The Origin and Distribution of 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 local and regional topography influences ice deposition and preservation on Mars. Our findings suggest that local topography does influence ice distribution on Mars, particularly relative relief. These results have implications for understanding Martian paleoclimate, and will be compared to the outputs from climate models.

Introduction: Surface ice on Mars is currently unstable below 60° latitude [1], but an abundance of features exist in the mid-latitudes (30°-60°) [2] that appear to be primarily composed of water ice [3]. A subset of these icy features display morphological characteristics typical of downslope flow of ice on Earth, and are collectively known as Viscous Flow Features (VFF) [4]. The persistence of VFF and other icy deposits has been taken as evidence that the Martian mid-latitude climate when these deposits were emplaced, a few hundreds of millions of years ago, must have been significantly different from today [5-6]. This climatic shift might have been driven by an increase in Mars's mean obliquity, and once obliquity reduced again degradation of these deposits began, leaving the remnants present today [6]. However, exactly how and why these changes in obliquity resulted in the deposition and distribution of icy material across the Martian mid-latitudes is still mostly unknown [2]. Determining which factors control the location of VFF and non-flowing icy material is crucial to understanding the paleoclimate of Mars and how it is impacted by orbital excursions, as well as determining the current and former water inventory of Mars [7].

On Earth, the distribution of glacier ice is driven by precipitation and temperature, which are heavily influenced by latitude, altitude, and other topographic variables (e.g. aspect, slope and relative relief) [6]. Such factors are also important in the development or preservation of icy material on Mars [2, 6, 8]. These include:

Latitude: Like Earth, the higher latitudes of Mars are colder than the equatorial regions as they currently receive less solar radiation per square meter, thus ice is less susceptible to degradation at higher latitudes [1].

Elevation: The atmospheric pressure, temperature profile and water vapor content of the Martian atmosphere changes with height above the surface and altitude [9]. These changes likely impact ice deposition and preservation, so need to be investigated.

Slope: Slope is thought to influence the formation of VFFs, as flow is much easier to initiate on inclined surfaces than flat ones [10]. However, the slope preferences for non-flowing material is currently unknown.

Relative Relief: Relative relief is the difference between the highest and lowest elevation points in a given area. Relative relief can impact the amount of precipitation, incoming solar radiation and debris that glaciers on Earth receive [11], and so may influence the formation or preservation of icy material on Mars too.

Aspect: Different topographic orientations result in surfaces at the same latitudes being exposed to differing annual solar irradiance. For example, poleward facing slopes receive less insolation than equator facing ones [6] leading to less ice degradation than equatorward facing slopes.

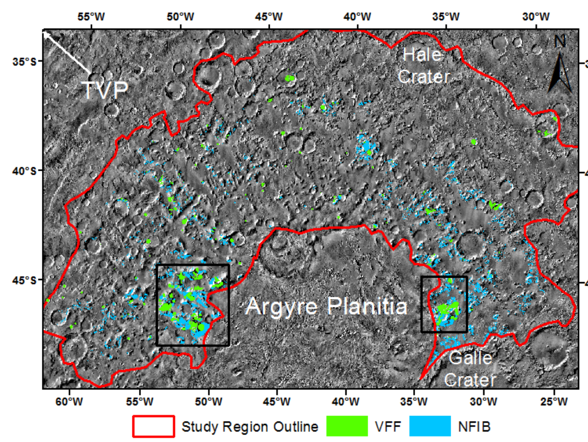

Figure 1: THEMIS imagery overlain with the mapped VFF and NFIB, and the locations of Arygre Planitia, Hale Crater, Galle Crater and the Tharsis Volcanic Province (TVP).

Study area: Regional and local topography may influence the formation or preservation of icy material on Mars, though this is currently poorly understood [2]. Examples include the impact basins Hellas and Argyre. These enormous structures may influence the atmospheric dynamics within and surrounding them [6, 10], producing conditions that differ from other ice-bearing areas, such as the dichotomy boundary [2]. They may also act as sinks [12-13] that trap icy material. Assessing the distribution of icy material in these craters compared to other regions, may reveal more about the conditions promoting the formation and persistence of ice on Mars. As a well-preserved large impact crater [13], the Argyre Impact Basin (AIB) is the ideal location to evaluate the relationship between the distribution of icy material and the topographic characteristics of the surrounding landscape, as it possesses a wide range of slope angles, elevations, relief, and aspect. The Nereidum Montes mountain range, which runs across the northern rim of the AIB, is particularly suited for this study [14]. This site has a relatively low latitude (34°S to 50°S), close to the latitudinal limit of surface ice deposits, so provides a contrast to higher latitude areas, such as the Charitum Montes in the southern AIB, allowing latitudinal control to be tested.

Methods: To assess the importance of elevation, slope, relative relief and aspect on the distribution of icy material in the Nereidum Montes, we mapped all VFF in the Nereidum Montes at a scale of 1:25,000 using ConTeXt Camera (CTX) [15] imagery. Furthermore, all deposits with similar surface textures to the VFF were mapped as deposits of Non-Flowing Icy Bodies (NFIB). The elevation, slope, relative relief and aspect of these features were then extracted from MOLA DEM [16] data and products derived from this DEM.

Results & Discussion: Our mapping shows that more icy material is found at higher latitudes within the Nereidum Montes (Fig. 1). When normalized by area, this relationship between latitude and the percentage of ice surface area is not linear, indicating that latitude is not the only control on the presence of icy material.

Elevation has a complex relationship with the distribution of icy material (Fig. 2). The majority of icy material is found between -1000m and 500m, but when normalized by area, three distinct peaks at -3500 m to -3500 m, -500 m to -1 m and 2000 m to 2500 m appear. This suggests elevation is not the only determining factor for ice distribution either.

Icy material is predominantly found on slopes of 3°-6° and is rare on flat surfaces. This is unsurprising for VFF, as it is easier to initiate flow on inclined surfaces compared to flat ones, but the relationship is also true for deposits with no morphological indication of flow.

Icy material is almost ubiquitous in areas with high relative relief, yet almost completely absent in areas with little relief. As on Earth [11], this could reflect higher precipitation, and higher availability of debris. Areas of higher relief will undergo more mass wasting and provide more debris to protect icy material from degradation. The large relative relief may also increase shading of the deposits from incoming solar radiation.

Aspect does not show a strong relationship with the location of icy material, but poleward-facing slopes do possess slightly more icy material than equator facing ones.

Our results suggest that not one single driver determines the deposition and preservation of icy material on Mars. Instead, we suggest that it is the result of complex interactions of all the factors we evaluated. This would explain why two mountainous areas centered at 46°S 52°W and 47°S 32°W (black boxes in Fig. 1) have the largest continuous expanses of VFF and NFIB in the Nereidum Montes. These mountainous regions lie at moderately high latitudes and possess significant variations in elevation ranges, slope angles, aspects and relative relief, all within a relatively small area compared to the Nereidum Montes as a whole. Other, less mountainous areas, i.e. close to Hale Crater have little icy material. Even within the highly mountainous zones however, icy material does not form a complete surface cover, indicating that localized factors can impact the distribution of icy material.

These findings indicate that, like Earth, local and regional topography does play a role in ice deposition in the Nereidum Montes. Future work will attempt to match these mapped deposits to those predicted by climate models.

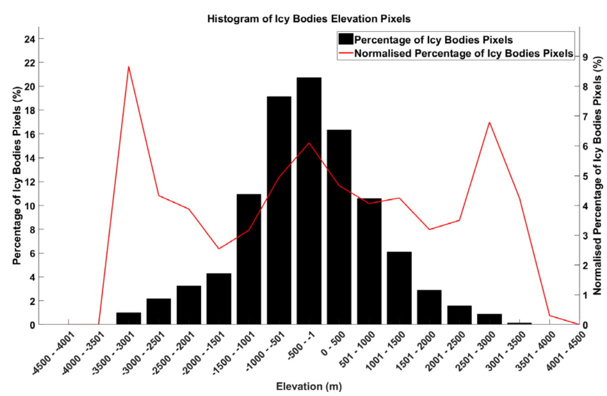

Figure 2: The elevation distribution of icy material in the Nereidum Montes, in 500m bins.

References: [1] Head et al., (2005) *Nature,* 434, E7031, 346-351 [2] Brough et al (2019), *EPSL,* 507, 10-20 [3] Holt et al., (2008) *Science*, 322, E5905, 1235-1238 [4] Souness et al., (2012) *Icarus*, 217, 243-255 [5] Levy et al., (2010) *Icarus*, 209, I2, 390-404 [6] Forget et al., (2006)*, Science*, 311, E5759, 368-371 [7] Levy et al., (2014) JGR: Planets, 119, I10,2188-2196 [8] Dickson et al. (2012) *Icarus,* 219, 723-732 [9] Tellman et al., (2013) *JGR: Planets*, 118, 306-320 [10] Voelker et al., (2017) *PSS*, 145, 49-70 [11] Scherler et al., (2011) *JGR: Earth Surface*, 116, 1-21 [12] William et al., (2017) *Icarus*, 293, 8-26 [13] Dohm et al., (2015) *Icarus*, 253, 66-98 [14] Banks et al., (2008) *JGR:Planets*, 113, I12, 1-20 [15] Malin *et al.,* (2007) *JGR: Planets*, 112, I5, 1-25 [16] Smith et al., (2001) *JGR: Planets*, 106, I10, 23689-23722.