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Multiple Glaciations on Mars?

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Abstract

The existence of ice on Mars has been known since the first photographs of the red planet were taken. Visible ice exists at both the north and south poles of Mars, but, beneath debris at mid-latitude regions, ice also exists. Specifically, ice has been proven to exist within a lobate debris apron (LDA) surrounding Euripus Mons, a mountain east of the Hellas impact crater (45°S 105°E). The motivation behind this project was to determine if this ice, held within the Euripus Mons LDA, ever advanced beyond the current observed boundaries. Additionally, if the ice did advance was it a singular event, or, did multiple advances occur.

Milankovitch cycles are generally accepted as a driving factor of terrestrial glaciation, so it is plausible that similar cycles control glaciations on Mars. However, one factor within these cycles, the obliquity shifts, is a major difference between Earth and Mars. The large obliquity shifts of Mars causes a redistribution of ice from the north and south poles to mid-latitude regions, and therefore, it is plausible to believe that during large obliquity shifts of Mars, mid-latitude ice would increase in volume.

It was discovered that the ice did advance beyond the current observed boundaries of the Euripus Mons LDA and evidence of multiple advances appears plausible based upon textural degradation features specific to LDA's. These multiple advances confirm local climatic shifts, most likely occurring during large obliquity shifts of the planet. Confirming an advance of ice at the Euripus Mons site allows for an in depth look into the previous climatic conditions of Mars as well as lays a foundation upon which a comparison of Milankovitch cycles for Mars and Earth can begin to take place.

1. Introduction and motivation

Visible ice sheets exist at both the northern and southern poles of Mars. Though not visible, ice also exists at mid-latitude regions of Mars, buried beneath debris (Mahaney et al., 2006; Head et al., 2005). Collecting at mid-latitude regions due to large obliquity shifts, mid-latitude ice is currently degrading and redistributing, as Mars is presently in an interglacial period. In contrast, a glacial period on Mars can be described as a redistribution and accumulation of ice at mid-latitude regions (Head et al., 2003).

Earth also undergoes obliquity shifts within the Milankovitch cycle, which also takes precession and eccentricity shifts into account. Milankovitch cycles are a driving force behind terrestrial glaciation and it is plausible that Mars also is affected by similar cycles. However, the most important factor in Martian glaciation appears to be the much larger obliquity shifts experienced by the planet in comparison to Earth (Fig. 1). Given the current state of retreat of Martian mid-latitude ice and recognizing the past obliquity shifts of Mars, it is plausible that at some point in Martian history, mid-latitude ice was increasing in volume.

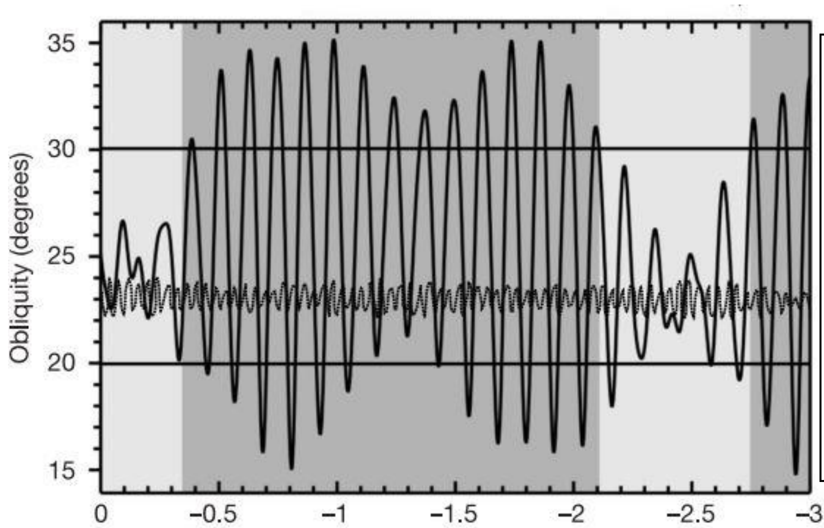


Fig. 1 Obliquity shifts of Mars in comparison to Earth (Earth shifts are the smaller waves). Time, in myrs, is on the x-axis represented as time from present. The light grey sections are interglacial periods and dark grey sections glacial periods. Accumulation periods exist above the 30 degree horizontal line and below the 20 degree horizontal and in-between the two horizontal lines are periods of desiccation and sublimation. Image modified from Head et. al. (2003)

Euripus Mons, a mountain peak east of the Hellas impact crater within the mid-latitude zone, is surrounded by a lobate debris apron (LDA). Lobate debris aprons often form around mountains and can be seen using remote sensing techniques. Proven to contain ice (Holt, 2008) beneath a protective layer of debris, the lobate debris apron at Euripus Mons presents an opportunity to research a possible past advancement of ice.

The main objective of this project is to discover if a previous advancement of ice could be found at the Euripus Mons site. Additionally, if a past advancement can be confirmed, is it representative of one or multiple advancements. Determining a previous advancement of Martian mid-latitude ice would provide details into the previous climatic conditions of Mars, and, lays a foundation upon which a comparison of how Milankovitch cycles effect Earth versus different planets within the solar system.

2. Previous Research

Previous research for this project can be divided into two broad categories; terrestrial analogs and glaciation on Mars.

2.1 Glaciation on Earth/ Terrestrial Analogs

Glaciers on Earth have been studied since the 1850's, and methods of identification, formation and flow have been established. Multiple glaciations have occurred on Earth and determining the past extent of these glaciations has also been a focus of study. There are many ways to determine a glacial extent on Earth, but specific to Mars are glacial landforms. Specific landforms to acknowledge are drumlins and moraines. Drumlins are formed as glacial ice retreats and carve unique streamlined hills which appear egg shaped. The sharper end of the egg shape points down glacier, showing a direction of flow. Moraines are linear ridges composed of till which mark advancement of glacial ice. As ice extends, it collects regolith forming a hill at the ending point of glacial expansion, a terminal moraine (Compton, 2005).

In glacially eroded areas, it is common to observe flutes, grooves, and striations on exposed bed rock. Additionally, in recent glaciated areas, aeolian deposits and landforms are common because of the lack of vegetation and exposed regolith (Compton, 2005). Notable in this project are also rock glaciers. Rock glaciers are lobate or tongue shaped debris-ice mixtures with very steep sides and a similarly steep snout that slowly creeps downslope (Berger et al., 2003). Rock glaciers have a unique lava-flow-like surface and longitudinal and/or transverse ridges that appear on top of these debris covered ice bodies. Though covered by a layer of debris, rock glaciers still respond to climatic change (Berger et al., 2003).

2.2 Glaciation on Mars

Mid-latitude glaciation in Mars has been the subject of study since the late 1990's. Specifically dealing with rock glaciers and flow patterns, mid-latitude glaciation is dependent on debris coverage, as exposed ice will sublimate (Head et al., 2005; Head et al., 2006; Mahaney et al., 2007). These studies are based on remote sensing methods and comparison with terrestrial analogs. Additional observations include that of moraine like ridges, which provide evidence for a past advancement of ice (Arfstrom and Hartmann, 2005).

Obliquity shifts of Mars are a major reason for glacial growth, especially at mid-latitude regions. Typical cycles for Mars over the past three myrs show an average obliquity change of 20° or more. This, in comparison to Earth's 2° max obliquity change, would drastically change the local climate (Head et al., 2003; Laskar et al., 2004). These obliquity shifts of Mars are confirmed by layered ice mantling deposits at mid-latitude regions (Head et al., 2003).

The previous research preformed on the study area's LDA proves the existence of ice beneath a 10 meter layer of regolith (Holt et al., 2008). Observed on the surface of the LDA are flow patterns, which suggest the presence of ice, but does not prove it (Holt et al., 2008). There are over 90 of these LDAs and further investigation is required to determine if these all hold ice or are just rubble accumulated through mass wasting processes. Using Shallow Radar (SHARAD) aboard the Mars Reconnaissance Orbiter (MRO), radar was used to investigate the inner contents of the LDA, and around 28,000 km^3 of water ice was discovered in this one LDA alone (Holt et al., 2008).

Research dealing with LDA's morphologies and textural characteristics has also taken place. Through comparison studies of LDA's, both within the Hellas region and Tempe Terra regions of Mars, similar characteristics of LDA degradation have been examined and analyzed (Pierce and Crown, 2003; Chuang and Crown 2005). Splitting the LDA into two parts, the upper LDA and lower LDA, different textures are apparent and unique to LDA degradation.

2.3 Advancement of Glaciers on Mars

No direct work has been done on a possible past advancement of ice at the Euripus Mons site. Martian glaciation studies focus on observations made that prove the existence of ice through comparison with terrestrial analogs. Backing up these studies is Martian climatic research that points to ice age conditions on Mars within the past three myrs. (Laskar et al., 2004; Head et al., 2003). Pierce and Crown (2003) compared the degradation and unique textural features associated with LDA's, yet do not directly focus on previous advancements.

3. Methods

Using Pierce and Crown's (2003) observations of LDA degradation a variety of unique morphologic and textural patterns can be seen using both MOC and HiRISE images. By identifying and comparing textural features at the Euripus Mons LDA with that of Pierce and Crowns (2003) observations, a maximum extent of the LDA can be established.

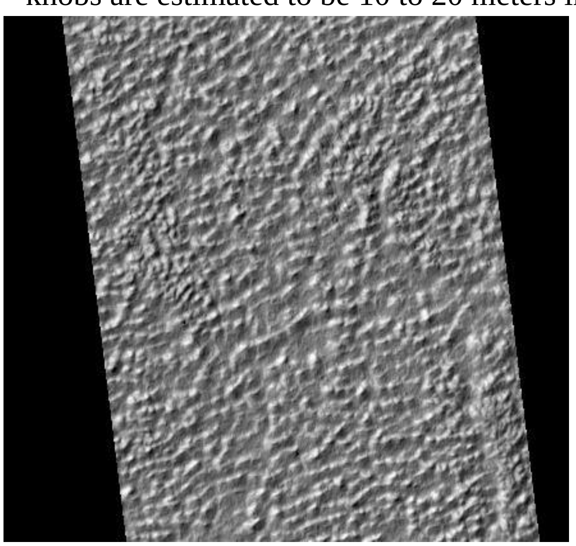
3.1 Textures

Outlined by Pierce and Crown (2003), the following surface features can be used as identifying features specific to LDA's and LDA degradation.

The features are broken down into two categories; the upper LDA and lower LDA. Features are defined as patterns in small-scale topography, surface roughness and superposition relationships (Pierce and Crown, 2003).

The Upper LDA

Knobby textures (Fig. 2): Defined by the presence of evenly distributed knobs whose shapes are roughly equidimensional, though more-elongate forms sometime occur (Pierce and Crown, 2003). Spacing between knobs is typically a few tens of meters and the typical heights of these knobs are estimated to be 10 to 20 meters in height, based upon shadow measurements. The



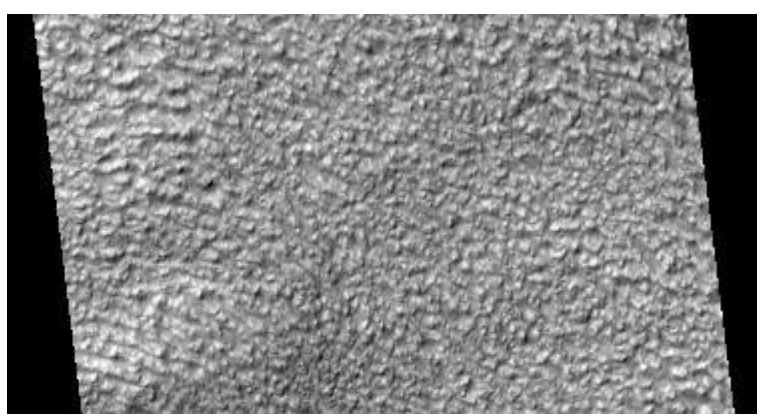


Fig. 2. Examples of Knobby texture (Part of MOC images M02-03331and M04-03657).

knobby texture may be a result of degradation of the apron surface or may be a result of initial emplacement (Pierce and Crown, 2003).

Ridge-and-valley textures (Fig. 3): Defined by evenly spaced, continuous ridges and valleys whose long axes are typically oriented parallel to the apron/plain boundary (Pierce and Crown, 2003). The ridge and valley texture marks a gradational zone moving from the upper LDA knobby texture into the lower LDA sharp ridge texture.

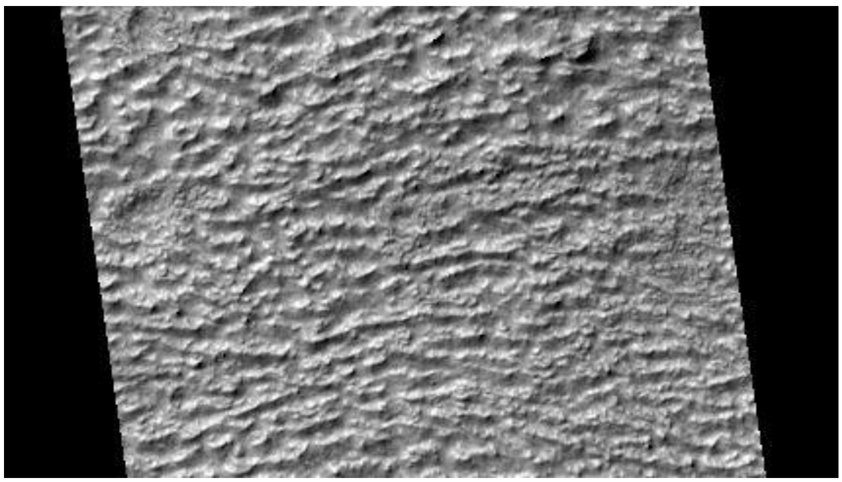


Fig. 3. Ridge and valley texture (Part of MOC image M04-03657).

Lower LDA

Sharp-ridge textures (Fig. 4): Defined by a pattern of sharp, narrow ridges that separate smooth, low-lying, featureless areas (Pierce and Crown, 2003). The pattern of this texture can appear polygonal, linear, curvilinear, irregular or combinations of all patterns. Several ideas exist as to how the sharp-ridge feature is formed and what it signifies. This texture may be the exposed interior portions of the ridge-and-valley texture, which would suggest that this texture forms similar to the ridge-and-valley texture, but appears different due to the relative thickness of the LDA ice. The shape and angularity of the sharp-ridge texture result from differing slope angles and these features forming transvers to the slope may result simply from the downslope movement of the apron mass (Pierce and Crown, 2003).

Smooth textures (Fig. 5): Defined as smooth, generally flat and featureless texture, typically occurring in low-lying areas. The smooth texture can be easily seen in the transition from the sharp-ridge texture which occurs in similar, low-lying areas (Pierce and Crown, 2003). Important to note, the smooth texture is often dotted by hummocky, knobby features which resemble the knobby texture described in the upper LDA. The smooth texture is the result from an overlying mass, most likely being ice, that has been removed, ideally through sublimation (Pierce and Crown, 2003).

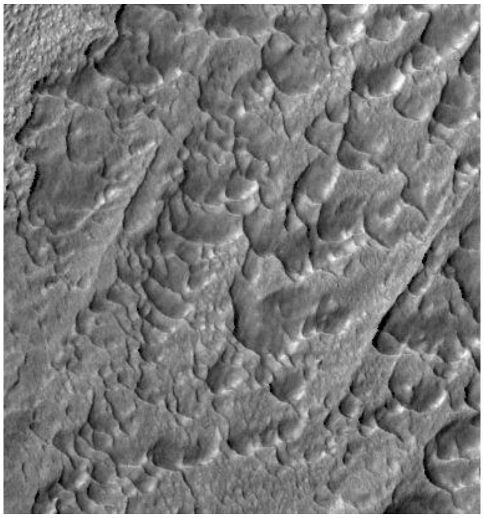


Fig. 4. Sharp ridge texture (Part of MOC image M11-03531)

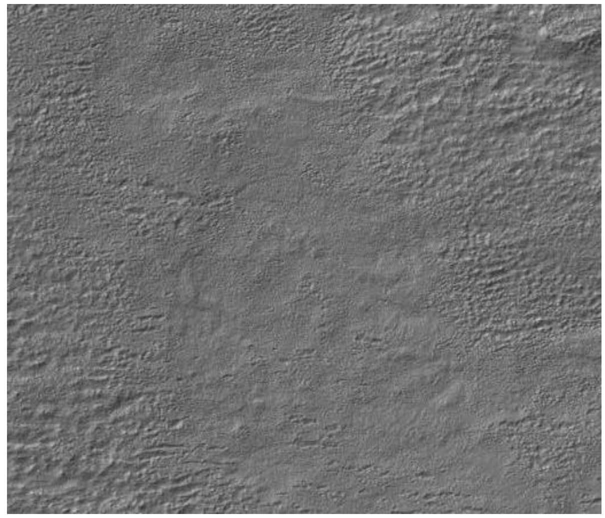


Fig. 5. Smooth texture (Part of MOC image E01-01981)

3.2 Features at Euripus Mons LDA

Using the textural features of degradation laid out by Pierce and Crown (2003), photos collected of the Euripus Mons LDA (through MOC and HiRISE, Fig.6) where analyzed looking for similar degradation features compared to those of Pierce and Crown (2003). At the maximum extent of degradation features, a measurement was made to discover how far the LDA has advanced in the past.

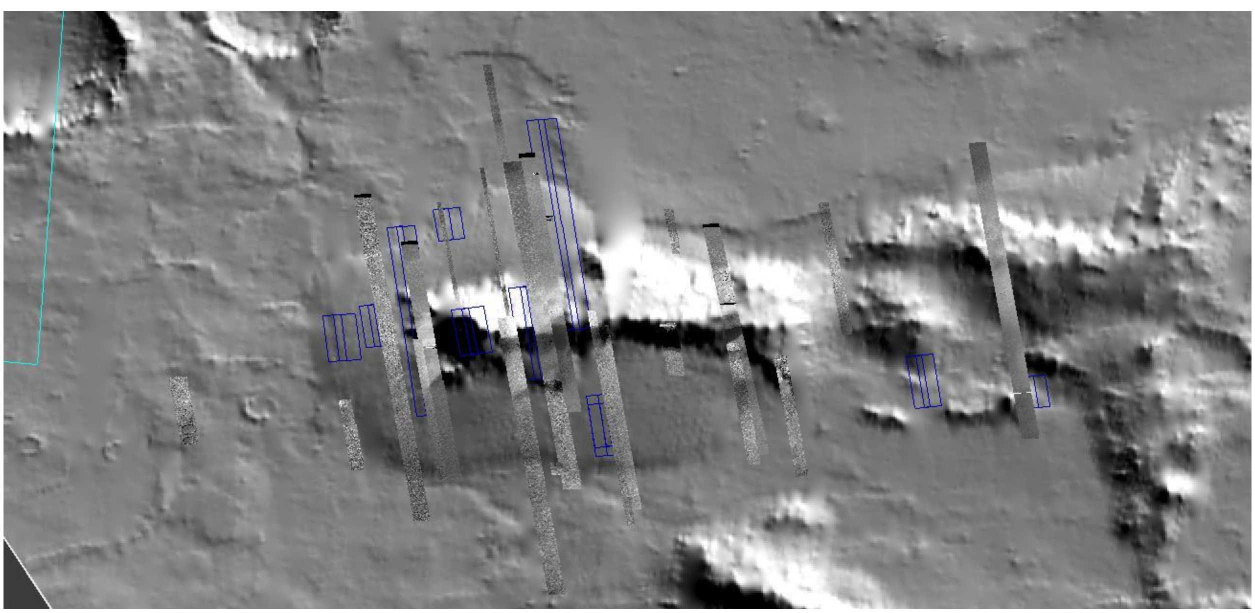


Fig. 6. Photos compiled through JMARS program. Rendered photo "stripes" are from MOC images and purple outlined rectangles represent HiRISE photos used in this study. The current LDA boundaries extend 29 km to the North, 30 km to the South and 27.4 km to the West (Measurements taken through the JMARS and HiRISE program).

4. Results

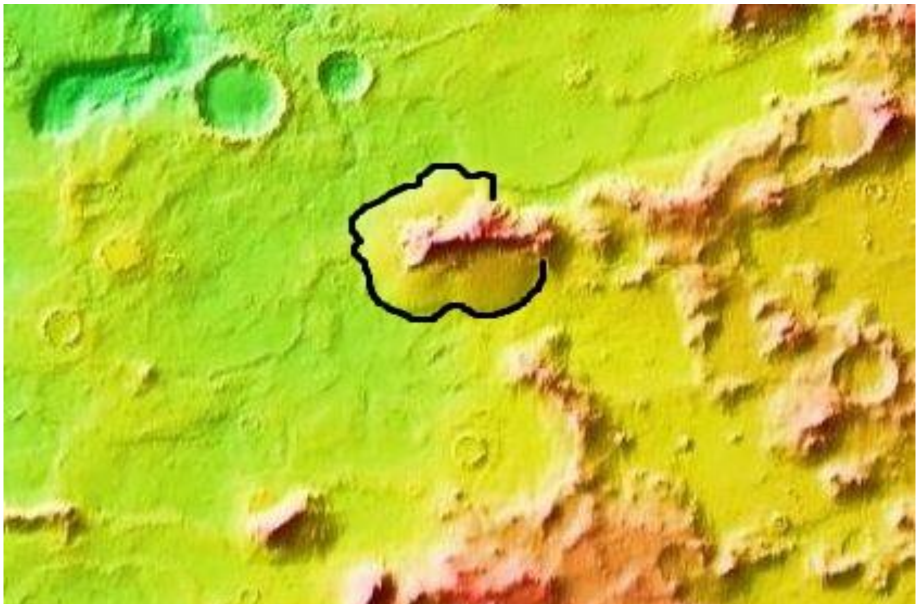


Fig. 7 Current boundary of the Euripus Mons LDA. All results come from outside of this current boundary (see Fig. 13 for context image). Image modified from Google Mars.

To the north, MOC images allowed for an examination of an additional 30 km beyond the current LDA boundary, 33.7 km to the south and 4 km to the west (the current boundary is outlined in Fig. 7). HiRISE photos allowed for greater resolution of features and were used to confirm features found in the MOC images.

The northern MOC image (M11-03223) shows patterns consistent with Pierce and Crown's observations on LDA degradation. At the furthest extent, the textural pattern seems to align with the knobby to ridge and valley texture (Fig. 8). Confined to the upper LDA, observing this textural feature seems to indicate that at some point in the past, the upper LDA existed 30 km from the current observed boundary. Moving 13 km to the south, still within M11-03233, lays a texture that does align with Pierce and Crown's observations of lower LDA degradation, the smooth texture (Fig. 9).

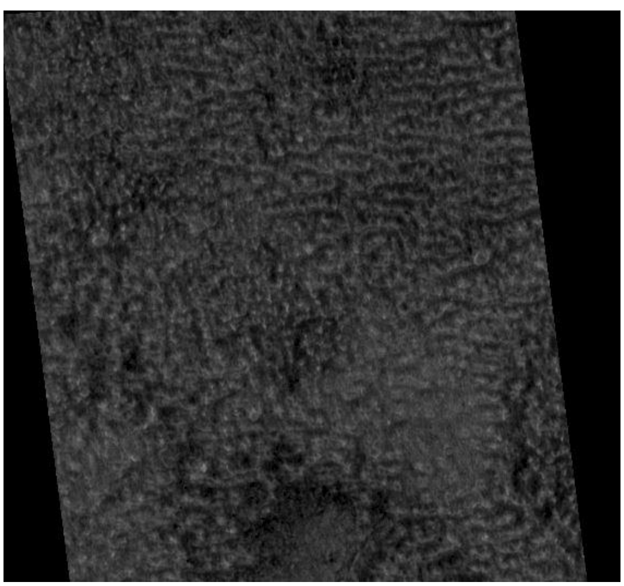


Fig. 8. Furthest extent to the North of Euripus Mons LDA (Part of MOC image M11-03223), the textural pattern resembles an upper LDA degradation feature noted by Pierce and Crown (2003).

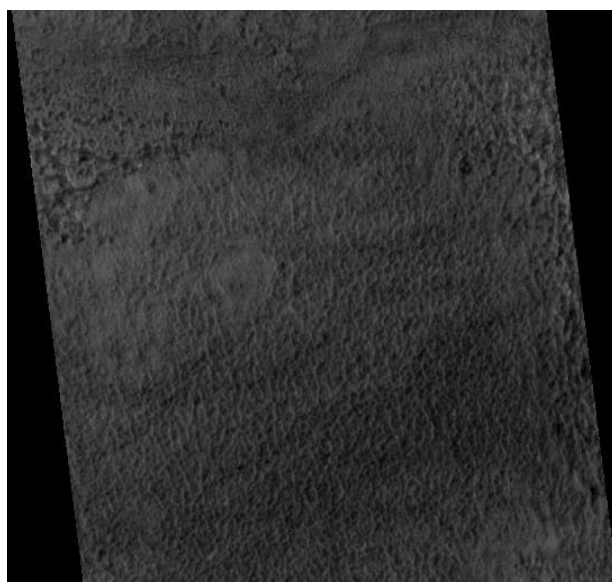


Fig. 9. 13 km south of the furthest extent of MOC image M11-03223. The textural pattern is similar to Pierce and Crown's observations of a smooth texture.

The southern MOC image (R11-02575) appears to alternate between the sharp ridge texture and smooth texture beyond the current observed LDA boundaries. At the furthest extent of image R11-02575, a smooth texture can be observed (Fig. 10). One km to the north, still within image R11-02575 lays a pristine smooth feature which directly aligns with the observations made by Pierce and Crown (2003) (Fig. 11).

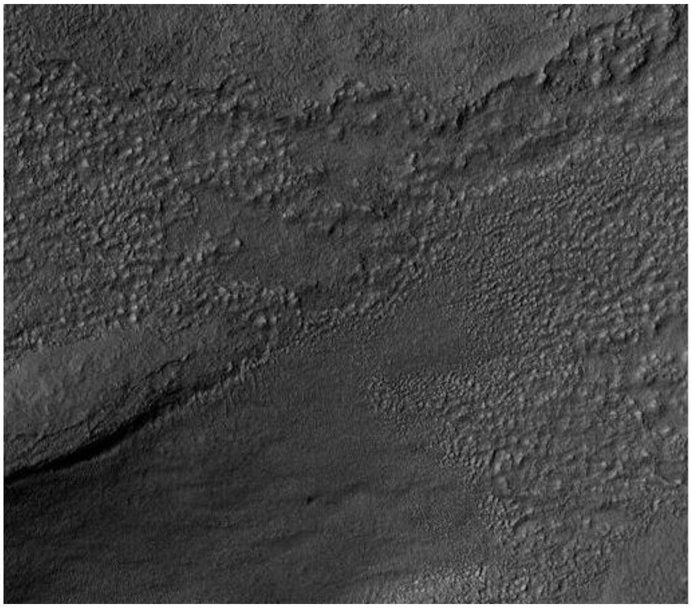


Fig. 10. Smooth texture seen at the furthest extent of MOC image R11-02575

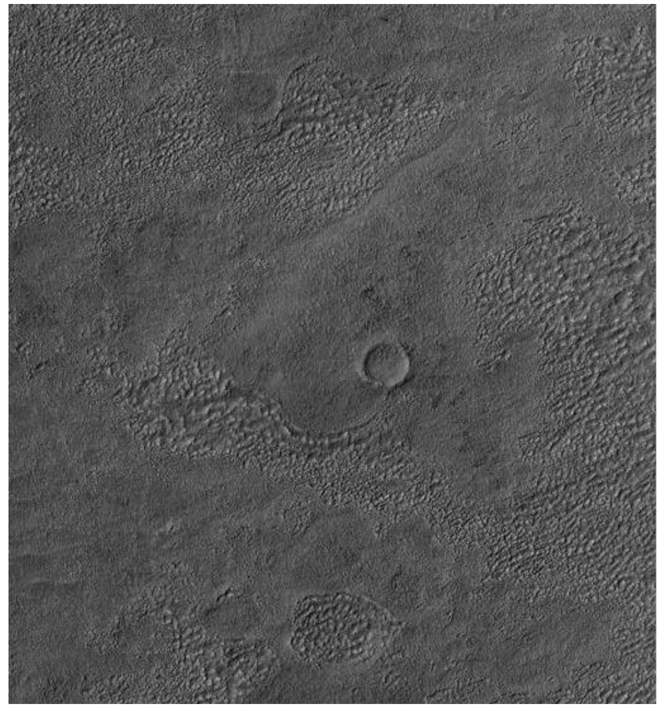


Fig. 11. Pristine smooth texture 1 km from furthest extent of MOC image R11-02575

To the west lies the biggest gap in data (photos). The only relevant photo comes from MOC image M19-00362, which extends further south than west, extending a maximum of 4 km west of the current LDA boundary. The textural pattern aligns with that of the smooth texture, indicating a small advancement on the western side of the Euripus Mons LDA (Fig. 12). As more data is collected to the west of Euripus Mons, it is plausible that an advancement of more than 4 km can be established.

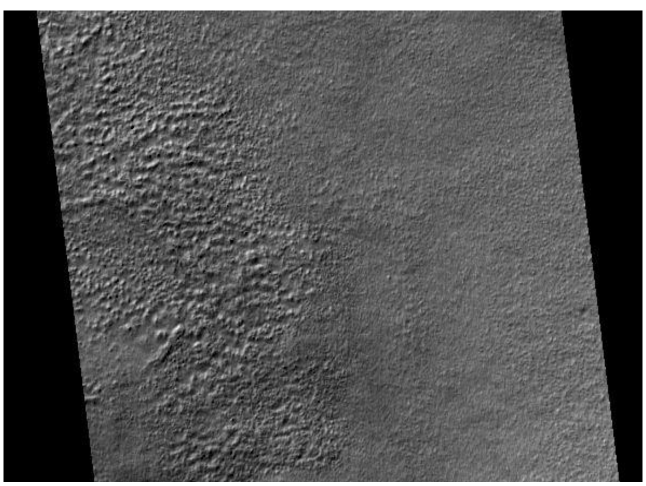


Fig. 12 Smooth texture seen 4 km southwest of Euripus Mons. Part of MOC image M19-00362

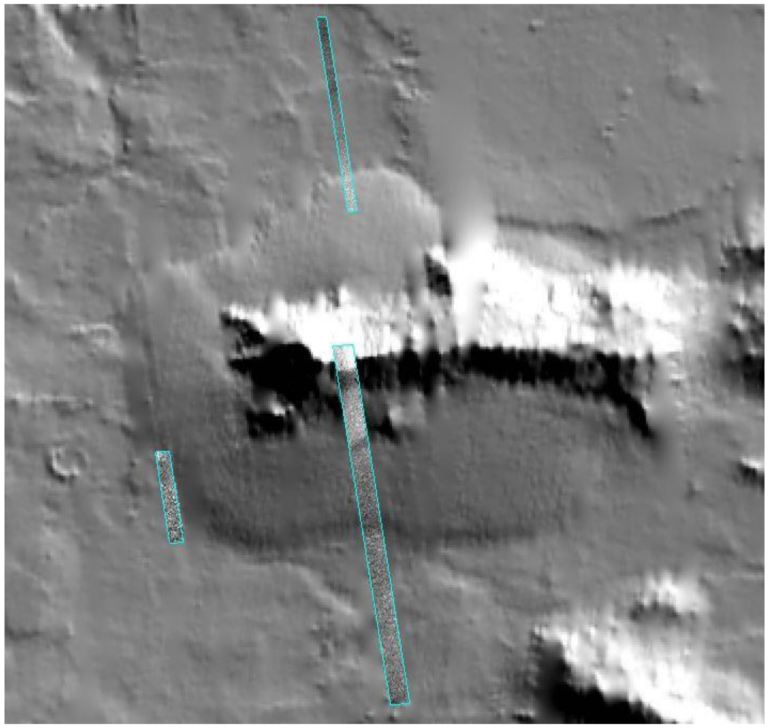


Fig. 13 Context image for results. MOC stripes outlined represent the northern photo, southern photo and western photo used to determine maximum advancement.

5. Discussion

Using Pierce and Crowns (2003) observations, a past advancement of ice can be confirmed beyond the current LDA boundaries. Given adequate photos, this method of observations could be used on similar LDAs to determine past advancements. However, do these observations indicate one advancement, or multiple?

The obliquity shifts of Mars points to multiple advances of ice at mid-latitude regions throughout the last three million years (Lasker et al., 2004) (Fig.1). It is likely that in these ice-age conditions (defined as an equatorward movement of ice from the north and south poles), an advancement of ice at the Euripus Mons LDA could take place. Currently in an interglacial period, the ice within the LDA is redistributing through sublimation, creating, or helping to create, the textural features defined by Pierce and Crown (2003).

Based upon obliquity data (Fig. 1) and the current observations at the Euripus Mons LDA, it is more likely that a set of multiple advancements have occurred. This point can be explained through the observations at the northern side of the Euripus Mons LDA. In figures six and seven an interesting textural feature associated with the upper LDA was noted to exist beyond a lower LDA feature. If indeed this is an upper LDA textural feature existing beyond the lower, smooth-texture LDA feature, the only possible explanation would be that multiple advancements have occurred, one of which advancing at least 13 km past the lower LDA feature noted. The alternating pattern observed in the south seems to confirm multiple advancements, though, because the alternating pattern is between two lower LDA features, it is more difficult to determine if these features do confirm multiple advances.

However, the textural feature beyond the noted smooth texture to the north may not be associated with the LDA at all. These studies are based on comparison photos, which were taken more than ten years ago. It is possible that the texture noted in the north may be completely independent of the LDA. If a single advancement did take place, perhaps the current observed boundaries of the LDA are the remnants of said advancement. An advancement of around 20 km can be applied to the north and south, which is a significant distance, and possibly formed at the most extreme obliquity shifts, recently occurring around two myrs ago (Fig. 1). This singular advancement then went through periods of slight growth and substantial sublimation, to form what is seen today at the Euripus Mons LDA.

6. Conclusions

The existence of ice has been proven by Holt (2008) within the Euripus Mons LDA. Based upon obliquity shifts of the planet (Head et al., 2003, Fig. 1) and the subsequent movement of ice from polar regions to mid-latitudes during these shifts, it is plausible that at some point in Martian history, the ice within the Euripus Mons LDA advanced beyond the current observed boundaries.

The Euripus Mons LDA ice has advanced beyond the current observed boundaries at some point in Martian history. This past advancement can be proved through measuring the maximum distance at which Pierce and Crowns (2003) observations on LDA degradation exist. To the north, it can be confirmed that the LDA advanced out to, at least, 17 km beyond the current observed boundaries of the Euripus Mons LDA. To the south, an advancement of at least 33 km beyond the current observed boundary occurred. The western side of the LDA is limited to photo coverage. A maximum advancement of 4 km could be established, but, with future photo coverage of the area, it is likely that a larger advancement could be proven on the western side of the Euripus Mons LDA.

A series of ice advancements at the Euripus Mons LDA seems to be the most plausible due to the pattern of obliquity shifts that Mars has undergone over the last three million years. The upper LDA feature noted 13 km past the smooth texture in the north as well as the alternating textural pattern noted in the south appears to confirm the multiple advancement approach. These textual patterns point to at least two advancements, though it is likely many more occurred, but the evidence for these advancements has been destroyed due to the most recent advancements, or, that the photos of the research site do not cover enough area to confirm more advances. According to obliquity data provided through Head et. al. (2003) (Fig. 1) at least two advances should be apparent at the Euripus Mons site, and, although two advancements seem to be confirmed through degredational features, it is likely many more advances happened in accordance to the obliquity shifts of Mars (Fig. 1).

More research into how these features form and what they represent needs to occur in order to confirm a multiple advancement theory, as well as application of this method at other LDA sites in order to determine reliability of this method. However, based upon the results of this research, both a previous advance and number of advances could possibly be confirmed through the methods used in this project. By applying the methods outlined in this project to other LDA sites, a firm foundation can be laid in beginning to compare and contrast Milankovitch cycles on Earth and Mars as well as shed light into the previous climatic conditions of Mars, which would encourage mid-latitude ice accumulation.

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