GEOGRAPHICAL CONTROLS ON THE DISTRIBUTION OF GLACIER-LIKE FORMS IN MARS' MID-LATITUDES: OBSERVATIONS FROM A SURVEY OF MARS RECONNAISSANCE ORBITER CONTEXT CAMERA DATA.

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Introduction: It is widely held that Mars' recent geological past has been dominated by the action of ice-related processes (e.g. [1]) and a great deal of work has been published describing and attempting to explain the range and formation mechanisms of potentially ice-related features observed on the surface of Mars. Many of these features share visible characteristics with terrestrial glaciers, [2-4], their overall morphology indicating viscous or ductile down-slope flow, leading to the assignation of the broadly inclusive term 'viscous flow feature' or 'VFF', [5]. Here we use new satellite data to examine these features and their relation to geographical parameters in greater detail, thus providing information on whether they are controlled by mass-balance or gravity-driven processes.

Milliken et al., [5], conducted a global survey of VFF distribution by examining over 13,000 Mars Orbiter Camera (MOC) images. Of these images, 146 were identified as featuring individual VFFs, almost all of which were located in the mid-latitudes, the maximum frequency of occurrence lying at the 40° line of latitude in both hemispheres. This distribution is consistent with retrospective Martian climatic models which suggest that conditions conducive to mid-latitude ice precipitation and subsequent accumulation may have existed as recently as ~5 x 10^6 years before present [6]. It follows from this model that the VFFs observed today represent only the remnants of what were probably larger ice masses that have receeded since a hypothesised Martian glacial maximum [7-8]. However, these residual deposits appear to have experienced flow in the period elapsed since the Martian glacial maximum and the present day, and the driving forces behind this flow remain poorly understood. In particular, it is unclear whether there was (or is still) a mass-balance-type regime in operation, or whether VFF-type features owe their flow-like appearance only to viscous creep on high-relief surfaces.

Mass-Balance in Terrestrial Glaciers: On Earth, temperature and precipitation (along with the presence of a land base) exert the dominant controls on the global distribution of flowing glacier ice. These factors are in turn mediated by geographical variables including, most importantly, latitude and altitude. Ice accumulates at the lowest elevations towards the poles, where air temperatures are coldest. As ambient air temperatures increase towards the equator, the elevation at which permanent ice masses occur generally increases. This dependence on elevation initiates a regime of mass-balance and ice movement whereby ice accumulation above a threshold altitude (termed the equilibrium line altitude, or 'ELA') is broadly matched by annual ice loss below the ELA.

The ELA for any given year coincides with the position of the snowline visible on a glacier at the end of the summer melt season. Snow deposits remaining above this ELA represent mass accumulation. The overall shape of an ice mass is predominantly determined and subsequently maintained by the transfer of ice from this accumulation area into the ablation area.

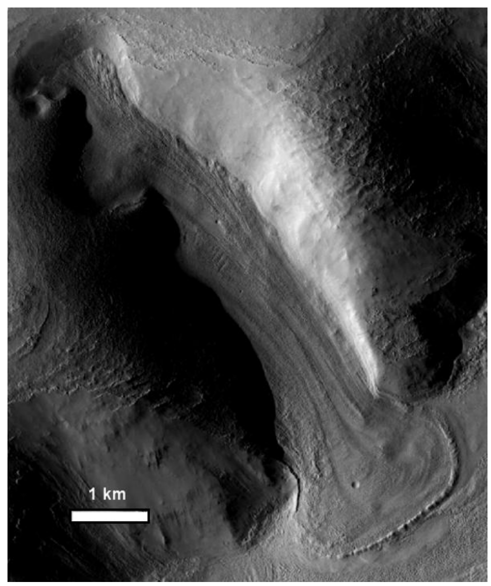

Fig. 1: A GLF in Protonilus Mensae; Mars' N. mid-latitudes (picture oriented north-up). Note the moraine-like structures at the GLF's lower extremity (flow is directed to the S-E) and the crevasse patterns visible towards it's mid-reaches.

How this mass-balance regime operates has a strong influence on how a glacier flows – steeper mass-change gradients generally driving faster flow. However, no firm evidence exists to suggest that accumulation and ablation are (or were) spatially biased at the surface of Martian VFFs where atmospheric temperatures are currently ubiquitously below the freezing point of water. Thus, to date, no ELA can be identified on the current surface of Mars.

Methods: To better understand the processes operating on Mars, analogs are often identified on Earth that can provide hypothetical process models which can then be 'tested' on Mars. In order to improve our understanding of how Martian VFFs grow and flow Earth-based valley glaciers can be used as an analog for smaller-scale, low-order valley VFFs. The similarity of such low-order Martian VFFs to terrestrial valley glaciers has been remarked upon on numerous occasions in recent literature (e.g-[9]). Therefore, in this study, only VFFs which most closely resemble Earth's valley glaciers are examined. The descriptive term 'glacier-like form' (GLF) is used [10] (figure 1).

This study represents the preliminary phase of a fine resolution survey of GLF distribution, contributing to ongoing investigations into the mechanisms of GLF origins and evolution. We surveyed Mars' mid latitudes using new imagery with the aims of (i) extending the spatial coverage of Milliken et al.'s survey, [5] and (ii) resolving a more detailed picture (now facilitated by the availability of ~6 m/pixel, 30 km-wide CTX images) of where GLFs occur in these latitudinal ranges. Spatial variations in GLF concentration are analysed with respect to the likely controlling variables of latitude, elevation and relief in order to characterise the relationships between GLF occurrence and variations in these candidate determinants.

A survey of Mars' mid-latitudes (from 25° to 65° north and south) was performed using 8058 CTX images. These images were inspected systematically by hemisphere and sequentially by longitude, individual GLFs being identified and counted in every image. A set of criteria were designed to isolate GLFs from other sub-types of VFF. These criteria were developed from those used in the previous survey conducted by Milliken et al. [5] and from the wealth of information available in the literature of terrestrial glaciology. Post-survey analyses of GLF concentration relative to geographical determinant factors latitude, elevation and relief was facilitated by sectorized data extracted from the 128 pixels per degree Mars Orbiter Laser Altimeter (MOLA) global dataset.

Results: Inspection of the available CTX data isolated 771 images which were observed to contain a total of 1327 glacier-like forms (GLFs). Of these, 720 were identified in the northern mid-latitudes and 607 were located in the south. Preliminary results indicate that these GLFs occur in highly clustered populations in both hemispheres, favouring areas of mid-range elevation, apparently medium-to-high topographic relief and appearing predominantly at 39-40° latitude in both hemispheres. Preliminary low-spatial resolution analyses correlating GLF population density with latitude, elevation and local relief, respectively, suggests latitude to be the dominant determinant followed by relief and finally, of least importance, elevation.

Conclusions: This ranking of geographical determinants suggests that the current distribution of GLFs has been strongly influenced by latitudinally-forced factors, both in Mars' geological past and under the present-day regime. This contemporary sensitivity of Martian GLFs to latitude echoes the cryospheric scenario on Earth. However, on Mars the GLF distribution is less dependent on elevation than on local relief. This implies that, although terrestrial glaciers and Martian GLFs both flow downslope under the influence of gravity, those on Mars are probably not controlled by elevation-driven spatial patterns of accumulation and ablation such as that to which all terrestrial glaciers conform. Martian GLFs may have initiated through viscous creep of a pre-existing ice mass in response to local topography.

The subordination of altitude to relief, as well as the observed predilection of GLFs for mid-elevations on Mars, rather than an increased frequency with altitude, suggests either that contemporary GLFs have evolved under a regime very different to the mass-balance processes that operate on Earth, or that spatial patterns of ice accumulation and ablation on Mars are quite distinct from those on Earth. This suggests that GLFs developed flow morphologies primarily through gravity-induced mass mobilisation and not through processes of thermally-sensitive ice accumulation and ablation-driven flow. This has implications for our understanding of Mars' recent climate, inferring that even during high-obliquity events such as occurred ~5 x 10^6 years bp [6], low-elevation atmospheric temperatures in mars' mid-latitudes were still predominantly below the H^2O freezing point. This restricts the feasibility of 'wet-based' glacial activity, thus affecting the extent to which the evolution of Mars' surface in recent geological times can be attributed to the activity of GLFs and associated VFFs.

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