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Ice-related Landfoms in Danielson Crater, Arabia Terra region, Mars

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Abstract

This paper describe the ice-related landforms investigated within Danielson crater, a Martian deep crater which is centered at about 7°W and 8°N, in the region of southwestern Arabia Terra about 775 km south of Becquerel crater.

A morphological and morphometric survey of the study area through an integrated analysis of the available Mars images was carried out. The morphological features of the landforms were analyzed through an integrated analysis of Reconnaissance Orbiter (MRO) High Resolution Imaging Science Experiment (HiRISE) and Context Camera (CTX) data. In addition, a DTM of the study area within the Danielson crater was built using two stereo pair HiRISE images. Different landforms interpreted as due to ice-related processes was observed in the study area. The landforms investigated resemble similarly ice-related landforms that can be observed both in the cold region on the Earth, and in other region of Mars.

The analysis carried out seem to indicate the presence of landforms attributed to the presence of ground ice and ice-melting processes which can reflect significantly climatic changes and different climatic conditions than those existing now. Moreover, they appear to display young erosional age, suggesting that are quite young, probably of middle-late Amazonian age.

Keywords: Mars; Danielson crater; Ice-related landforms; Climate change.

1. Introduction

Mars is currently a hyper arid, hypothermal desert and its largest reservoirs of surficial water ice are located at the poles. However, general atmospheric circulation models suggest that ice migrates directly to equatorial regions during periods of higher obliquity [1].

Spacecraft data from the Mars Global Surveyor and Mars Odyssey have supported earlier hypotheses[2] that glaciation might have occurred in non-polar regions on Mars. However, the presence of large quantities of ice that could have served as equatorial sources in the recent geological past has not yet been fully and directly documented. Studies have only recently found evidence for the possible presence of ice in the planet's tropical and equatorial regions [3, 4].

The analysis of most recently acquired high-resolution satellite images has identified features attributed to present or previous near-surface ground ice at low latitudes or/and equatorial areas of the planet[4, 5].

Impact craters have also been shown to be useful targets for the identification of glacial features because their interiors function as cold traps, shielding volatile elements from the ablative effects of insolation or wind and preserving icy bodies that would otherwise be removed in an open plain [3, 6].

Arabia Terra is a province in the southern Martian highlands near the crustal dichotomy bordering the equatorial area (Figure 1A and1B).Danielson Crater is located in southwestern Arabia Terra, about 775 km south of Becquerel Crater (Figure 1B and 1C).The morphology of a portion of the crater's floor appears to display a landscape showing landforms very different from these surrounding (Figure 1C1and1D) [7].

The goal of this study was to investigate the presence of these landforms in Danielson Crater by performing a detailed morphological analysis of available images of Mars. Study aims were to identify and describe these morphologies and to determine, where possible, the morphogenetic processes involved in their formation.

Morphological features of the landforms were investigated through an integrated analysis of Mars Reconnaissance Orbiter, High Resolution Imaging Science Experiment (HiRISE), and Context Camera data. In addition, a digital terrain model of the study area in Danielson Crater was built using two HiRISEstereo image pairs (PSP_002878_1880 and PSP_002733_1880).

2. Study Area

Arabia Terra is a relatively low-elevation, high-albedo, densely cratered province in the southern Martian highlands (Figure 1A and1B). It is the largest portion of ancient cratered crust in the planet's northern hemisphere, with crater densities indicating a predominantly Noachian age [8]. Several lines of evidence suggest that Arabia Terra may have had a lengthy aqueous history. Laterally continuous strata across the region [9] and inferred shoreline terraces along the crustal dichotomy [10] suggest the possibility of deposition associated with a persistent aqueous basin to the north of Arabia Terra and denudation of highland material due to long-term fluvial activity to the south [11]. The localized presence of hydrated mineral deposits within intracrater deposits [12] suggests the existence of a persistent volatile-rich substrate [13].

Danielson Crateris located in western Arabia Terra at 8.0° N, 7.0° W (Figure 1B and 1C1). It has a diameter of about 67 km, an intracrater plane elevation of about –1862 m, and steep symmetrical walls (Figure 1C1).Hundreds of meters of exposed strata showing stacked couplets of strikingly uniform erosional expression extend up the crater walls from its floor. The strata in the center of Danielson Crater are nearly flat lying, but those overlying the lower crater walls dip 15 - 20° toward the basin interior, in conformity with the wall slopes[7].These bedded strata appear to display evidence of post depositional erosion characterized by the removal of sedimentary material. The depositional origin of this material, however, is poorly understood [14], although wave-like layering in Danielson Crater is thought to be the result of periodic changes in climate related to changes in the tilt of the planet.

As in many craters in the Arabia Terra region, the stratified sediments of Danielson Crater have been heavily eroded over time. These terrain features, known as yardangs, indicate that the wind must have blown primarily from the north–northeast. A 30-km-long area of dunes bisecting the yardangsin Danielson Crateralso displays aeolian effects (Figure 1C and 1C1).

The northeastern crater floor adjacent to the wall containsa subcircular dome-shaped mound called the Danielson Crater Mound (referred below as DCM; Figure 1C1and1D). The morphological features and location of the DCMare somewhat anomalous; its morphology differs markedly from the surrounding landscape despite apparently equivalent material content, and its position is eccentric with respect to an expected central peak within a crater complex (Figure 1Cand1C1).Viewed from above this area morphologically resembles a shallow impact crater with an internal valley system (Figure 1D).

3. Morphological and Geological Analysis

3.1. DCM Features

The present morphological analysis revealed that the DCM rises about 200 m from the crater floor and has a rounded, plane shape. Its longest (10km) axis trends northwest–southeast and its width is about 8 km. The crestal region of the DCM is centrally located and consists of a rounded depression surrounded by steeply sloping flanks (Figure2E).The topography of this large depressed area is irregular, consisting mainly of flat-topped hills separated by valleys (Figure 2A). The DCM layers are composed on the top of the sequence by a cap rock unit of hard material, massive or sometimes layered, with an average thickness of about 5 m, that overlies an apparently weaker material, with low albedo and characterized by a massive or, sometimes, finely layered unit, that can be well observed in the lower part next to the DCM bottom. These two kinds of layers, even if resemble the layered outside DCM in terms of photographic properties, at the HiRISE observation are very different, displaying anomalies in layers' continuity, different thicknesses, lack of materials' alternation and different spatial geometry. At large scale, an unconformity along the northeastern edge of DCM that apparently gradually changes in conformity in the southwest area can be observed. In fact, the "external" layered deposits observed in the northeast area of the DCM, seem to be interrupted by the edge of the DCM apparently forming an "on-lap" relation with the DCM rim, while in the southwest area of the DCM a continuity relation between the DCM deposits and the Danielson layered deposits, apparently without interruptions or unconformities, can be observed.

3.2. Valleys

A valley system occupies the central depression of the DCM (Figure2A). Most main valleys are oriented southwest, in accordance with the regional slope direction. Topographic analyses of valleys in the DCM showed broad U-shaped cross-sectional profiles with ascending and descending series of scalloped concave forms, smooth ridges separating concave curves, steep side walls that curve inward at the base, and almost flat valley floors (Figures2A,2C and2D). Valley length sreach more than 1 km, widths range from 60 m to more than 350 m, and depths are about 100 m. smallertributary valleys are present in the southern part of the area (Figure2C). Some valley slopes contain steps with smooth, nearly horizontal surfaces and well-developed fan deposit systems consisting of chaotic material that appear to be very steep, display terminal lobes and seem to lackwell development gullies (Figures2B and2D). The fan deposits extend from the upper part along all valley sides, apparentely lacking of any wind morphologies.

The valley floors appear to be very flat, but most are obscured by dark sediments with dune morphology or high-albedo debris (Figures2A-2E).

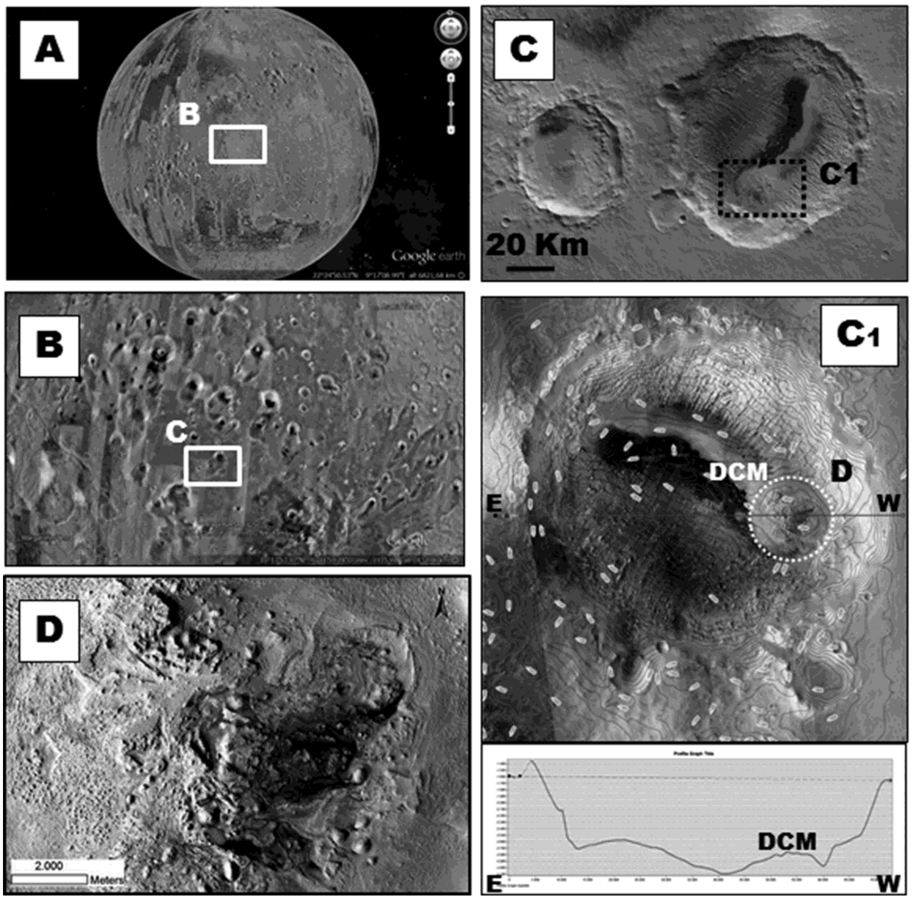

Figure 1: (A) Location of Danielson Crater on Mars (white box). Image NASA/USGS/ESA/DLR/FU Berlin (G.Neukum) taken from Google Mars (www.google.com/mars). (B) Arabia Terra regionn with the location of the study area (white box). (C) Kalocsa (left) and Danielson (right) craters with the location of the study area (black box). Image (modified) High-Resolution Stereo Camera (HRSC) ESA/DLR/FU Berlin (G. Neukum) taken from the ESA website (http://www.esa.int) (north toward right). (C1) Location of the DCM (white dashed circle) in Danielson crater(upper); topographic profile (E-W) of the Danielson crater and the DCM (lower). (D) DCM viewed from above showing the differences landcape from the surrounding. Image (modified) CTX P20_008930_1879_XI_07N006W (north toward left).

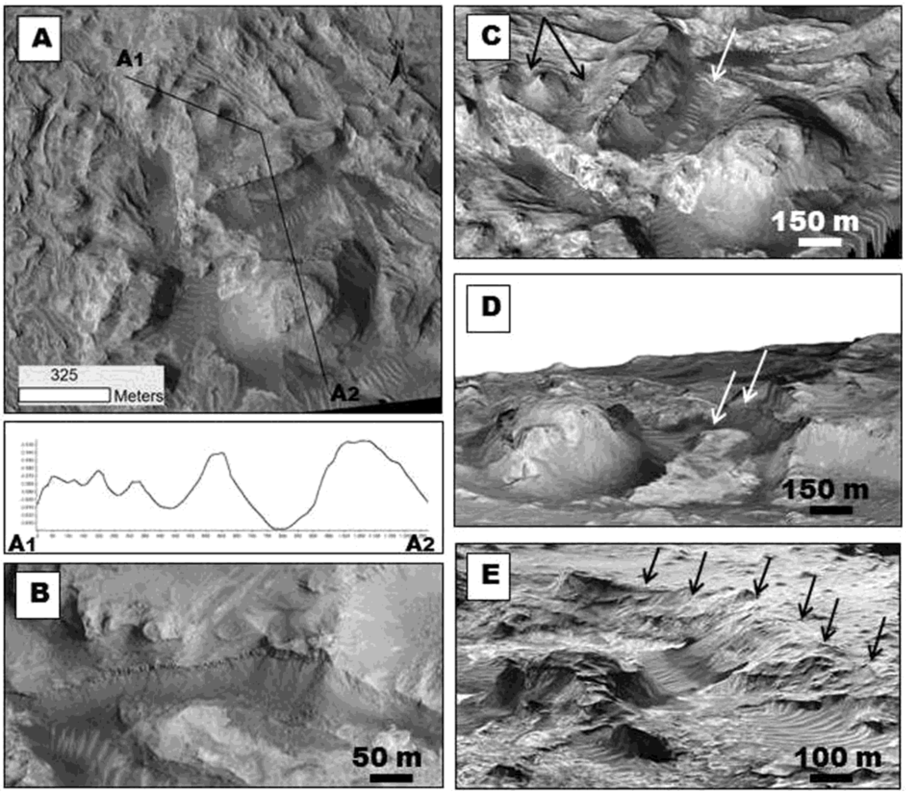

Figure 2: (A) (up) valleys occupying the central depression of the DCM, and location of the topographic cross section A1-A2 (black line); (down) Topographic profile showing U-shaped cross-sectional valleys with steep side walls curving inwards at the base and flat valleys floors, separated by smooth ridge (Image HiRISE PSP_002733_1880) (north toward up). (B) Fan deposits system developed along valley slope in the central area of the DCM. The deposits appear to be steep and at their foots boulders can be observed (Image HiRISE PSP_002733_1880) (north toward up). (C) U-shaped valley (center, white arrow) with secondary smaller tributary valleys (left, black arrows) displaying flat floors covered by dark sediments displaying dune morphology (center). In the main valley left slope a step with smoothed nearly horizontal surface can be observed. (Image DTM stereo pair HiRISE PSP_002878_1880 and PSP_002733_1880) (north toward up). (D) Valley displaying slopes with fan deposits system with boulders at the foots. Steps with smoothed nearly horizontal surfaces can be observed in the right slope (white arrows). The flat floor is covered by debris showing high albedo. (Image DTM stereo pair HiRISE PSP_002878_1880 and PSP_002733_1880) (north toward right) . (E) North-eastern borderline of the DCM central depression represented by a continuos ridge with steeply sloping flank (black arrows) (Image DTM stereo pair HiRISE PSP_002878_1880 and PSP_002733_1880) (north toward right).

3.2. Cirque-like Morphologies

The upper sides of some hills contain a few cirque-like landforms (Figure 3). These depressions are arcuate in plan with gently sloping or nearly horizontal floors and concave profiles; they are open downslope and bounded upslope by steep or vertical arcuate slopes known on Earth as headwalls (Figures 3A - 3C) [15]. The depressions have lengths (distance from the headwall to threshold) from 50 m to 160 m, widths (distance between sidewall)are generally between 40 m to 140 m, while depths (measured from the headwall crest to the floor) range from 30 m to 80 m.The depressions are located on the sides of main valleys. These morphological features resemble glacial cirques found in cold regions on Earth, such as in Norway (Figure 3E), Alaska (Figure 3F), mountainous regions of the United States (Figure 3D) and Europe.

3.3. Thermokarst

Many closed, shallow, rimless depressions of various sizes can be observed (Figure 4).These morphologic features, which lack evidence of aeolian and erosional actions associated with the evolution of impact craters, have been previously interpreted as thermokarst depressions[16]. In fact, these depressions were not created by other processes such as wind deflation, because they lack a preferred orientation, or by impact craters, because they lack rims and ejecta. In particular, depressions shaped by wind action on the Earth are very elongate along wind flow direction, display mostly arcuate sides and thick accumulation of sediments at the foot of the wall facing the wind. The observed depressions in the DCM do not display any of these features.

They are present on lower hillslopes and in the region adjacent to the study area, toward the center of the crater, andtheir location and shape seem to be unrelated to the surface slope or bedding plane.

The depressions display a variety of plan shapes, ranging from rounded (Figures 4A, 4B and 4C) to elliptical (Figure 4D). The depressions generally range in length (the long axes of the depressions are defined by the outermost closed contour line) from 15m to 40 m for rounded shapes and from 30 m to 150 m for elliptical shapes.Widths are generally between 15 m to 50 m, depending on shape.These features have very steep to vertical walls and flat floors, most of which are covered by dark dust or sediment.

The morphology of these landforms resembles that of terrestrial thermokarst depressions located in cold regions, where the thawing of ice-rich permafrost often involves the formation of flat-floored rimless depressions with stepped sides, which are usually filled with water. In particular, they display morphometric (sizes) and morphologic (shapes, bottoms, walls) similarities with the depressions, also called alases, that are common on periglacialalluvial or glaciofluvial outwash plains [17, 18].

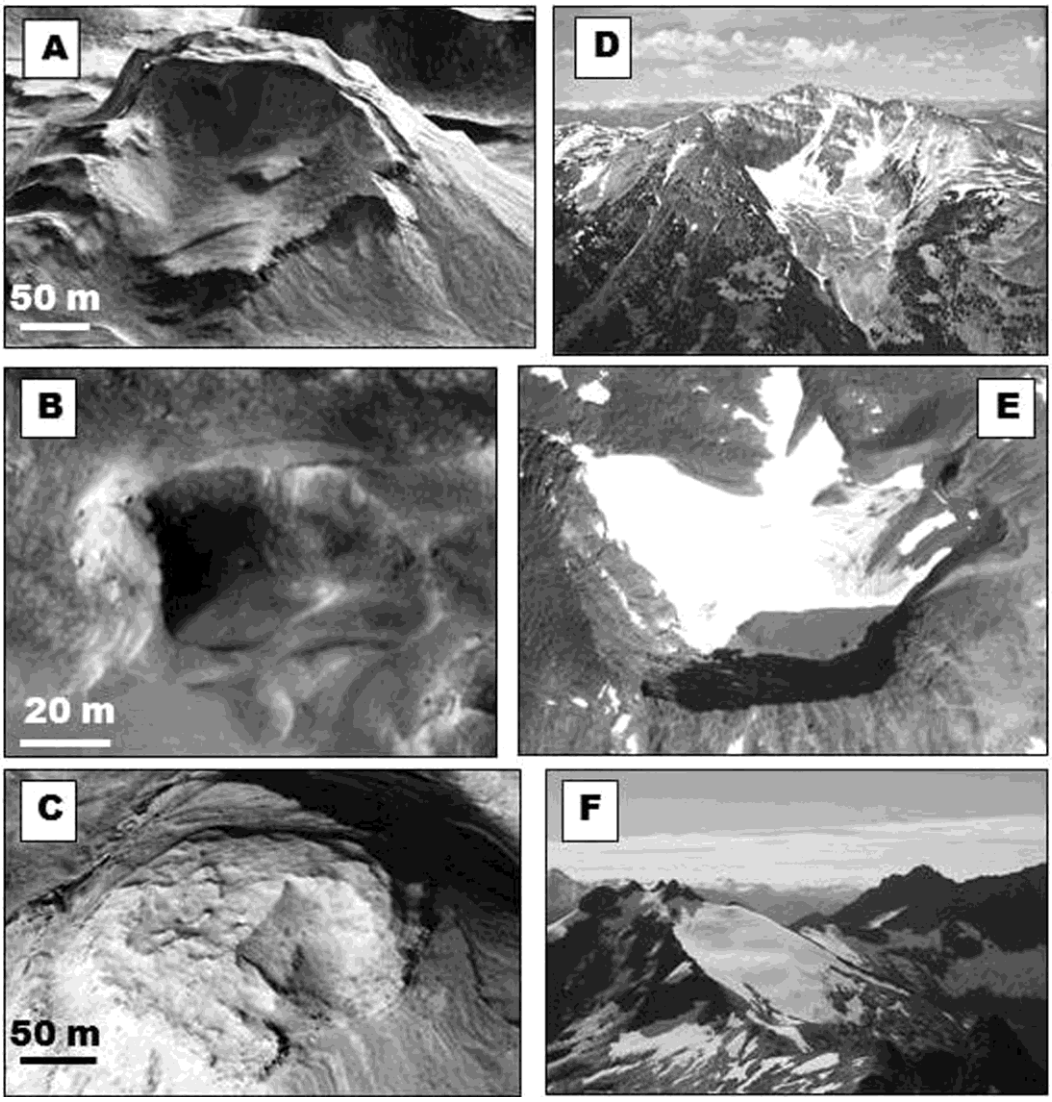

Figure 3: (A) Cirque-like morphology characterizated by steep headwall and slow slope floor in the northern area of the DCM (Image DTM stereo pair HiRISE PSP_002878_1880 and PSP_002733_1880). (B) Cirque-like morphology characterized by vertical headwall and sub-horizontal floor in the central area of the DCM (Image HiRISE PSP_002733_1880). (C) Cirque-like morphology characterized by steep headwall and low slope floor in the southern area of the DCM (Image DTM stereo pair HiRISE PSP_002878_1880 and PSP_002733_1880). (D) Glacial cirque on east face of Electric Peak, northern Gallatin Range, Yellowstone Park, U.S.A. (Image taken and modified by Geological Survey Bulletin 1347 on line at the website). http://www.cr.nps.gov/history/online_books/geology/publications/bul/1347/sec4.htm). (E) Glacial cirque in northern Norvay (Image taken by the wesite http://www.studyblue.com). (F) Glacier cirque in the Icy peak, Alaska, U.S.A. (Image taken from the website http//johnrroegop.blogspot.it/2012_10_01_archiviehtml).

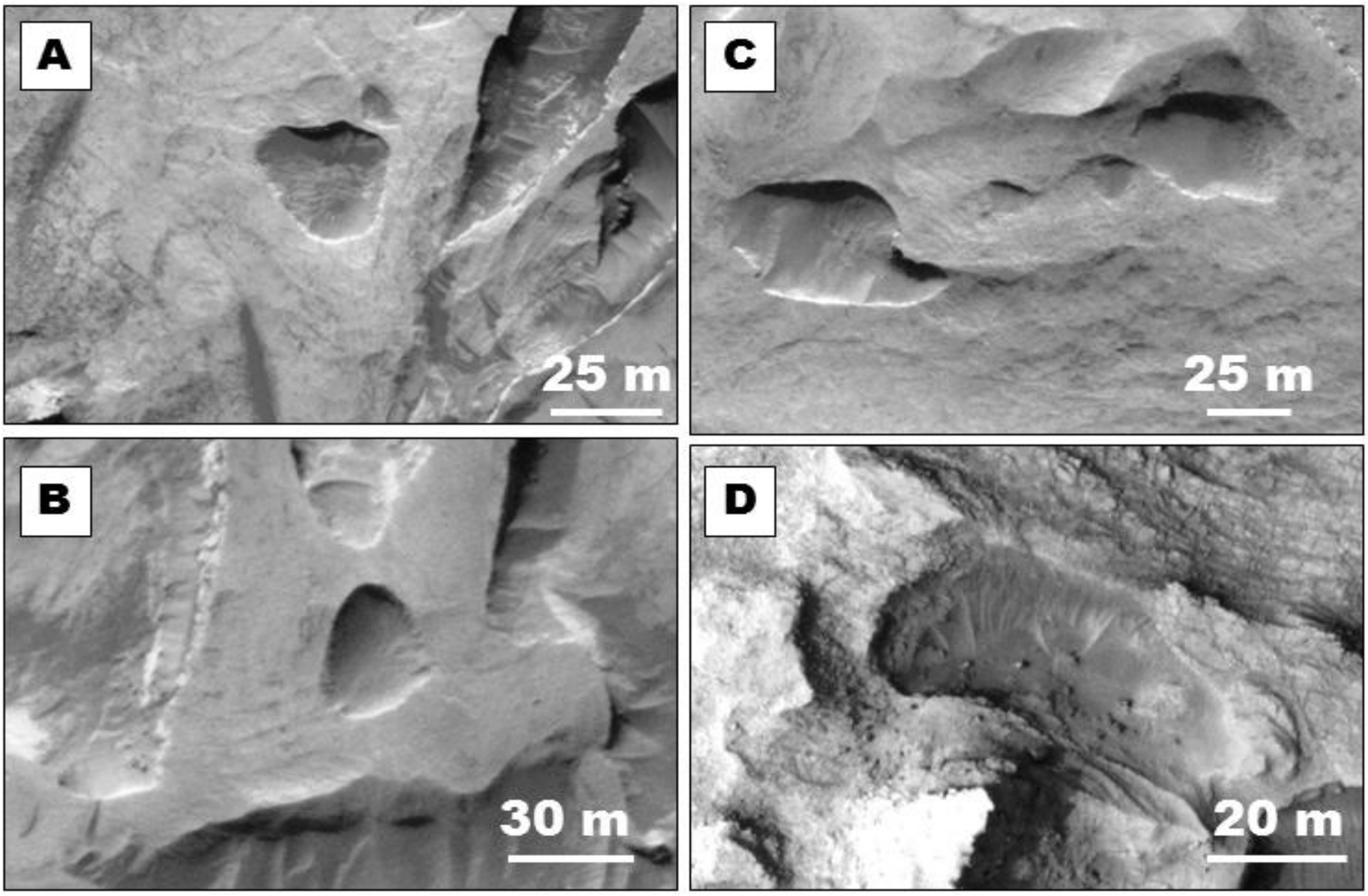

Figure 4: (A) Rounded depression displaying steep sides and flat floor covered by dark sediments in the area next to the DCM crater toward the regional slope (Image HiRISE PSP_002733_1880) (north toward up). (B) Rounded depression displaying steep sides and flat floor covered by dark sediments in the area next to the DCM crater toward the regional slope (Image HiRISE PSP_002733_1880) (north toward up). (C) Rounded depressions displaying vertical sides and flat floor covered by dark sediments in the area next to the DCM crater toward the regional slope (Image HiRISE PSP_002733_1880) (north toward up). (D) Elliptical depression displaying steep sides and flat floor covered by dark sediments in the central area within the DCM (Image HiRISE PSP_002733_1880) (north toward up).

4. Discussion

The landform features observed in the DCM appear to reflect ice-related processes, indicating that ice deposition and ice melting probably played a prominent role in their formation.

The topographic cross sections of the valley system in the central depression of the DCM resemble profiles considered to be almost exclusively diagnostic of glaciated terrainson Earth. The valley morphology is consistent with typical terrestrial U-shaped glacial valleys, as opposed to mature river valleys, which characteristically have V-shaped cross-sectional profiles. The shapes of the valley cannot be due to wind action only because both the presence along the sides of the fan deposits that do not show any winds modification and/or morphologies, and the lack of any wind morphologies even in the upper part. Instead, on the Earth the valleys shaped by wind action show aeolian morphologies along the sides and usually fan deposits can be found only at the foot of the sides.

The cirque-like morphologies observed display strong morphological similarity with those observed on the Earth and were not created by wind deflation lacking a dominant orientation. On the Earth cirques are among the most characteristic landforms of glacial erosion in muontainous terrain[19, 20].

The thermokarst depressions appear to have formed as a result of ice melting, in a manner analogous to the development of similar landforms on Earth. Ice melting has been assumed to be necessary for subsidence and/or collapse processes, similar to hypothesized processes explaining thermokarst landforms and topography in other regions on Mars [21, 22]. Moreover, the freshness of the termokarst landforms and the absence of landforms with wind-related modification suggest a young erosional age.

The development of landforms related to presence of ice and ice-melting on Mars could have been triggered by the deposition of ice and/or permafrost followed by ice-melting and/or sublimation processes. Recent studies have posited that periods of ice-rich deposition occurred due to changes in the obliquity of Mars [23]. The presence of ice in the planet’s tropical and equatorial regions is also plausible [3 – 5, 24, 25], and the occurrence of mid-latitude glaciationin the Amazonian period has been proposed [26, 27].

Changes in Martian obliquity might be key to the construction of a plausible scenario to explain the landforms observed in the DCM. Thereafter, exposure of the central ice core, previously depositated, and/or another change in the planet's obliquity caused the ice to melt[16], enlarging the fractures on the top of the feature to form valleys, collapsing the DCM summit, forming the observed moroholohies in the study area.

The landforms observed in the DCM appear to be well preserved and not deeply reworked or modified, even by wind erosion. The relatively recent origin of the DCM surface is also supported by the absence of impact craters. We believe that no substantial erosional effect leading to an underestimation of the DCM's true age occurred. Even on the highest-resolution images available, impact craters are scarce on the well-exposed surfaces, further suggesting a young erosional age for this feature.

The interpretation of morphological features was performed by observing the landscape within the geological context, in an attempt to avoid problems due to possible morphological convergence (or equifinality) reported in a previous study of periglacial landscapes on Mars [28].We believe that some other combination of processes is highly unlikely to have resulted in an assemblage of landforms so closely resembling terrestrial analogs shaped by ice-related processes in cold regions on Earth.

5. Summary

The analysis performed in this study suggests the following conclusions:

(i) The investigated landforms in Danielson Crater appear to be ice related.

(ii) The degree of cratering and erosional features of the landforms suggests that they are relatively young, probably of middle–late Amazonian age.

(iii) Landforms attributed to ice-deposition followed by ice-melting processes, such as those observed in the study area, reflect significantly changes in climatic conditions. They suggest the occurrence of ice deposition followed by a geologically wet episode during which ice melted, thus water was available, in the Amazonian age.

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7. References

1. Levrard B, Forget F, Montmessin F, Laskar J (2004) Recent ice-rich deposits formed at high latitudes on Mars by sublimation of unstable equatorial ice during low obliquity, Nature 431, 1072-1075.
2. Kargel JS, Strom RG (1992) Ancient glaciation on Mars. Geology 20: 3-7.
3. Shean DE (2010) Candidate ice-rich material within equatorial craters on Mars, Geophysical Research Letters 37, L24202. Doi: 10.1029/2010GL045181.
4. Mège D, Bourgeois O (2011) Equatorial glaciations on Mars revealed by gravitational collapse of VallesMarineris wall slope, Earth and Planetary Science Letters 310, 182-191.
5. Schon CS, Head JW (2012) Decameter-scale pedestral craters in the tropic of Mars: Evidence for the recent presence of very young regional ice deposits in Tharsis, Earth and Planetary Science Letters 317-318, 68-75.
6. Levy JS, Head JW, Marchante DR (2009) Concentric crater fill in Utopia Planitia: History and intercation between glacial "brain terrain and periglacial mantle processes, Icarus 202, 462-476.
7. Murana A (2012)Stratigrafia e morfologiadeidepositidelcratere Danielson, Marte. MSc Dissertation,Parma University.
8. Hartmann WK (2005) Martian cratering 8: Isochron refinement and the chronology of Mars, Icarus 174, 294-320.
9. Edgett KS (2005)The sedimentary rocks of Sinus Meridiani: Five key observations from data acquired by the Mars Global Surveyor and Mars Odyssey Orbiters, Mars 1, 5–58.
10. Perron JT, Mitrovica JX, Manga M, Matsuyama I, Richards MA (2007) Evidence for an ancient martian ocean in the topography of deformed shorelines, Nature 447, 840-843.
11. Hynek BM, Phillips RJ (2008)The stratigraphy of MeridianiPlanum, Mars, and implications for the layered deposits' origin, Earth Planetary Science Letters 274, 214–220.
12. Fialips CI, Carey,JW, Vaniman DT, Bish DL, Feldman WC, Mellon MT (2005) Hydration state of zeolites, clays, and hydrated salts under present-day martian surface conditions: Can hydrous minerals account for Mars Odyssey observations of near-equatorial water-equivalent hydrogen?, Icarus 178, 74-83.
13. Anderson RC, Dohm JM, Haldemann AFC, Pounders E, Golombek M, Castano A (2008) Centers of tectonic activity in the eastern hemisphere of Mars, Icarus 195, 537-546.
14. Cadieux SB (2011) Constraining Martian sedimentation via analysis of strata packaging, intracrater layered deposits, Arabia Terra, Mars. MScDissertation, University of Tennessee.
15. Bennett MR, Glasser NF (2009) Glacial Geology: Ice Sheets and Landforms (John Wiley & Sons Ltd, Chichester, U.K. 2009).

16. Baioni D, Murana A, Tramontana M (2014) Amazonian Thermokarst in Danielson Crater, Arabia Terra region, Mars, Planetary and Space Science 104, 310-317.
17. Czudek T, Demek J (1970)Thermokarst in Siberia and its influence on the development of lowland relief, Quaternary Research 1, 103-120.
18. Costard FM, Kargel JS (1995) Outwash plains and thermokarst on Mars, Icarus 114, 93-112.
19. Evans IS, Cox NJ (1974)Geomorphometry and the operational definition of cirques, Area 6, 150-153.
20. Barr ID, Spagnolo M (2015)Glacial cirques as palaeoenvironmental indicators: Their potential and limitations, Earth-Science Reviews 151, 48-78.
21. Balme M, Gallagher C (2009)An equatorial periglacial landscape on Mars, Earth and Planetary Science Letters 285 (1-2), 1–15.
22. Warner N, Gupta S, Kim JR, Lin SY, Muller JP (2010) Hesperian equatorial thermokarst lakes in Ares Vallis as evidence for transient warm conditions on Mars,Geology 38, 71-74.
23. Laskar J, Correia ACM, Gastineau M, Joutel F, Levrard B, Robutel P (2004) Long term evolution and chaotic diffusion of the insolation quantities of Mars, Icarus 170, 343–364.
24. Hynek BM (2009) Ancient equatorial ice on Mars?, Nature Geoscience 2, 169-170.
25. Niles PB, Michalski J (2009)MeridianiPlanum sediments on Mars formed through weathering in massive ice deposits, Nature Geoscience 2(3), 215-220.
26. Madeleine JB, Forget F, Head JW, Levrard B, Montmessin F, Millaur E (2009) Amazonian northern mid-latitude glaciation on Mars: A proposed climate scenario, Icarus 203, 390-405.
27. Soare RJ, Osinski GR, Roehm CL (2008)Thermokarst lakes and ponds on Mars in the very recent (late Amazonian) past, Earth and Planetary Science Letters 272 (1-2), 382-393.
28. Hauber E., Reiss D., Ulrich M., Preusker F., Trauthan F., et al., (2011)Periglacial landscapes on Svalbard: Terrestrial analogs for cold-climate landforms on Mars, Geological Society of America Special Paper 483, 177-201.