Large Area Glacier-Like Forms on Mars: Insights from Impact Crater Morphologies and Crater Retention Ages.
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Introduction: Ice-rich landforms known as Viscos-Flow Features (VFFs) are common in Mars' mid-latitudes [e.g., 1-2]. Glacier-Like Forms (GLFs) are a distinct sub-category of VFFs and appear morphologically similar to terrestrial valley glaciers or rock glaciers [e.g., 2-4]. GLFs are thought to be the result of the redistribution of water ice from the Martian poles during periods of high obliquity (>35º) and the Last Martian Glacial Maximum (LMGM), which ended ~5 Myr.

Numerous distinct impact crater morphologies have been observed on Martian ice-rich terrains. Investigations suggest that this variation results from interactions between landform lithologies and surface evolution through depositional and erosional processes [5]. We investigated impact crater counts and morphologies on 100 GLFs with large surface areas and attempted to determine Crater Retention Ages (CRAs) for the landforms. We expect erosional processes, such as sublimation and atmospheric erosion, to have eliminated a portion of the true crater record since formation. While exact ages cannot be determined, analysis of CRAs and crater morphologies can provide valuable insight into relative erosional rates on a segment of the global GLF population. Observing this apparent change may give us estimations of the geological evolution of GLFs across Mars.

Methods: Using a recently compiled database of GLFs [4], the 100 GLFs with the largest surface area were selected for analysis, ranging in size from 285.92 to 21.67 square kilometres. Each GLF was mapped in ArcGIS PRO 3.0 with CTX (6m/px) images. Where possible, HiRISE (~0.5m/px) images were used to provide geological context and ensure crater mapping accuracy. Each crater was measured for its diameter and assigned a morphological classification created for this study based on a previous classification system [5]. Craters with diameters =>30m were used for the analysis to ensure accuracy against the CTX resolution. We calculated CRAs using the CraterStats 2.0 Software with non-binned crater-size frequency distributions (CSFD) with Hartmann & Daubar (2017) production functions.

Results: We counted 3631 craters across the 100 GLFs ranging in diameter from 30m to 752m. Crater counts ranged from 640 to 0 per GLF, averaging 36.31 craters/GLF. CRAs could not be determined for three of the GLFs. By not binning the crater data, resurfacing events could be observed in the CSFDs. Up to six different resurfacing events were observed in some GLF CSFDs. Minimum surface ages range from 190 ±9 Ma to 3.1 ±1 Ma. Some GLFs showed older age ranges but with significant error bars (e.g., GLF #3 CRA: 1000 Ma ±400). Despite the error bars, these older ages provide some evidence that some GLFs are significantly older than others.

Of the 15 classifications of crater morphology, the maximum variation on any one GLF was 13, with an average of 4 types/GLF. Craters that were difficult to classify due to dust coverage or CTX image quality were assigned an 'ambiguous' classification.

Discussion: The range of CRAs, particularly the minimum surface ages, suggests that GLF ages are globally varied from ~3 Ma to potentially being as old as ~1 Ga. Some GLF minimum CRAs are relatively old (e.g., GLF #5: 190 ±9), suggesting a lack of resurfacing processes in these local areas or a difference in GLF composition, slowing the erosion of older craters. GLFs with younger surface ages have limited crater quantities, diameters, and morphological variation (Figure 1), suggesting that GLFs need time and a variety of surface processes to create the different crater morphologies observed.

On average, the GLFs in the southern hemisphere have younger CRAs than those in the northern hemisphere, along with the crater quantity and morphological variety. While initially thought to be a result of CTX image quality, which can be varied in the southern hemisphere, further investigation with HiRISE images (0.5m/px) on the limited coverage of GLFs available showed that this is not the case. HiRISE images revealed that GLF surfaces that appear dust-rich on CTX are, in fact, relatively dust-free. Their surfaces appear to have been eroded, possibly by aeolian methods, into dune-like forms rich in thermal contraction polygons commonly observed on martian ice-rich terrains. This is further evidence that a population of southern-hemisphere GLFs in alpine settings appear younger than their northern equivalents.

The data suggests several scenarios for GLFs across Mars. (1) That some GLFs have the potential to be very young, having perhaps formed in the last few million years during the LMGM. (2) That some GLFs may have formed before the LMGM (>20Ma) but have high resurfacing rates, partially removing their impact records. (3) That some GLFs formed before the LMGM and have medium to very low resurfacing rates. These GLFs have surfaces with greater quantities and morphological variation of craters. Consequently, they also appear to record more resurfacing events and have more comprehensive CRA ranges. These low resurfacing rates suggest that these GLFs have not been in favourable depositional environments for an extended period and are possibly in low erosional settings. This lower rate of deposition and erosion is most likely the source of the variation in crater morphologies observed on their surfaces.

The study hints that while high Martian obliquity periods can favour glaciation, material accumulation, and resurfacing events, this occurs within local geographical constraints and that not all periods of glaciation are favourable to all GLFs across the planet.

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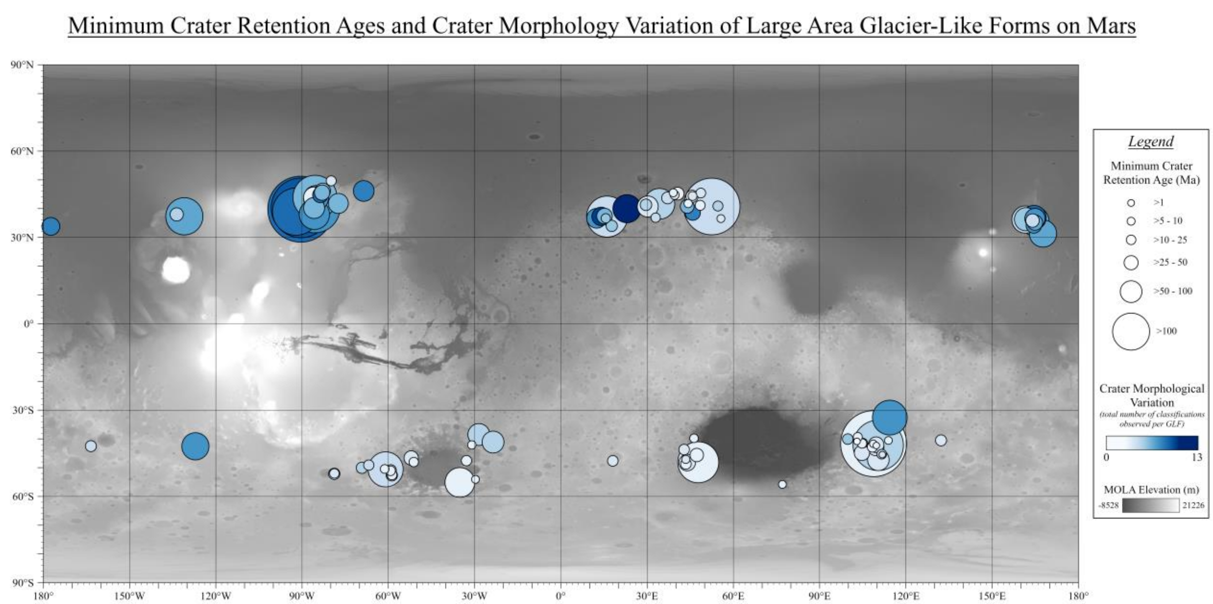

Figure 1: A MOLA Topographic Map of Mars showing the location of the 100 GLFs analysed in this research. Each circle size corresponds to the minimum crater retention age calculated for each GLF. The colours of each circle indicate the total number of crater morphological classifications observed on that particular GLF. On average, GLFs in the northern hemisphere have older minimum CRAs and are populated with craters with more morphological variety than those in the southern hemisphere. The variation observed in each cluster suggests that different erosional and accumulation processes may affect local GLF populations. Some GLFs may potentially be very young (< 20 Ma), particularly in the southern hemisphere.