is consistent with water erosional processes operating within a fluvial system. Integrated drainage patterns are characteristic of water erosion and fluvial activity. Additionally, we also note that many of the debris aprons are heavily dissected by channels with levees (for example see fig. 3). This is consistent with fluvial activity where flow transitions from confined to unconfined and is associated with a sudden decrease in slope. As flow spreads out on the apron, water infiltrates and evaporates, sediment concentration increases and flow behaves more like a debris flow.

DTM analysis: In our previous [2-9] and current studies, we find that most gullies that we've studied have concave profiles. Deviations in the longitudinal

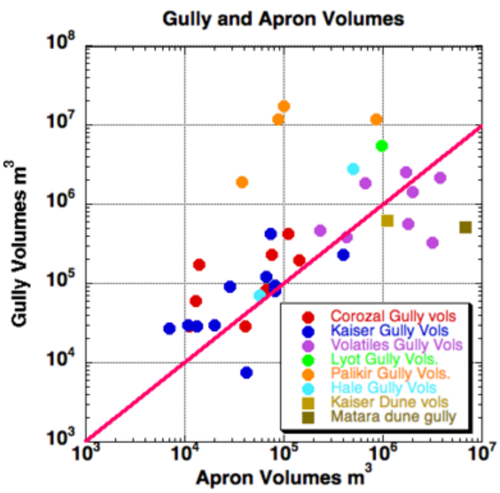


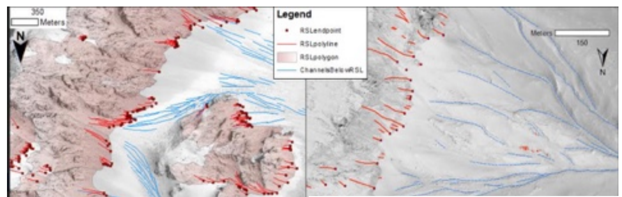
Figure 4: Gully volumes plotted against their apron volumes in studied gully sites.

profiles generally correlate to areas where the gullies have incised through stratigraphic layers.

We also note several interesting correlations/associations in our study locations. When we compare the individual gully volumes with their associated debris aprons, the gully volumes are significantly larger than the apron volumes Figure 4. This is a finding that we initially reported in [6] and have attributed the discrepancy in volumes to the potential water, ice, and volatile volumes initially contained in the system and that were lost to the system during gully formation. In comparing the resulting volume discrepancies in the two dune gullies to the crater gullies, we see that the apron volumes are generally similar or larger than their gully volumes.

Gullies associated with RSL? In mapping the gully drainage systems in detail at HiRISE resolution, we also noted a spatial association with RSL in some locations particularly in the Palikir and Hale study sites (Figure 5). RSL are often found either in the tributaries of these integrated systems or in adjacent regions. Therefore, this suggests that RSL may play a role in initiating gully formation and/or mark the last vestiges of water activity in these locations.

Summary and Conclusions: Studying gully systems in a variety of environmental settings at HiRISE resolution and analyzing these systems with DTMs continues to provide additional insights to understanding gully formation. We find that the more highly integrated gullies have eroded volumes significantly larger than their deposited apron volumes, suggesting that the missing volumes may reflect the volatile volumes involved in gully formation. In contrast, the Matara dune gully, and the Kaiser dune gully, which are much less integrated, either have minimal volume discrepancy or larger apron volumes when compared to their gully volumes. Apron volumes that equal or exceed their



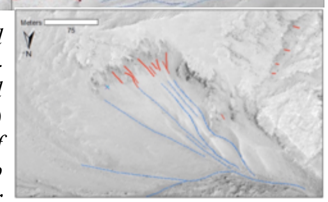


Figure 5: RSL in red and downslope gully channels in blue on the central peak of Hale crater (left) and on the eastern slope of Palikir crater (right). Top right is gully P and lower right is lower alcove of gully M in Palikir. Do RSL play an integral role in gully formation or are they simply the last vestiges of a more active hydrologic cycle?

gully volumes suggest that dry flows, avalanching, gully infill, active dune processes or other dry processes may have been more important in these less integrated systems. These associations suggest that although there are various gully morphologies on Mars that reflect the involvement of multiple processes, we find gully systems in Moni, Corozal, Palikir, Lyot, and Hale craters to be consistent with a primary formation by fluvial processes.

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References: [1] Harrison et al 2015. [2] Narlesky C. and Gulick V. 2014. *LPSC abstract* # 2870; [3] Hernandez, D. Gulick V. and Narlesky C. 2014 LPSC Abstract #1198; [4] Gulick et al, 2016, AGU Fall mtg.; [5] Hart S.D. et al. (2010) LPSC Abstract #2662. [6] Gulick et al., (2014), *8th Int. Conf. on Mars,* Abstract #1490. [7] Gulick & Glines (2016), *DPS/EPSC,* Abstract #513.06. [8] Glines et al., (2016), *47th LPSC,* Abstract #2464. [9] Gulick et al., 2016, *GSA Rocky Mt. Sec.,* Abstract #276281.