SURVEY OF MARTIAN MID-LATITUDINAL CRATERS CONTAINING POSSIBLE GLACIAL LANDFORMS

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Introduction: Variations in the obliquity of Earth's rotational axis (~22.1° to 24.5°) heavily influence Earth's climate. Martian obliquity, however, varies to a much greater degree (~10° to 82°) suggesting that Mars' climate is subject to more drastic climate variability [1]. Today, most of the water on Mars is located at its poles; however, obliquity-driven climate change likely resulted in the migration of large quantities of water-ice to the mid-latitudes and other regions. Surface features indicative of glacial activity record these past changes in climate [1-2]. Using high-resolution satellite imagery and altimetry data we located and identified glacier-like forms (GLFs) within mid-latitudinal impact craters, and identified relationships between GLFs and other crater features to interpret their origin and evolution over time.

Methods: Our survey consisted of identifying, characterizing, and ranking regions based on their 1) location, 2) main associated surface features, 3) suspected origin of those features, and 4) a possible reconstruction of the past events based on cross-cutting relationships. Regions were marked if they possessed geomorphic features indicative of or associated with past glacial activity, including moraines, massifs, and viscous flow features [3-4]. In the Northern Hemisphere (NH), three regions were investigated further and in the Southern Hemisphere (SH), four.

Chosen regions were then surveyed for craters that contain geomorphic features along their walls and floors indicative of past glacial activity, such as gullies, lobate debris aprons (LDA), lineated valley fill (LVF), concentric crater fill (CCF), ring-mold craters (RMC), or beheaded glaciers (BHG) [4-7]. A total of 48 craters in the NH and 50 craters in the SH were marked and ranked into four tiers based on their likelihood for further investigation. Of these craters, nine in the NH and seven in the SH were investigated further. Although we identified other craters with comparable surface features, we limited our investigation to craters with sufficient high-resolution imagery coverage and cross-cutting geomorphic features.

Identified craters were analyzed in ArcGIS to create detailed annotated topographic maps and geomorphometric analyses of craters (e.g. elevation, aspect, slope, surface roughness). These maps were used to create an in-depth description of each crater and to propose a relative chronology of geologic and climatic events that led to the crater's current morphology. First, images from the Context Camera (CTX) and High Resolution Imaging Science Experiment (HiRISE) instruments were annotated to highlight the specific geomorphic features indicative of past glaciation. Then, we superimposed the CTX imagery on a digital elevation model (DEM) derived from the High Resolution Stereo Camera (HRSC) and Mars Orbiter Laser Altimeter (MOLA) instruments. We then performed additional analyses, including one that simultaneously shows aspect and slope, and another that displays the standard deviation of the elevation values within a neighborhood around it to make a focal statistics map.

Results: In general, several different GLFs, specifically CCF, BHGs, LDAs, RMCs, and gullies in the crater wall, were common in analyzed craters and displayed general patterns in each hemisphere.

In the NH, craters tend to contain more crater fill material, such that the entire crater floor is often completely covered. This is shown by a relative abundance of concentric fill lines along the interior rims. Gullies show no tendency to form along any particular section of the crater wall in the north. Additionally, there are fewer craters per unit area in the NH than the SH.

In the SH, craters contain less fill material, and the crater floor was often only partially covered. The entirety of the southern highlands has a far greater concentration of craters than the north with a fairly uniform areal distribution. Concentric deposition along the interior rims was less prevalent, though multiple LDAs often appeared within each crater. Gullies primarily occur along the northern wall with occasionally small groups along the eastern and western walls. SH gullies were often larger and more complex, and associated with BHGs more often. What follows is an in-depth examination of one surveyed NH crater (Fig 1).

This crater is located near Coloe Fossae, a set of troughs in the NH of Mars, at about 34°N, 51°E (Fig 1B). The crater has a diameter of ~15 km and formed on top of two older craters (Fig 1C). The crater's ejecta blanket is visible to the east and south of the crater wall, but is either obscured by the two older craters' interiors or no longer present due to weathering and erosion. Distinct layering along the southwest and northeast walls (Fig 2F & 2G) coupled with channels along the south and southwest walls (Fig 2A) suggest that, following impact, localized ice accumulation and subsequent sublimation led to accumulation of surface debris cover. The chaotic patterning implies multiple cycles of glaciation.

Based on the cross-cutting relationships between features in this crater, we propose a relative geologic history:

1) Initial impact upon the two older craters. 2) Ice and debris begin accumulating along southern and western crater walls. 3) Channel incision along the southern and southwestern walls. 4) Southwest to northeast ice & debris flow begins. 5) Eastern wall degrades as ice exits crater's interior. 6) Enhanced sublimation causes BHGs to form along the southeastern crater wall [4]. 7) Northern wall degrades. 8) East-facing LDA forms along northern wall. 9) Channels along northwest wall form. 10) Northwest to center of crater flow of ice and debris.

Discussion: Impact craters across Mars' mid-latitudinal bands contain many geomorphic features similar to those associated with glacial processes on Earth [8]. Furthermore, many of these craters contain smaller ring-mold craters, direct evidence for subsurface ice [7]. The distribution of craters along mid-latitudes containing GLFs is consistent with Martian climate models that simulate variations in obliquity, ranging from about 10° to 82°, that lead to climate conditions conducive to ice accumulation in the mid-latitudes [1-2,12]. We conclude that these examined craters support an obliquity-driven climate change cycle and provide further evidence for past glacial activity on Mars.

The inter-hemispheric differences in crater geomorphology on Mars may be related to the Martian Dichotomy, a global topographic boundary separating the southern highlands from the northern lowlands [9-10]. The southern highlands are characterized by relatively old, uniformly-cratered rock at elevations 1 to 3 km higher than the northern lowlands [9]. In the north, the surface is relatively young and smooth [9]. The Martian Dichotomy also differentially influences climatic conditions and atmospheric patterns in each hemisphere, which are exaggerated by Mars' eccentric orbit and variable axial obliquity [11]. These topographic, climatic, and atmospheric differences could affect glacial and periglacial activity in each hemisphere. Further investigation is needed to determine if the differing conditions influence the formation of GLFs, and if they are related to the general trends we observed in our survey. Additionally, approximation of crater age and crater floor ice and debris coverage will assist in quantifying rates of landscape evolution [2,12].

Figures:

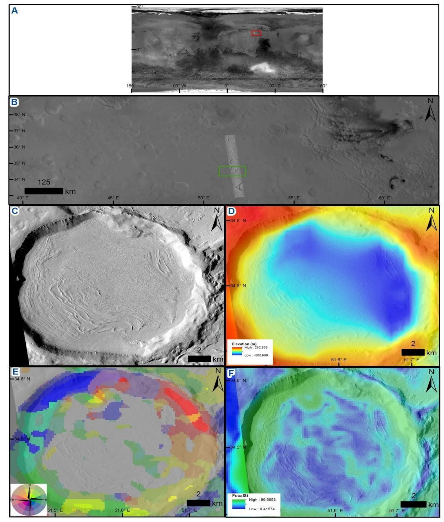

Fig. 1. Image & elevation analysis for Crater 1.1. (A) Global overview map. (B) Location of the crater in Martian northern hemisphere. (C) CTX Image (B20_017512_2151_XN_35N308W). (D) Crater elevation. (E) Aspect-Slope map derived from HRSC; color hue corresponds to aspect, hue intensity corresponds to slope. (F) Focal Statistics (standard deviation) of elevation data for crater.

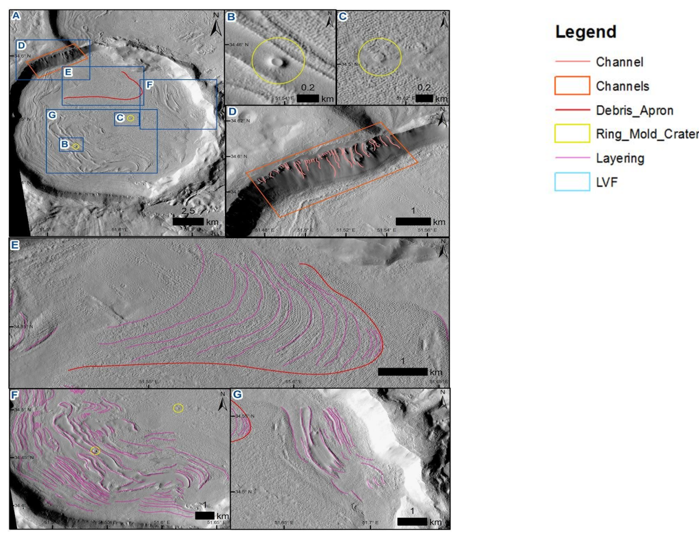

Fig. 2. Annotated geomorphology of Crater 1.1. (A) Survey of large-scale GLFs. (B) Ring-mold crater 1. (C) Ring-mold crater 2. (D) Gullies along northwest crater wall. (E) East-facing debris apron. (F) Well-defined concentric crater fill in southwest quadrant of crater. (G) Concentric crater fill in northeast quadrant.

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