The Comparative Distribution of Flowing and Non-Flowing Icy Material in the Nereidum Montes; Mars J. L. Collins-May[1], J. R. Carr[1], M. R. Balme[2], S. Brough[1], C. Gallagher[3], N. Ross[1] A. J. Russell[1], [1]Geography Politics and Sociology, Newcastle University, UK (j.collins-may@newcastle.ac.uk) [2] School of Physical Sciences, The Open University, UK, [3] UCD School of Geography, University College Dublin, Ireland

Summary: The aim of this work is to investigate whether there are significant topographical differences in the locations of flowing versus non-flowing deposits of ice in the Nereidum Montes. These results have implications for understanding Martian paleoclimate, as flowing deposits of ice should have formed in preferential locations for ice to accumulate, where deposits reach the required thicknesses to be able to flow.

Introduction: An abundance of features exist in the mid-latitudes of Mars (30°-60°) [1] that appear to be primarily composed of water ice [2]. Surface ice on Mars is currently unstable at the surface below 60° latitude [3], so the persistence of ice in the mid-latitudes indicates the climate must have been significantly different from today when these deposits were emplaced within the last few hundreds of millions of years [4-5]. This climatic shift might have been driven by an increase in Mars's mean obliquity [5], mobilizing ice from the polar regions to the mid-latitudes.

A subset of these mid-latitude icy deposits display morphological characteristics typical of downslope flow of ice on Earth, such as diverting around obstacles, lobate termini and arcuate surface ridges [6]. These flowing landforms are collectively known as Viscous Flow Features (VFF), [6] and are theorized to have developed during one or multiple high obliquity periods, possibly as layers of icy mantling materials built up to sufficient thicknesses to begin to flow [6]. Therefore, VFF should be located in more preferential areas for ice to form and survive than non-flowing icy deposits.

Determining which factors control the accumulation of enough ice to begin to flow and form a VFF is crucial to understanding the paleoclimate of Mars and how it is impacted by orbital excursions [7].

In this work, we compare the distribution of VFF and non-flowing icy material across several topographic variables that influence the development of glacier ice on Earth. These are: latitude, longitude, elevation, surface slope, relative relief and aspect.

Study Area: The Nereidum Montes mountain range, which forms the northern rim of the Argyre Impact Basin, is particularly well suited for this study [8]. This site has a relatively low latitude (34°S to 50°S), close to the latitudinal limit of surface ice deposits. The climate at these latitudes is harsh for ice deposits to exist in, due to greater insolation compared to higher latitudes. Therefore any ice deposits in the Nereidum Montes are located in the most favorable locations for ice, so areas with VFF should have more easily distinguishable characteristics than areas with non-flowing ice. The Nereidum Montes also possesses a large range in longitude (~40°), elevation (~8500 m), surface slope (0° to 49°), relative relief (~3500 m) and aspect, which is crucial for an analysis how these factors may control where VFF features form rather than non-flowing ice deposits.

Methods: We mapped all VFF in the Nereidum Montes at a scale of 1:25,000 using ConTeXt Camera (CTX) [9] imagery. Deposits with surface textures similar to VFF but lacking indications of flow, were mapped as Non-Flowing Icy Bodies (NFIB). The elevation, slope, relative relief and aspect of VFF and NFIB were then extracted from MOLA DEM [10] data.

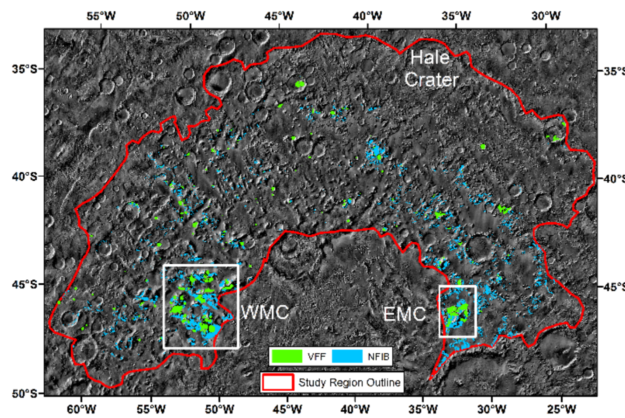

Figure 1: THEMIS Daytime Infrared imagery overlain with the mapped VFF and NFIB. Also highlighted is the location of two mountainous regions exhibiting large concentrations of VFF and NFIB, the Eastern Mountain Cluster (EMC) and the Western Mountain Cluster WMC).

Results & Discussion: Our mapping reveals that more VFF and NFIB is located at higher latitudes in Nereidum Montes than lower ones (Fig. 1). NFIB is more prevalent than VFF at almost all latitudes (Fig. 1), so increased ice survival at higher latitudes does not appear to promote the formation of VFF over NFIB. There are longitudinal patterns in the distribution of VFF and NFIB, with both types being the most prevalent in two regions of the Nereidum Montes that we term the Eastern Mountain Cluster (EMC) and Western Mountain Cluster (WMC) (Fig. 1). However, VFF are much more common in the WMC than the EMC (Fig. 1).

The clearest differences between non-flowing and flowing icy material are in surface slope (Fig. 2). NFIB deposits tend to have lower surface slopes than VFF do, with a clear peak in abundance at 12°. The surface slope distribution of VFF material is more consistent across the range of surface slope values than NFIB, and almost all of the mapped material with a surface slope of over 30° is VFF material. This may reflect a difference in internal dynamics between VFF and NFIB deposits.

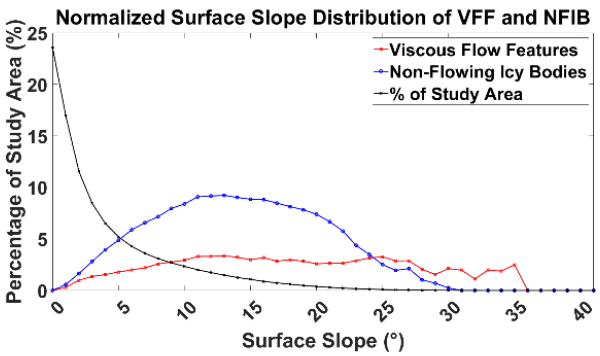

Figure 2: The surface slope distribution of VFF and NFIB in 1° bins.

Increasing relative relief promotes greater surface coverage by icy material overall, with no icy material found in locations with less than 300 m of relief. However, NFIB material is more common than VFF in the majority of relative relief bins present at the study site (Fig. 3). Though VFF coverage at 3500 m to 3600 m of relative relief is 100%, this bin is composed of one pixel and may not be representative of the actual relationship. Therefore, increasing relief does not appear to promote the development of VFF over NFIB.

Aspect also influences the distribution of icy material (Fig. 4). Icy material has a clear preference for southerly aspects, with very little material facing northwards. This is anticipated, as south facing aspects reduce direct insolation in the southern hemisphere of Mars. Though southerly aspects appear to be the most preferential for the formation or survivability of ice, this factor does not appear to drive the formation of more VFF than NFIB, as NFIB covers more of the Nereidum Montes than VFF in every aspect direction.

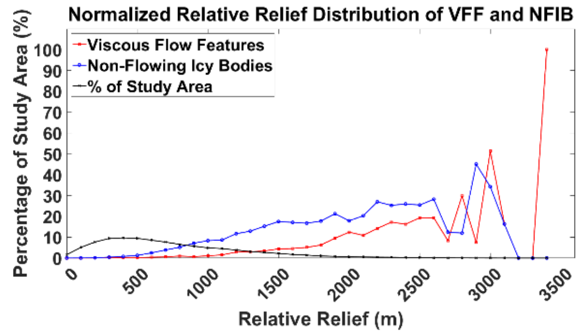

Figure 3: The relative relief distribution of VFF and NFIB in 100 m bins.

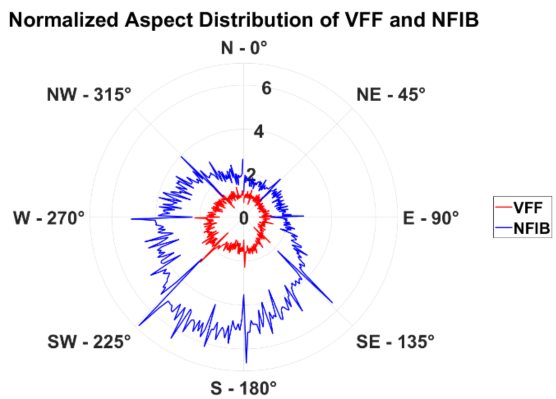

Figure 4: The aspect distribution of VFF and NFIB in 1° bins.

Overall, topography influences the presence of VFF and NFIB in similar ways, supporting the idea that VFF are formed or preserved by the same conditions that NFIB deposits are. The broadly similar distribution of VFF and NFIB also suggests that VFF are composed of the same material as NFIB. However, while topography plays a role in determining where icy material survives overall, the formation of VFF over NFIB is likely due to other factors. An example may be wind patterns, driving the deposition of more ice in certain locations.

References: [1] Brough et al (2019), *EPSL,* 507, 10-20 [2] Holt et al., (2008) *Science*, 322, E5905, 1235-1238 [3] Head et al., (2005) *Nature,* 434, E7031, 346-351 [4] Levy et al., (2010) *Icarus*, 209, I2, 390-404 [5] Forget et al., (2006)*, Science*, 311, E5759, 368-371 [6] Milliken et al., (2003), *JGR; Planets,* 108, I6, 1-11 [7] Levy et al., (2014) *JGR: Planets*, 119, I10,2188-2196 [8] Banks et al., (2008) *JGR:Planets*, 113, I12, 1-20 [9] Malin *et al.,* (2007) *JGR: Planets*, 112, I5, 1-25 [10] Smith et al., (2001) *JGR: Planets*, 106, I10, 23689-23722.