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Possible Transport of Basal Debris to the Surface of a Mid-Latitude Glacier on Mars.

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Introduction: We observe internal flow structures within a viscous flow feature (VFF; 51.24°W, 42.53°S) interpreted as a debris-covered glacier in Nereidum Montes, Mars. The structures are exposed in the wall of a gully that is incised through the VFF, parallel to its flow-direction. They are near to the glacier terminus and appear to connect its deep interior (and possibly its bed) to arcuate flow-transverse foliations on its surface. Such foliations are common on VFF surfaces, but their relation to VFF-internal structures and ice flow is poorly understood. The VFF-internal structures we observe are reminiscent of up-glacier dipping shear structures that transport basal debris to glacier surfaces on Earth.

Subglacial environments on Mars are of astrobiological interest due to the availability of water ice and shelter from Mars' surface radiation environment. However, current limitations in drilling technology prevent their direct exploration. If debris on VFF surfaces contains a component of englacial and/or subglacial debris, those materials could be sampled without access to the subsurface. This could reduce the potential cost and complexity of future missions that aim to explore englacial and subglacial environments on Mars.

Methods: We use a 1 m/pixel digital elevation model (DEM) derived from 25 cm/pixel High Resolution Imaging Science Experiment (HiRISE) stereo-pair images, and a false-colour (merged IRB) HiRISE image. We measured the dip and strike of the VFF-internal structures using ArcGIS 10.7 and QGIS software. We also input the DEM (and an inferred glacier bed topography derived from it) into ice flow simulations using the Ice Sheet System Model, assuming no basal sliding and present-day mean annual surface temperature (210K).

Results and Discussion: The VFF-internal structures dip up-glacier at ~20° from the bed. This is inconsistent with their formation by bed-parallel ice-accumulation layering without modification by ice flow. The VFF-internal structures and surface foliations are spectrally 'redder' than adjacent VFF portions, which appear 'bluer'. This could result from differences in debris concentration and/or surficial dust trapping between the internal structures and the bulk VFF. Modelling experiments suggest that the up-glacier-dipping structures occur at the onset of a compressional regime as ice flow slowed towards the VFF terminus.

In cold-based glaciers on Earth, up-glacier-dipping folds are common approaching zones of enhanced ice rigidity near the glacier margin. Where multiple folds co-exist, the outermost typically comprises basal ice with a component of subglacial debris entrained in the presence of interfacial films of liquid water at sub-freezing temperatures. In polythermal glaciers, debris-rich up-glacier-dipping thrust faults form where sliding wet-based ice converges with cold-based ice.

Conclusions: We propose that the observed up-glacier-dipping VFF-internal structures are englacial shear zones formed by compressional ice flow. They could represent transport pathways for englacial and subglacial material to the VFF surface. The majority of extant mid-latitude VFF on Mars are thought to have been perennially cold-based; thus we favour the hypothesis that the VFF-internal structures are folds formed under a cold-based thermal regime. Under this mechanism, the outermost surface foliation, and its corresponding VFF-internal structure, is the most likely to contain subglacial debris.