Introduction: Martian gully channels [1], which typically incise indurated fine-grain material like the latitude-dependent mantle and dunes [2], frequently emanate from amphitheater-shaped alcoves that are eroded into bedrock at the crest of steep slopes [1], most commonly crater walls in the mid-latitudes of Mars. Though gully channels are morphologically similar to water-carved landforms on Earth, recent work has tied these features to seasonal CO₂ activity [3]. If gully channels can be incised by processes that do not involve H₂O, does the same hold true for alcoves, which are made of considerably stronger material? This project aims to explore the role of dry rockfall in the erosion of the bedrock alcoves of Martian gullies. Bedrock alcoves may also preserve a longer record of gully activity than their associated channels, which have been shown to be ephemeral features over long timescales.

To understand the capacity for bedrock erosion on steep slopes in a completely dry environment, we follow upon the work of Bart [4] and Kumar et al. [5], who have shown that features that are broadly visually similar to Martian gullies are observed on fresh crater slopes on the Moon [5]. The long duration success of both the Mars Reconnaissance Orbiter and the Lunar Reconnaissance Orbiter allow us to make observations and measurements using data not previously available.

We generated high resolution Digital Elevation Models (DEMs) from High Resolution Imaging Science Experiment (HiRISE) [6] and the Lunar Reconnaissance Orbiter Narrow Angle Camera (LRO NAC) [7] imagery for Mars and the Moon respectively, to determine if Mars-like bedrock gully alcoves can form on an airless body (without volatile activity).

Lunar Survey: Target locations for Lunar erosion were identified using a slope map generated from Kaguya Terrain Camera [8] data to filter locations with slopes between 30-40°. All potential LRO NAC stereo pairs that overlap an area of sufficiently steep slope were visually inspected for erosional landforms (Fig. 1).

Alcove Comparison: DEMs of target locations on Mars and the Moon were produced using NASA’s Ames Stereo Pipeline [9]. The morphologies of Lunar erosional landforms were analyzed using qualitative observations and quantitative measurements taken from the DEMs. These were compared with measurements of characteristic alcoves in a range of Martian environments that do and do not host gullies (Figs. 2-3): high altitude (Fig. 3D), equatorial (steep slopes without gullies) (Fig. 3C), mid-latitude pole facing (steep slopes with gullies) (Fig. 3A), and mid-latitude equator facing (Fig. 3B). We used data extracted from the DEMs of each location to measure the depths of alcoves in a “suite”, which we defined as 4 or more alcoves of comparable size and shape forming sequentially on a slope. Depths of alcoves along equipotential contours within the crater rim were averaged for each location, and sorted by category (Fig. 2).

Preliminary results show that alcove depths fall along a spectrum, with shallow Lunar alcoves (Fig 3E) rarely exceeding 10m in depth on one end, and Martian mid-latitude pole-facing alcoves (Fig 3A) at the other. Alcove suites on Martian slopes that are not known to

Figure 1: Global distribution of NAC stereopairs covering steep slopes. WAC Mosaic courtesy of GSFC/ASU/MSSS.
produce gullies (Fig 3B-D) had alcoves of depths that spanned the gap between Lunar alcoves and mid-latitude pole-facing alcoves. The observation that mid-latitude pole-facing slopes had significantly deeper alcoves (Fig. 2) is consistent with gully channels preferentially forming on pole-facing mid-latitude slopes [1]. Lunar alcoves are most consistent with high-altitude alcoves on Mars. We also observed a clear disparity in alcove depth between pole and equator facing slopes in midlatitude Martian craters. A more robust survey is being conducted to measure the disparity between pole and equator facing slopes at different latitudes.

Implications: While our lunar survey revealed some debris chutes on the Moon that can mimic some gully channels on Mars [4-5], we have not observed bedrock alcoves on the Moon that have morphologies comparable to gully-hosting alcoves on Mars. High-altitude alcoves on Mars, where gullies are not found, are morphologically similar to lunar alcoves, suggesting that volatile-free processes can indeed erode bedrock on steep slopes on Mars. The spectrum of measured alcove depths spanning from shallowest Lunar alcoves to deepest Martian midlatitude alcoves leads us to conclude that CO$_2$ and H$_2$O play a role in the erosion of bedrock alcoves in Martian gully systems, not just gully channels [3]. The mechanism by which bedrock alcoves are eroded on Mars requires further testing, and may involve volatile-processes from previous climate regimes not directly related to the process that carves gully channels (e.g. glaciation), that also prefer cold, pole-facing mid-latitude slopes.

Our results implicate volatile activity within gully alcoves, which preserve a much longer geologic record than typically ephemeral gully channels. Thus, gully alcoves could potentially reveal H$_2$O and CO$_2$ related processes within terrains that do not host gullies on contemporary Mars.


Figure 2: Average depth of alcoves in each category

Figure 3: Examples of a characteristic alcoves on slopes: a) mid-latitude pole-facing b) mid-latitude equator-facing c) equatorial d) high altitude and e) Lunar.