

MORPHOMETRIC ANALYSES OF CIRQUE-LIKE ALCOVES IN DEUTERONILUS MNSAE, MARS.

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Introduction: Deuteronilus Mensae (39.6°N to 50.2°N and 13.6°E to 35.4 °E) is a region in the mid-latitudes of Mars that contains fretted terrain [e.g., 1], including steep-sided mesas with glacier-like forms (GLFs) and the mesas are often encompassed by lobate debris aprons (LDAs) [e.g., 2]. Analogous to terrestrial debris-covered valley glaciers or rock glaciers, GLFs often originate from cirque-like alcoves or valleys, and appear to flow downslope to form a tongue that is frequently bordered by moraine-like ridges [3, 4, 5, 6, 7]. GLFs are predominantly found in the mid-latitudes of Mars between 25 to 40° N and S [6, 7], and generally increase in volume with increasing latitude [8]. A total population of over 1200 GLFs has been mapped globally, including approximately 102 GLFs in the Deuteronilus Mensae region [8].

While cirque-like alcoves are often associated with GLFs, in this work we map cirque-like alcoves that do not host a mapped GLF. It is an open question if these alcoves were eroded by glacial processes during one or more phases of glaciation, by non-glacial processes, or by both. For example, nivation hollows, mass-movement scars (from rockfalls, landslides), karstic depressions, or craters can all generate cirque-like forms on Earth [9]. Non-glacial processes may provide an initial depression where glacial cirques evolve, and periglacial processes (primarily freeze-thaw) can erode the lateral margins and headwall base of cirques [9]. We evaluate if cirque-like alcoves on Mars may have formed similarly to glacial cirques on Earth.

Terrestrial cirques (also referred to as corries) are typically characterized by a concave basin connected to a steep backwall [10] and are expected to form from depressions in mountainsides that fill with snow/ice and over time support active glaciers that deepen the depressions by glacial erosion. Terrestrial cirques that are glacier-free provide a possible analog for the alcoves we see on Mars that do not host a GLF. Individual cirques on Earth have been analyzed and groupings of cirques can be informative about the style and duration of glacial, periglacial, and non-glacial activity in the past. For example, if cirque widening and lengthening outpace cirque deepening then periglacial processes may be driving the evolution of cirque morphology, whereas glacial processes likely lead to isometric growth [9, 11]. On Earth, cirques are important paleoenvironmental indicators for the interaction of glaciers, climate, and topography [9, 11]. However, cirque morphometrics can be interpreted in different ways. In cases where bedrock lithology and structure or regional

topography affect cirque distribution or morphometry, focusing on regional populations of cirques may help to separate geological controls from paleoenvironmental conditions [9]. Here, we begin to investigate how our understanding of cirque metrics on Earth may inform the interpretation of a regional population of cirque-like alcoves on Mars.

Mapping alcoves that do not contain GLFs: Using the MRO Context Camera (CTX) mosaic [12], we conducted a pilot study of cirque-like alcoves across a portion of Deuteronilus Mensae (Fig. 1).

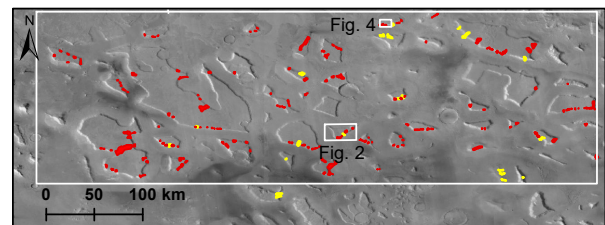


Figure 1: Pilot study region in Deuteronilus Mensae (large white box), spanning 20-30°E, 44-47°N. Red polygons are cirque-like alcoves and yellow polygons are GLFs [8].

In this pilot study region we mapped 221 possible cirque-like alcoves that have different characteristics (see Fig. 2 for examples), and this is a region where 20 GLFs had previously been mapped [8]. Fig. 2 shows one mesa where alcoves were mapped, and where there is one GLF emanating from an additional alcove [8] and smaller-scale incisions that were not mapped. Our pilot study included all alcove incisions that were wider than 500 meters, and which did not host a GLF.

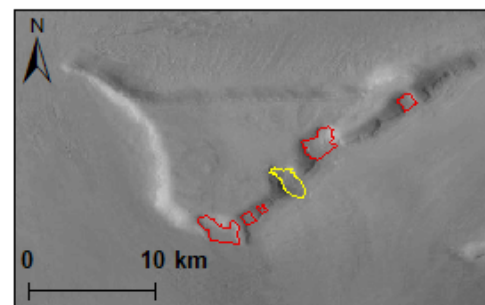


Figure 2: Centered at 25.32°E, 44.9°N. Multiple cirque-like alcoves (red polygons) of different sizes are found along the same mesa sidewall where one GLF has been mapped (yellow polygon [8]).

Initial application of cirque morphometric analyses to Mars: To avoid inconsistencies in measurement techniques for terrestrial cirque metrics, Spagnolo et al. [13] developed a GIS tool for Automated

Cirque Metric Extraction (ACME). ACME can be used for the extraction of 16 glacial cirque metrics including length (L), width (W), circularity, planar and 3D area, elevation, slope, aspect, and hypsometry [13].

We applied ACME to our population of alcoves on Mars. While alcoves in our study do not typically appear similar to classic cirques on Earth that have an arcuate headwall and bowl shape with a portion that opens down valley [e.g., 14], ACME can still be run on more complex shapes [13]. We found that most alcoves had L/W ratios between 0.5 to 1 and greater than 1 (Fig. 3). On Earth, processes that develop cirques may be reflected in the ratio of length to width [9, 15]. For $L/W > 1$, cirques are considered to have been eroded by valley glaciers; $0.5 < L/W < 1$ is for most likely cirque-type glaciers; and $L/W < 0.5$ is most likely post-glacial processes [9]. Circularity, defined as the ratio of the alcove's perimeter to the circumference of a circle with the same area as the alcove, is often considered alongside the L/W ratio [9, 16]. We find a mean circularity of 1.28 and a mean L/W of 1.19, but we note that some of the longest features appear similar to GLFs (but are lacking one or more criteria to be mapped as a GLF). Based on the different L/W ratios seen in Fig. 3, the set of alcoves likely formed by glacially related and/or glacially unrelated processes, and/or over different amounts of time. The mean morphometric ratio of cirques on Earth is $L/W = 1.03$ [9], and we can use this as a guide to further analyze a significant portion of our mapped population as possible cirques.

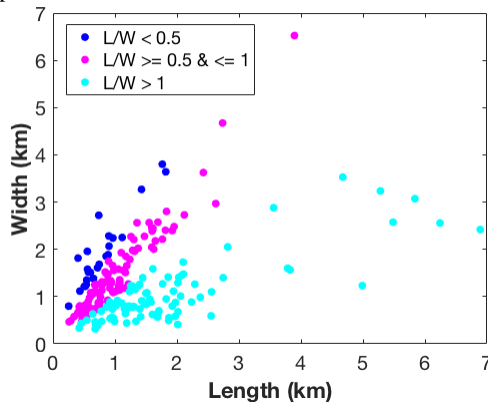


Figure 3: Plot of length (L) vs. width (W) for the 221 mapped cirque-like alcoves, color-coded by whether L/W is less than 0.5, between 0.5 and 1, or greater than 1.

Evidence for erosion of layered alcove headwalls: HiRISE [17] images covering alcoves in this region are limited, but Fig. 4 shows an example where there is evidence that the upper unit of the mesa is layered and the layering is exposed along the headwall of the alcove. A possible detached block from the headwall is also apparent, and may indicate a process of

mesa incision that widens and/or lengthens alcoves. Detached blocks along mesa slopes have been identified just outside of our target study region, and studied by [2]. We will evaluate high-resolution imagery for evidence of processes that erode these mesas, and use imagery and available topography to evaluate material that may remain within possible cirque-like alcoves.

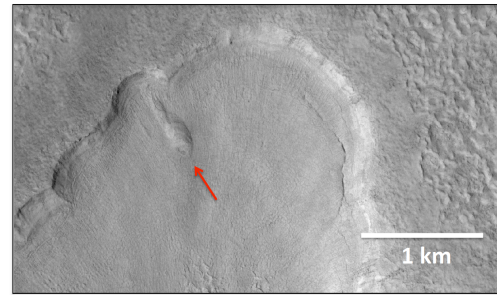


Figure 4: Centered at 26.13°E, 46.67°N. HiRISE image ESP_016247_2270. Red arrow indicates possible detached block that is ~160x80 m. Layers appear along exposed headwall. NASA/JPL/University of Arizona.

Extended alcove mapping and analysis: We plan to extend our alcove mapping across all of Deuteronilus Mensae. ACME can also calculate 3-D morphometrics if the DEM resolution is suitable given the feature size. 3D metrics for cirques such as aspect and altitude are used as indicators for the extent of past glaciation(s), solar radiation, paleo wind direction, and paleoprecipitation patterns [11, reviewed in 9]. We will apply the HRSC-MOLA blended DEM [18] to analyze as many alcoves as possible. Then, we will evaluate the 2D metrics in the context of both the available 3D metrics and their spatial distribution. We will use morphometric analyses to identify sub-populations of alcoves that relate to their characteristics and possible origin.

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