SLOPE ANALYSIS OF MARTIAN GULLIES IN THREE HIGH-NORTHERN LATITUDE CRATERS. R. I. Huang[1,3], V. C. Gulick[2,4], N. H. Glines[2,3,4]. [1]SETI Institute REU (huang.rowan@gmail.com), [2] NASA Ames Research Center, [3]NASA Ames Summer Internship Program, [4]SETI Institute.

Introduction: Gullies on Mars are generally defined by an alcove, an incised channel, and a downslope depositional apron [1]. This morphology is common for a vast majority of gullies, especially those in southern mid-latitudes, where the majority of martian gullies are located. However, several gullies in the northern high-latitudes (>50° N) show unique morphologies. Studying the morphology of gullies on Mars can provide clues of the environment in which they formed, which can in turn influence our understanding of Mars' geologic and hydrologic history. In previous studies, we have analyzed the detailed morphology of gullies in two high-northern latitude craters [2]. In this study, we have added an additional crater at 60.2° N. We have also expanded our evaluations to include slope measurements and preliminary volume analysis.

The first crater (NE Tantalus Fosse; 63.8°N 292.3°E) has one studied gully with a notably bright apron and an interesting gully network. The second crater (N Lyot Ejecta; 53.6°N 26.3°E) has two gullies with strikingly different morphologies: one gully with a well-defined alcove and dusty apron with channel-like forms, while the other has a very thick, pitted apron and few channels [2].

Our new site, Crater 3 (NE Arcadia Dorsa, 60.197° N 236.267° W), is 3.13 km in diameter with a unique micro-environment, likely due to differing insolation (Fig. 1a). Its southwest slope is devoid of gullies, though there is a series of lobate features pointing downslope, suggesting frost creep or gelifluction. All other slopes, especially the northeast and southwest, contain gullies with somewhat deeply incised channels. These gullies form laterally extensive distributary systems (Fig. 1b). While aprons are not associated with most gullies in this crater, there are several bright, discrete aprons on the north and east slopes (Fig. 1c). Gully alcoves form in the heavily degraded, crenulated crater rim.

Methods: We produced maps of drainage areas and gullies in ArcGIS Pro using HiRISE stereo images, Digital Terrain Models (DTMs), and generated hillshades. These are used to calculate drainage density, sinuosity, and other two-dimensional parameters, such as stream order and magnitude.

In addition to obtaining detailed slope data, three-dimensional data such as gully and apron volumes can be calculated in ArcGIS as well as ENVI by estimating the original crater shape and subtracting current elevation data.

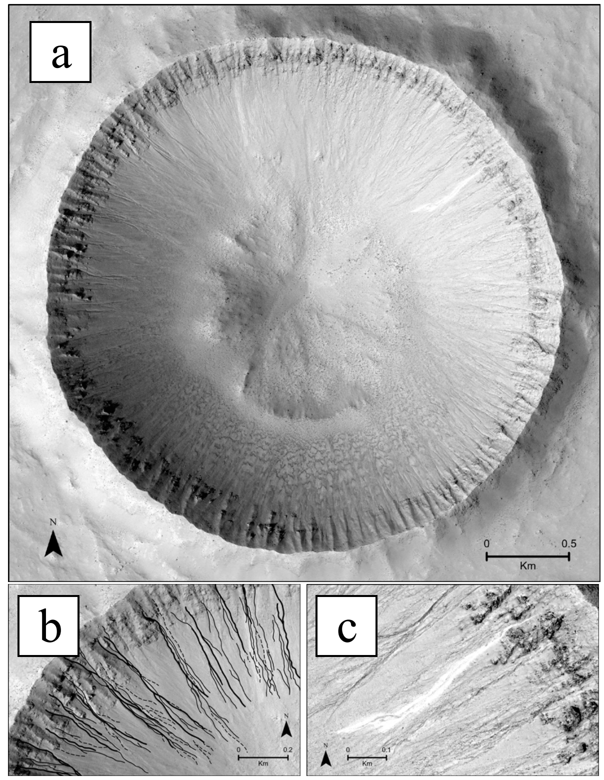

Figure 1. a) *Image of Crater 3 and associated landforms. b) Drainage maps of gully systems on NW slope. c) Bright flows on NE slope. Images from HiRISE orthoimages ESP_027065_2405 and ESP_026564_2405.*

Results and Discussion:

Slope analysis: Preliminary results show that the Crater 1 gully has an alcove slope ~16° and apex slope ~11°. The two Crater 2 gullies studied have higher alcove slopes (~30° and 27°) and apex slopes (20° and 20°). The six measured gullies in the newest crater have alcove slopes greater than 33° (35.07° average) and apex slopes greater than 32° (32.98° average).

The Crater 1 gully slope is well below both the angle of repose (~32°) and the apex slope angle required for dry flow deposition (>21°) [4], while the Crater 2 gully slopes are just below these thresholds (Fig. 2). Thus, the gully in Crater 1 was likely emplaced by fluidized flow, while the gullies in Crater 2 are more indeterminate as initial gully and terminal apex slopes are slightly below the angle of repose needed for dry gravitational flows in unconsolidated material. Crater 3 gullies are above the thresholds for fluidized flow.

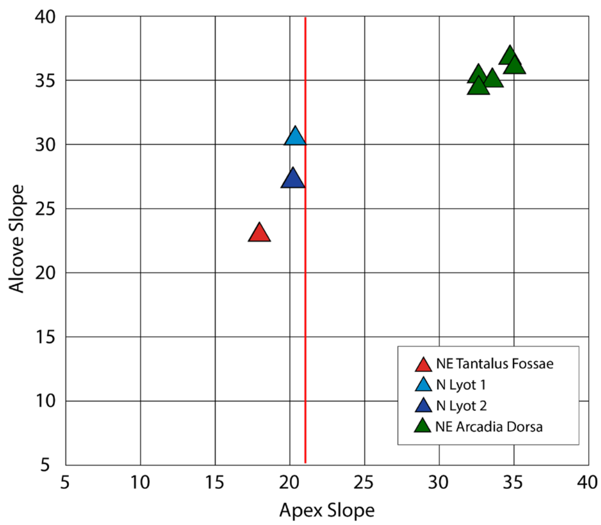

Figure 2. *Plot of alcove slope vs. apex slope of these high-latitude gullies (triangles). Red line represents the apex angle above which is required for dry flow deposition.*

Center stream profile: The concavity of the profile of the center stream line (or thalweg; the deepest and longest channel in the drainage network) can be indicative of the process that formed the gully. Straighter profiles are associated with dry flow processes, while more concave profiles are related to fluidized flow. In Fig. 3, we see that the second gully in Crater 2 (N Lyot 2) has a very straight profile, while the first gully of the same crater (N Lyot 1) is quite concave. The gully in Crater 1 and the measured gullies in Crater 3 are more moderate. Based on this, the gully in Crater 1 and gully 1 in Crater 2 are likely to be associated with fluidized flow, while the second gully of Crater 2 is implied to form by dry flow processes. The origins of the gullies in Crater 3 are more equivocal.

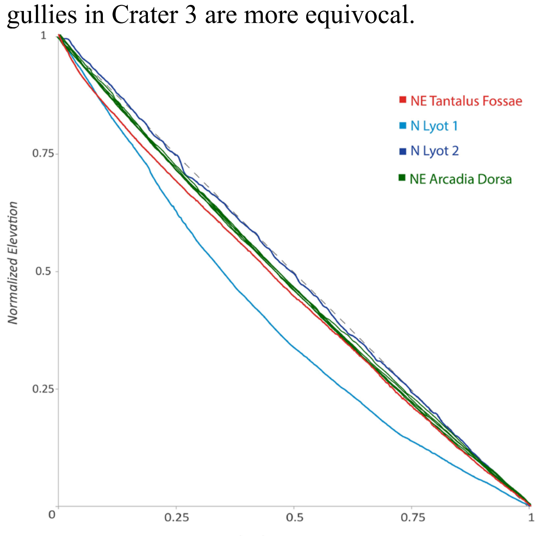

Figure 3: *Normalized gully center stream line profiles.*

Volume analysis: Preliminary results of volume analysis show greater volumes removed than deposited for all craters (Crater 1: 4.96% volume lost; Crater 2 gully 1: 25.41% lost, Crater 2 gully 2: 55.28% lost). The difference in volumes between the eroded gully and the deposited apron can be indicative of formation style for several reasons. In a dry flow process, the apron volume will equal or exceed gully volume as the shifted particles of the apron will have a lower packing density [3]. On the other hand, volatiles will be lost between the gully and the apron during fluidized flow processes. From this volume analysis, all of the gullies we have studied are implied to have formed by fluidized flow processes.

Conclusions: Based on several morphometric techniques, we can infer the formation mechanism for several gullies in the high-northern latitudes of Mars.

Crater 1: From slope analysis, the slope of this gully falls below the angle of repose required for dry-flow deposition, and we also see a more concave center stream line profile, suggesting it was formed by fluidized flow. This is supported by our preliminary volume analysis, which shows volume lost.

Crater 2, gully 1: This gully has a very distinct concave center stream line, as well volume loss between the gully and the apron, both of which support a fluidized flow origin. Its apex angle is somewhat closer to the angle of repose, so it is difficult to determine the formation process based on apex angles.

Crater 2, gully 2: Like the first gully of the same crater, this crater has an equivocal apex angle. Its straight center stream line profile is offset by the high degree to which volatiles were lost in this crater, making its origins unclear.

Crater 3: These gullies have yet to undergo detailed morphologic analysis, so their origin is indeterminate. They have very high apex angles, so they have potential to be created by dry flows. However, their center stream lines have a somewhat concave character which is indicative of fluidized flow.

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