CONSIDERATIONS FOR MARTIAN GULLY VOLUMETRIC STUDIES: MATARA DUNE GULLY
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Introduction: Loss discrepancies between the eroded volumes from classic alcove-chute-apron (ACA) crater wall/peak gullies and their depositional aprons have been linked to evidence of a significant volatile role in Martian gully formation [1,2,3,4].

To date, of the crater wall and peak gullies previously studied, volume loss averages ~60% [1,2,4]. ‘Basic-alcove’ gullies studied in Sisyphi Cavi lost between ~35 and 67% volume, while ‘multiple-alcove’ gullies have lost far less because of ice-rich ground abstraction, which results as the alcove and tributaries are eroded causing relief to be progressively reduced until there remains only a subtle depression. Most all volumes reported are high enough to remain a loss when including assumptions about the pre-depositional surface. What remains is an adjustment for settling/compression of the deposit. As water in pore space sublimates, the ground compresses, and so trends in volume loss may be used to infer a relative volatile content.

Using the High Resolution Imaging Science Experiment (HiRISE) multitemporal and Digital Terrain Model (DTM) data of an ACA-type dune gully in Matara Crater (49.5°S, 34.8°E), we have mapped the gully at the highest resolution, tracked changes, and measured volumes. We have found several results that differ from our previous results for classic type gullies.

Dune vs. Classic gullies: Given the connections between global gully form distribution [5], climate and obliquity changes, and required favorable melt conditions, in addition to morphologic observations, water as liquid, snow, or ice can best explain early gully formation on Mars. Classic ACA gullies in the setting of crater walls or peaks have previously been distinguished from dune gullies by morphology and by formation mechanisms, particularly the role of liquid water: ACA dune gullies lack a high degree of continuous channel integration, seen in high-resolution drainage network diagrams of the gullies (Fig.1C), they often have a U-shaped profile compared to the V-shaped of crater wall gullies, which aside from issues of the unconsolidated dune substrate could indicate a lack of deep, continuous linear stream incision, and dune gullies (ACA and linear) are active today. We can link dune gully formation to primarily CO2-based processes [6,7,8], although water may still play a role [9]. Classic gullies have also been reported to be active today [6,7]; however, this is likely due to modification processes, not original formation processes.

Linear dune gullies and terminal pit gullies are coeval and comingled on dunes with many ACA dune gullies, and they have been shown to form from dry ice blockslides during early spring [6,8,10]. We have detected faint ‘snowballs’ appearing and disappearing on the Matara dune gully apron, forming linear trails; it remains unproven whether these volatile snowballs formed upon the deposit surface, or were unearthed by downslope movement. Frost-related seasonal activities have been shown to trigger significant channel changes within this Matara dune gully [9,11,12,13,14,15,16]. Vincendon 2015 derived equal probabilities for both H2O and CO2 being present at the Matara site associated with alcove and channel changes [15].

If ACA dune gullies form by wind-driven surface frost-supported oversteepening and in springtime a consequent sublimation-driven collapse, we might not expect there to be a water-volatile component to any volume shift downslope; However, if volatiles may be found throughout the dune, a newly unearthed deposit could be expected to have a volatile loss component. Recent evidence predicts dunes on Mars may contain up to 40-50% water by mass [17]. Derivation features of deformational cracks or fractures we observe on the Matara dune may be evidence of snow/frost/ice preserved in the dunes.

Dune Gully Volume Results: We have measured the volumes removed and deposited of the ACA dune gully on the Matara Crater megadune. When comparing the alcoves and upper channel to the apron deposit, (Fig.1A) the gully has under a 15% volume loss, which would be at the lowest end for any ACA-type gully we’ve previously measured on Mars. This apron volume is 1000% greater than the volume directly within the small gully channels (colored alcoves, Fig. 1).

Conclusions: These results suggest that the Matara Megadune Gully formed by significant mass-movements, while the actual alcove channels visible today are surficial modifications or effects. The surficial channels we see are recent and may not necessarily be attributed to dune gully initiation.

The ~15% loss between the total volumes removed and deposited could mean several things, the most significant of which being it could indicate a volatile component throughout the dune. We propose that general volatile destabilization is the predominant process to form the Matara dune gully, perhaps triggered by natural wind-driven dune movement and sublimation.
A newly shadowed alcove and channel in the dune would provide a shelter or sink for frost activities, such as frost pack accumulation, and block or material sliding to form the surficial channels. Ice exploiting such alcoves has been seen on Earth, in the analog sand dunes of the Victoria Valley, Antarctica [18,19].

While the major sinuous channel changes downslope in the Matara gully might at first glance appear fluvial, detailed examination using network diagramming in HiRISE images (Fig.1C) shows they instead resemble a mass movement with both gravity-formed alcove ‘channels’ and surficial discontinuous ‘channels’ where frost blocks or ‘snowballs’ slide.

Considerations: Compressional volume is a factor when measuring gully and deposit volumes in geomorphometric studies, and there is likely a volatile component for both dune and classic ACA-type gullies; preliminary results indicate that either there is less volatile content to the original dune or that dune movement in the past affected alcove boundaries for the measurement.

If, as this preliminary research suggests, there is a volatile component to the dune gully deposits, and if that content has been preserved in the dune since the past climate change, or if frost has seeped down into the layers, would ice at depth within dunes be primarily water or CO2?

More ACA-type dune gullies need to be measured in order to round out this study. Additional modeling research would be useful to prove whether the dune would be capable of producing the deposit without being ice-rich throughout; if proven ice-rich, then further research would be required to predict the ice composition within the dune.


Figure 1: (A) Matara megadune gully with area divisions highlighted. Volume Removed = total alcove (blue alcove outline) plus the upper red trunk volume. Volume Deposited = total apron (within blue outline). Grey areas of the alcoves do not have major channels. Minor Alcoves 1-5 contain small, often discontinuous, channels, as seen in the (C) network diagram. (B) Illustration of the transect method of volume measurement.