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

@fegbutcher

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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.

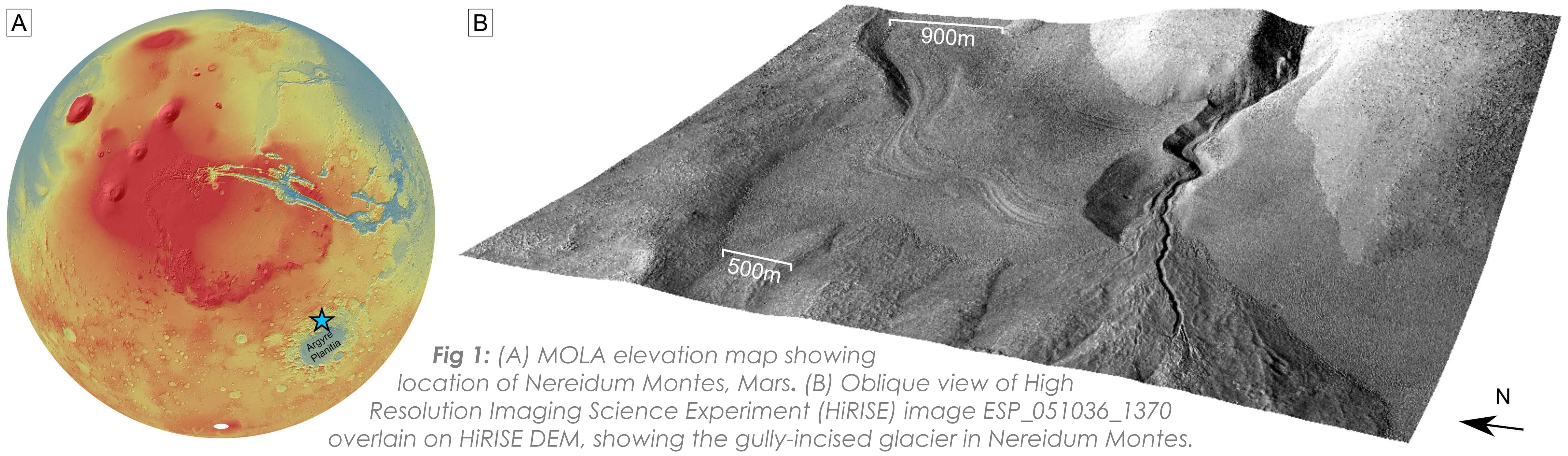


Fig 1: *(A) MOLA elevation map showing location of Nereidum Montes, Mars. (B) Oblique view of High Resolution Imaging Science Experiment (HiRISE) image ESP_051036_1370 overlain on HiRISE DEM, showing the gully-incised glacier in Nereidum Montes.*

The gully cuts through flowlines on the DCG surface, which are connected to DCG-internal structures exposed in the gully wall.

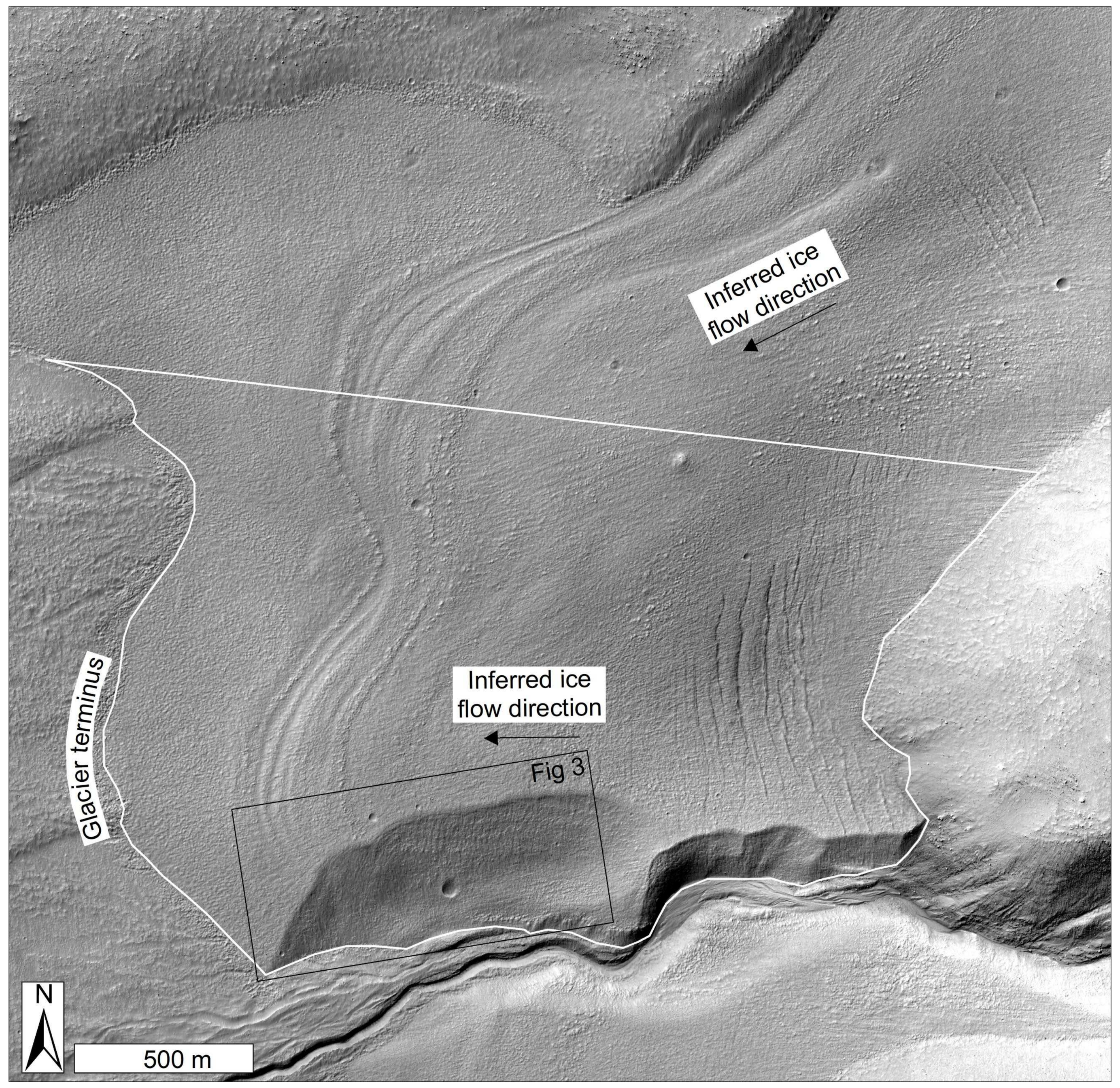


Fig 2: *Arcuate flow-transverse structures on the surface of the glacier, intersected by a gully incised subparallel to ice flow direction (right to left). Black box is extent of Fig 3. White line shows extent of model domain in Fig 5. HiRISE image ESP_051036_1370.*

- 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].

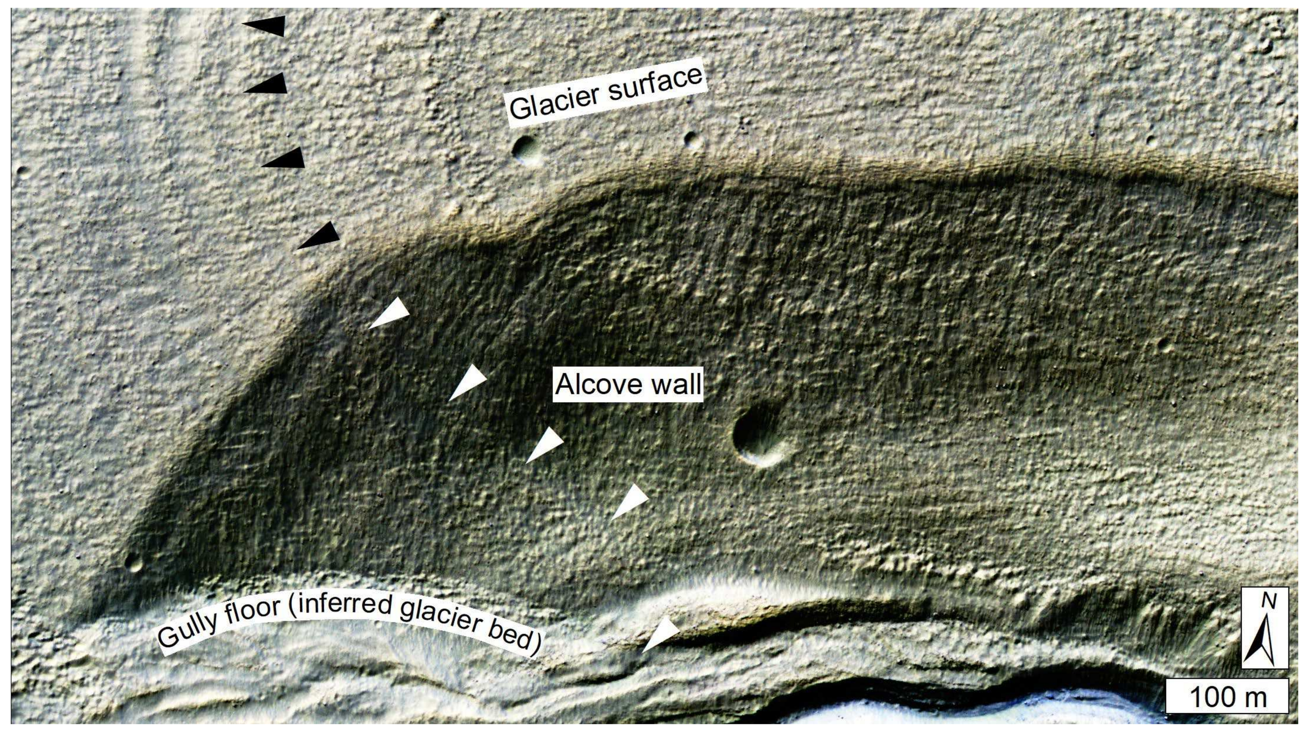
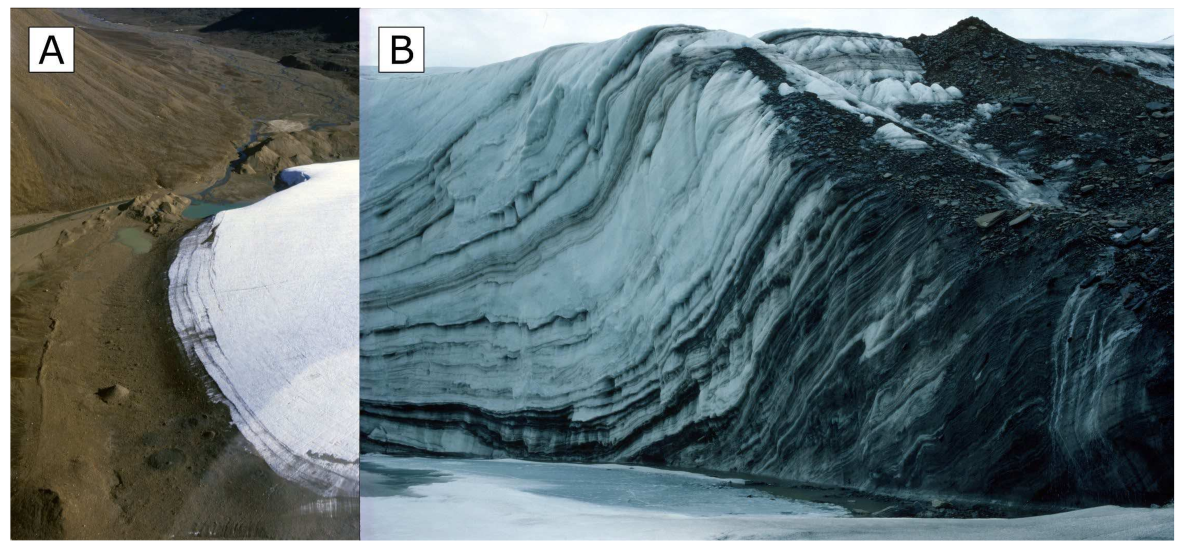


Fig 3: *HiRISE merged IRB image ESP_051036_1370 showing the colour signature of the DCG-internal structures (e.g. white arrows), and associated surface foliations (black arrows)*

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].

Fig 4: *(A) Aerial view of glacier flow compression lines, NW Ellesmere 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.*

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.**

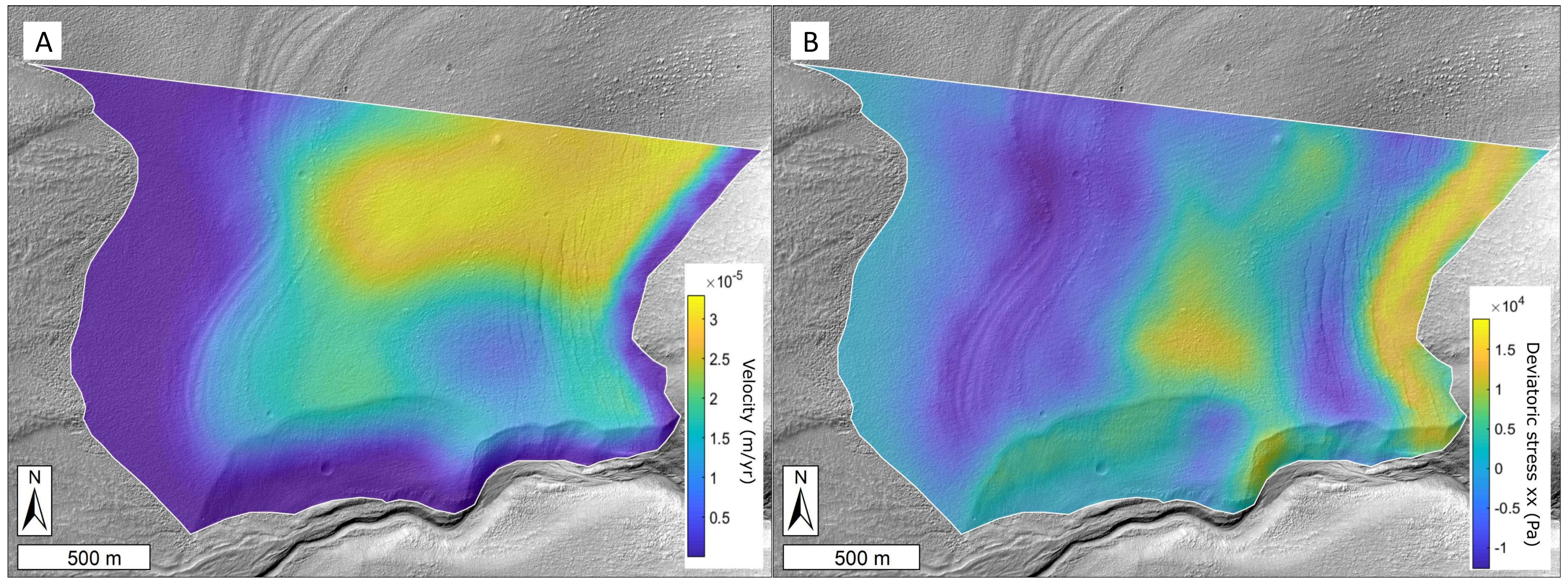


Fig 5: *Reconstructed velocity (panel A) and horizontal deviatoric stress (panel B) for the surface of the gully-incised DCG. Negative deviatoric stresses indicate longitudinal flow compression. Extent of model domain shown by white line in Fig 2. Basemap is HiRISE image ESP_051036_1370.*

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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