Geomorphology of Glacial and Periglacial Landforms within a Small Crater in Terra Cimmeria, Mars: Stratigraphy and Inferred Chronology of Processes.
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Introduction: We present a geomorphological map of a crater in Terra Cimmeria, Mars. We identified and assessed (both qualitatively and quantitatively) landforms which resemble features formed in terrestrial glacial and periglacial environments, *e.g.*, moraine-like features, gullies and their depositional fans, polygons, and possible solifluction lobes (Fig. 1A&B).

Data: We primarily used data from the High Resolution Imaging Science Experiment (HiRISE), as well as data from the Context Camera (CTX) and the High Resolution Stereo Camera (HRSC) to examine overall context morphologies. We created a HiRISE DEM (ESP_021781_1440 and ESP_021491_1440) using the AMES Stereo Pipeline [*e.g.,* 1] to determine the slopes and relief of features and compared these elevation data with HRSC for consistency.

Observations and Interpretations: The ~5 km crater is located at 35.88°S/147.59°E. Its overall slope is toward the SW due to its superposition on the NE rim of another crater (Ø ~37 km) (Fig. 1G).

Crater floor. The crater floor is hummocky and fractured. The crater has been filled with concentric crater fill (stratigraphically older) and/or a latitude-dependent mantle (LDM) [2] (stratigraphically younger). The LDM was later deposited and subsequently eroded locally (possibly due to aeolian processes, mass wasting, and the formation of gullies).

Former glacial, moraine-like, and distal push-up features. Multiple large lobate features are located on the northern (pole-facing) crater wall and floor (Fig. 1A&B). These large features (up to 500m diameter) have raised moraine-like distal ridges. In the center of the crater, distal to the lobate features, there are two large mounds to that appear be material that has been pushed up to create topographic highs (Fig. 1A&B).

Based on morphology the lobate features are interpreted as former glacial moraines. The associated glaciers would have been fed by ice accumulated and entrained on the northern crater wall. The moraine-like ridges denote the extent of the former glacier. The crater floor is consistent with a distal push-up moraine and uplifted concentric crater fill, formed by compression from the north (*i.e.,* the glacier) and from the east and west (*i.e.,* creep of material from the crater walls).

Layering. Layered material is present both inside and outside of the crater. The layer geometry (attitude) appears to follow topography. Layers are mostly observed on steep slopes where erosion has exposed them (*e.g.,* the outside crater wall, within gullies, and on moraine ridges; Fig. 1B&D). Layers are also present at the boundary of the crater floor and wall, traceable around almost the entire crater with the exception of areas covered by alluvial fans or moraines. We interpret this layered material as LDM [2,3].

Gullies and alluvial fans. Gullies are present on pole-facing slopes of this crater. Many of the gullies are deeply incised into LDM and bedrock of the crater wall. Gullies on the N crater are more abundant and appear more mature than those on the NW wall, having more tributaries. Depositional fans have been formed at the terminus of most gullies. Average fan slopes are between 12° and 17°, typical for small, well preserved fans on Mars. Fans on the NW crater wall have shallower slopes than those on the N crater wall. Additionally, fans on the NW wall are more degraded, many having been modified distally into pitted terrain.

Polygons, possible sorted stripes, and pitted terrain. Polygons are present on the eroded walls of many gullies in this crater (Fig. 1C). These features resemble thermal contraction cracks (*e.g.,* ice- or sand-wedge polygons). There are also many linear features of alternating bright and dark albedo, oriented downslope on the inside and outside of the crater walls (Fig. 1F). Similar features observed on Earth are referred to as “sorted stripes”, and form due to freeze-thaw related sorting [4]. Terrains with a pitted texture are also observed in and around this crater (Fig. 1E). This texture may be caused by a secondary degradation process and is commonly observed in hypothesized periglacial regions of Mars [3].

Crater wall lobes (Solifluction Lobes?). Lobe-like features are observed on the Eastern crater wall, which has a slope of ~26° (Fig. 1E). The lobes have widths between 10m - 130m. The morphology and location of the lobes resembles terrestrial solifluction lobes – which form and progress downslope seasonally in periglacial regions [5]. No noticeable changes were observed in the lobe morphologies over one Martian year (the longest time between available HiRISE images), but this does not preclude the possibility of these features being active over longer time periods.

Discussion and Conclusions: Through geomorphic mapping we have reconstructed the history of geologic processes in this crater. Based on morphological and stratigraphical relationships, we deduce that the crater was filled by a mixture of ice and debris (concentric crater fill). Later, a glacier was active, which pushed up the crater floor material into moraine-like features. A latitude dependent mantle of dust/ice was deposited regionally – now observable in areas where erosion has exposed layers that follow topography. After the glacier sublimated or melted, the northern crater wall (possibly oversteepened by glacial erosion) underwent mass wasting, and gullies and alluvial fans were formed. Finally, the formation of stripes, polygons, and pitted terrain shaped the topmost meters, and solifluction lobes were formed (and perhaps still form) on at least the eastern crater wall.

We infer a complex history of glacial and periglacial processes in this crater which entails that this region once had the appropriate temperatures and pressures to support surface ice and also liquid water (*e.g.*, gullies). The very recent Martian climate in the mid-latitude regions appears to be characterized by changing conditions that gave rise to a variety of landforms in close spatial proximity.

References: [1] Moratto et al. (2010) *LPS XXXXI*, Abstract #2364 [2] Schon et al. (2009) *GRL*, *36*, L15202. [3] Head et al. (2003) *Nature*, *426*, 18/25. [4] Hauber et al. (2011) *Geol. Soc. Lond., Spec. Publ. 356,* 111-131. [5] Johnsson et al. (2012) *Icarus 218*, 489-505.

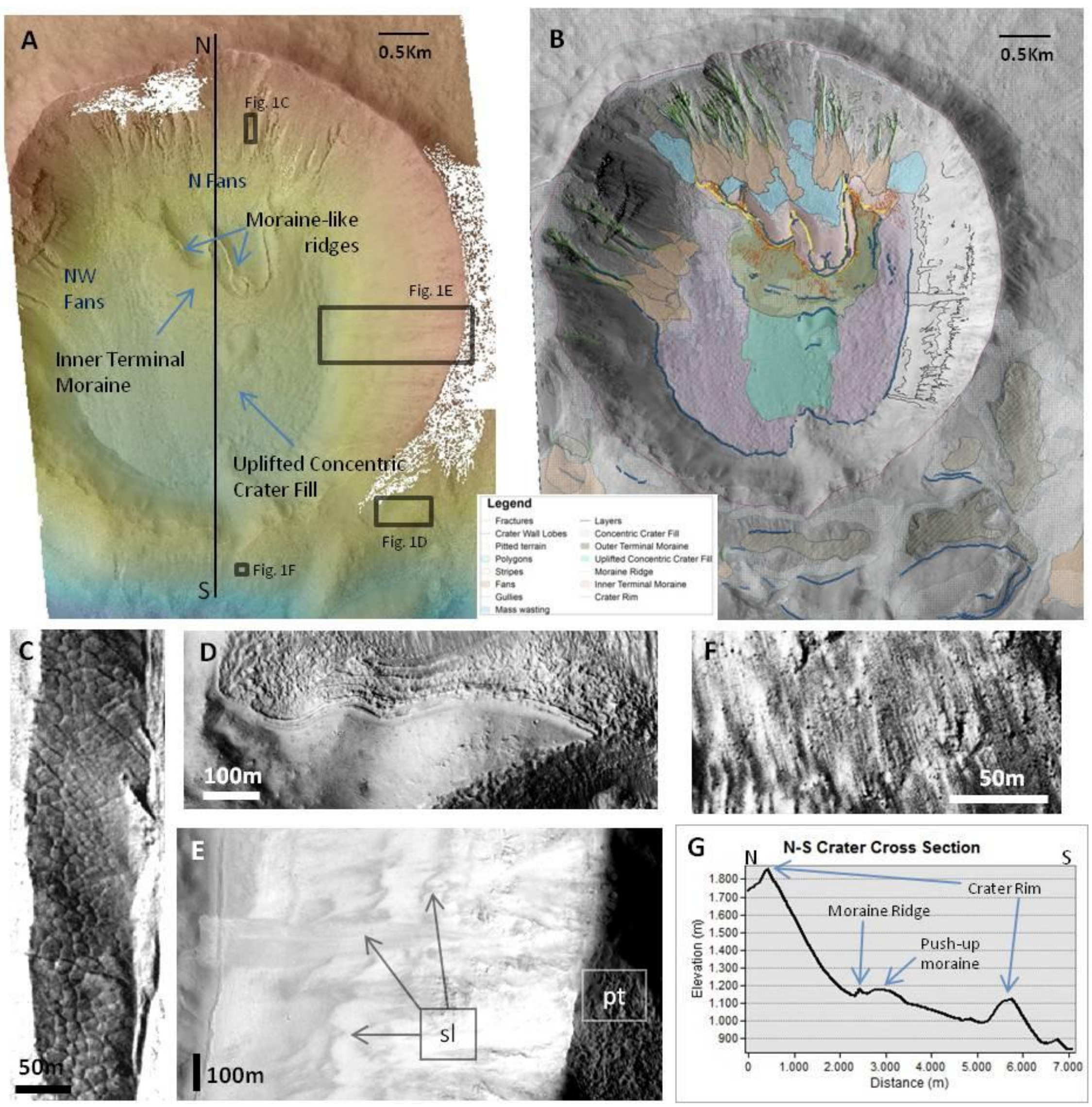

Figure 1: A) HiRISE DEM overlain on HiRISE image, line shows location of topographic profile in G. B) HiRISE image ESP_021781_1440 with geologic mapping superposed. C) Polygons on gully wall within the crater. D) Exposed layers on the outer pole-facing crater wall. E) Examples of hypothesized solifluction lobes (sl), and pitted terrain (pt). F) Possible "sorted stripes" on outer crater wall. G) Topographic profile of the crater using HiRISE DEM data. North is toward top of all images.