RADAR-BASED OBSERVATIONS OF VARIABLE THICKNESS DEBRIS COVER ON MARTIAN ICE MASSES: EVIDENCE OF DEBRIS TRANSFER BY FLOWING ICE ON MARS. C. J. Souness[1], S. Brough[1*], J. Woodward[2], B. Hubbard[1], J. Davis[3,4], P. M. Grindrod[3,5] [1]Centre for Glaciology, Dept. of Geography and Earth Sciences, Aberystwyth University, Wales, UK, SY23 3DB. [2]Dept. of Geography, Engineering and Environment, University of Northumbria, Newcastle, UK, NE1 8ST. [3]Centre for Planetary Sciences, at UCL/Birkbeck, London, UK. [4]Dept. of Earth Sciences, University College London, London, UK, WC1E 6BT. [5]Dept. of Earth and Planetary Sciences, Birkbeck, University of London, London, UK, WC1E 7HX. (*corresponding author: stb20@aber.ac.uk).

Introduction: The mid-latitudes of Mars host a variety of ice-based landforms. In recent years studies have concentrated on better understanding a particular meso-scale class of these known as viscous flow features (VFFs). These VFFs include several sub-types: alpine-style GLFs (glacier-like forms); broad, rampart-like LDAs (lobate debris aprons) semi-chaotic LVF (lineated valley fill) and concentric crater fill (CCF). Together these icy features constitute a diverse suite of landforms described as an 'integrated glacial landsystem' [1].

VFFs are similar to terrestrial glaciers in their overall morphology and have perhaps evolved in a broadly similar manner [2, 3]. This resemblance has led to VFFs being well studied [1, 4, 5, 6], and are hypothesized to have formed during past periods of high obliquity-induced glaciation. These VFFs are considered to have survived since the last martian glacial maximum ('LMGM',[7]) to the present day thanks to having become buried beneath a substantial protective layer of debris [8, 9]. This layer of debris has shielded the ice from Mars' hyper arid atmosphere which is drier than Earth's by a factor of ~1000 [10] and under which exposed ice would sublimate. However, the origins, internal structure and transportation history of this 'supra-VFF' debris layer are poorly understood.

The only means available for studying VFFs and their associated deposits have been through the use of remote sensing devices mounted on space-borne platforms such as the Mars Reconnaissance Orbiter (MRO). This limitation has restricted our understanding of VFF formation and the manner in which these ice masses have interacted with and shaped the surrounding martian landscape, both in the past and in the present. However, the SHARAD (SHAllow RADar) sensor mounted on the MRO, allows us some ability to 'look inside' VFFs.

Past use of SHARAD in studying ice-surface debris layers on Mars: VFFs are buried beneath a thick layer of dust and regolith which not only blocks the ice from view but also shields it from the martian atmosphere. SHARAD data inspected by Holt et al. [11] and Plaut et al. [12] indicated debris covers on their target ice masses ranging between 5 m and 10 m in thickness (based on the observation of one RADAR reflection rather than two in SHARAD transects dissecting large LDAs). However, nothing is known about how the thickness of this debris cover varies either on an inter- or intra-feature level. Therefore, we have thus far been limited in our ability to infer how it was sourced, how variability in its ubiquity may have affected the spatial character of VFF preservation and indeed how VFF flow may have influenced its redistribution over time.

Methods: We aim to better understand the surface debris deposits observed upon Mars' ice masses, offering a new perspective on the relationship between VFFs and surrounding landscapes by utilising a combination of visual mapping, SHARAD data and high-resolution, digital elevation models (DEMs). We describe an investigation of intra-VFF supraglacial debris heterogeneity at a site located in the Promethei Terra area to the east of Hellas Planitia in Mars' southern hemisphere (40^{o} 40'57" S, 102^{o} 33'29" E), representing part of a wider study which is currently in progress.

Studies were conducted exclusively using satellite-derived data including imagery and ground penetrating radargrams. The majority of the imagery used for mapping and analysis came from the Context (CTX) and the High resolution Imaging Science Experiment (HiRISE) imaging systems. The radar data were captured by the SHARAD sensor. SHARAD data was downloaded in pre-processed, image projected format from NASA's Planetary Data System (PDS) interface. These data were then inspected manually. Sub-surface reflectors were identified visually and mapped on to the radargrams. Ongoing investigations are aiming to confirm our initial interpretation that these reflectors are a true signal, rather than off-nadir clutter.

Geomorphological maps (based upon CTX and HiRISE imagery) were used to guide interpretation of subsurface data from the SHARAD datasets. Additionally, high-resolution stereoscopic CTX images were also used to build a 20 m/pixel DEM of the study site [13], which was used to further inform analyses of internal structures observed in the SHARAD profiles.

Results: The geomorphological map and DEM of the study site in Promethei Terra show a broad LDA fed by numerous GLFs. The LDA is composed of several flow units and inspection of the DEM shows distinct troughs between these units and as well as a surface profile which gradually steepens with distance from the feature's headwall. The five SHARAD profiles corresponding to the surface of this LDA were arranged in parallel succession and oriented transverse to the inferred direction of LDA flow, i.e. parallel to the feature's headwall (Fig. 1). Each profile features a bright, strongly prominent surface reflection over the LDA as well as a clear horizon in keeping with the LDA's basal interface. However, when inspected in downslope order, i.e. beginning with the transect closest to the headwall, a gradual thickening of the aforementioned surface reflection horizon was discernible, the final transect (#5, captured closest to the LDA's 'snout') even showing two distinct, parallel reflectors where previously only one had been observed (Fig. 1).

Conclusions: The observed thickening of the surface reflector at the study site (representing the surface debris layer) between the five sequential SHARAD profiles, and its eventual separation into two distinct and separate horizons, strongly suggests that the layer of superficial debris atop this LDA thickens with distance from its headwall / source area. The final resolution of two horizons suggests, based on previous studies [12, 13], that the surface debris layer is >10 m thick at this point. This observed flow-parallel asymmetry in debris thickness is similar to that recorded on many terrestrial glaciers, indicating that a cumulative downflow debris mass transfer, such as occurs on Earth, also operates / operated on martian VFFs. This suggests that glaciers on Mars have historically played (and may still play) a substantial role in redistributing lithic material from mountainous catchments to lower-lying areas, potentially throughout the glacial regions of Mars' mid-latitudes.

References: [1] Head, J. W., et al. (2010) *Earth Planet. Sci. Let., 294.* 306-320. [2] Marchant, D. R. and Head, J. W. (2003) *6th Int. Conf. on Mars*: 3091.pdf. [3] Milliken, R. E. et al. (2003) *J. Geophys. Res., 108.* E6. 5057. [4] Hubbard, B., et al. (2011) *Icarus, 211.* 330-346. [5] Souness, C. J., et al. (2012) *Icarus, 217.* 243-255. [6] Hubbard, B., et al. (2014) *The Cryosphere, 8.* 1-15. [7] Souness, C. J. and Hubbard, B. (2013) *Icarus, 225.* 495-505. [8] Fanale, F. P., et al. (1986) *Icarus, 67.* 1-18. [9] Bryson, K. L., et al. (2008) *Icarus, 196(2).* 446-458. [10] Read, P. L. and Lewis, S. R. (2004) *The martian climate revisited, Springer Praxis.* [11] Holt, J. W., et al. (2008) *Science, 322.* 1235-1238. [12] Plaut, J. J., et al. (2009) *Geophys. Res. Lett., 36.*.LO2203. [13] Brough, S., et al (2015) *Journal of Maps*, DOI: 10.1080/17445647.2015.1047907.

Figure 1: Here we show the SHARAD profiles #1 - #5, arranged across the LDA at our study site in Promethei Terra. The arrangement of the profiles is shown in relation to a DEM of the site, colored using CTX image B20_017616_1391_XI_40S257W. In the upper-right corner of the figure '#5a' Shows profile #5 (SHARAD observation r_1807101_001_ss19_700_1) in detail. The 'augmented' version of this profile, with internal reflectors highlighted, is shown at '#5b', in the lower-right-hand corner of the figure. Adjacent to this, in the lower-left-hand corner of the figure, 'Z' shows an elevation extracted from the DEM (marked 'Z' on the image).