Possible Transport of Basal Debris to the Surface of a Mid-Latitude Glacier on Mars
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Flow histories of mid-latitude debris-covered glaciers (DCGs) on Mars should manifest in their internal structure.
- Reflectors at the beds of some DCGs have been detected using orbital ground-penetrating radar [e.g., 1].
- Observations of DCG-internal structures have remained elusive.

A gully has incised a flow-parallel exposure through the interior of a DCG in Nereidum Montes.
- The gully (Fig 1, 51.24°W, 42.53°S) originates as an erosional bedrock alcove in the hillslope above the glacier, and terminates in a depositional fan, which extends beyond the DCG terminus.

The gully cuts through flowlines on the DCG surface, which are connected to DCG-internal structures exposed in the gully wall.
- The flowlines (Fig 2) appear to have formed by flow compression.
- The internal structures (Fig 3) dip up-glacier (NE) at ~20° from the bed, which dips ~12° to the SW.
- They are spectrally ‘redder’ (Fig 3) than the bulk DCG, which is ‘bluer.’ This could be due to differences in debris concentration and/or surface roughness [e.g., 2].

On Earth, similar up-glacier-dipping internal structures often transport basal and en-glacial debris to glacier surfaces [e.g., 3–4].
- Polythermal glaciers (Fig 4) can form up-glacier-dipping thrust-faults where sliding wet-based ice converges with cold-based marginal ice [e.g., 3].
- Cold-based glaciers can form similar structures, when compressional fold crests are beheaded by ice thinning [e.g., 4].

3D ice-flow models suggest the observed structures formed by compression.
- We reconstruct DCG velocity and stress regime using the Ice Sheet System Model [6] (Fig 5).
- We input a 1m/pixel HiRISE digital elevation model (DEM), and an inferred basal topography derived from it.
- We initially assume present-day mean annual surface temperature (210 K) and no basal sliding (cold-based).
- Flow deceleration towards thinner ice approaching the terminus (Fig 5A) induces an arcuate compressional zone (Fig 5B) which coincides with the DGC-surface flowlines.

Fig 1: (A) MOLA elevation map showing location of Nereidum Montes, Mars. (B) Oblique view of HiRISE Resolution Imaging Science Experiment (HiRISE) image ESP_031036_1370 overlain on HiRISE DEM, showing the gully-incised glacier in Nereidum Montes.

Fig 2: Arcuate flow-transverse structures on the surface of the glacier, intersected by a gully incised subparallel to ice flow direction (right to left). Black box is extent of Fig 3. White line shows extent of model domain in Fig 5. HiRISE image ESP_031036_1370.

Fig 3: HiRISE merged IR image ESP_031036_1370 showing the colour signature of the DCG-internal structures (e.g., white arrows), and associated surface foliations (black arrows).

Fig 4: (A) Aerial view of glacier flow compression lines, NW Blemmare Island. (B) Cliff exposure of up-glacier-dipping structures transporting basal debris to the surface features in A [5]. Images provided by D.J.A. Evans.

Fig 5: Reconstructed velocity (panel A) and horizontal deviatoric stress (panel B) for the surface of the gully-incised DCG. Negative deviatoric stresses indicate longitudinal flow compression. Extent of model domain shown by white line in Fig 2. Basemap is HiRISE image ESP_051036_1370.

Conclusions
- Gully incision has exposed internal flow compression structures within a mid-latitude glacier on Mars.
- The internal structures connect the glacier’s deep interior/bed to surface flow compression lines. The internal structures might have transported basal and/ or englacial debris the glacier surface. Compressional flow lines are common on mid-latitude debris-covered glaciers on Mars so this process might have been widespread.
- Flow-compression lines on Martian glacier surfaces could contain a component of basal and/or englacial debris, giving potential for sampling of subglacial and/or englacial environments without deep drilling.

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