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

Frances E.G. Butcher¹, Neil S. Arnold², Dan C. Berman³, Susan J. Conway⁴, Joel M. Davis⁵, Matt. R. Balme⁶

¹The University of Sheffield, UK (f.butcher@sheffield.ac.uk), ²Scott Polar Research Institute, University of Cambridge, UK, ³Planetary Science Institute, Tuscon, USA, ⁴CNRS, Laboratoire de Planétologie et Géodynamique, Nantes, France, ⁵Natural History Museum, UK, ⁶The Open University, UK.



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.

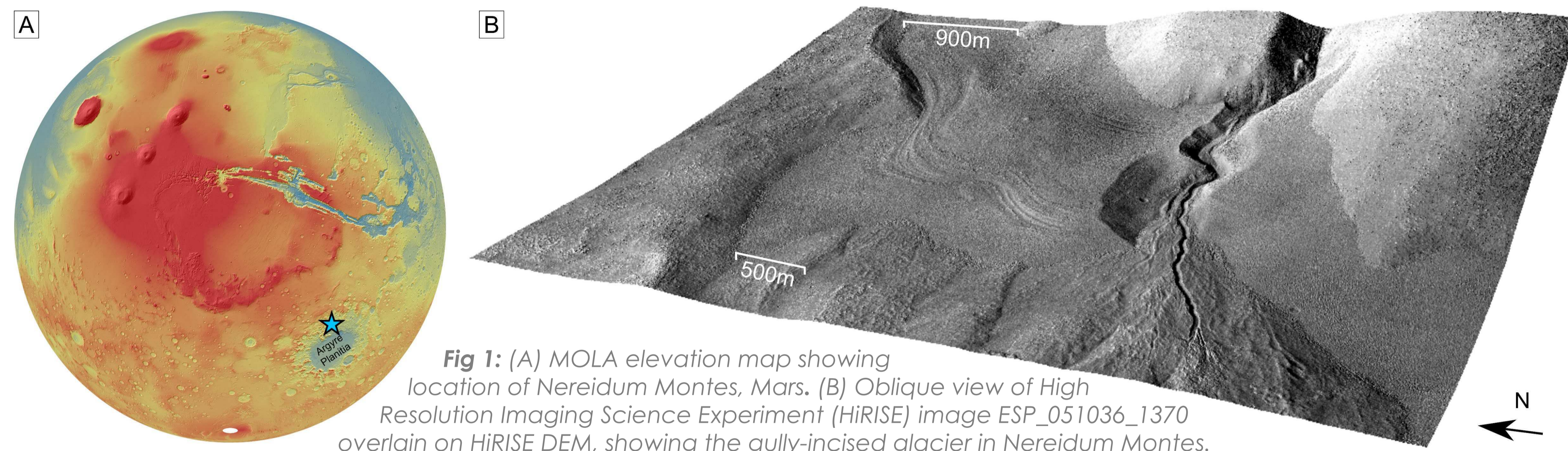


Fig 1: (A) MOLA elevation map showing location of Nereidum Montes, Mars. (B) Oblique view of High Resolution Imaging Science Experiment (HiRISE) image ESP_051036_1370 overlain on HiRISE DEM, showing the gully-incised glacier in Nereidum Montes.

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

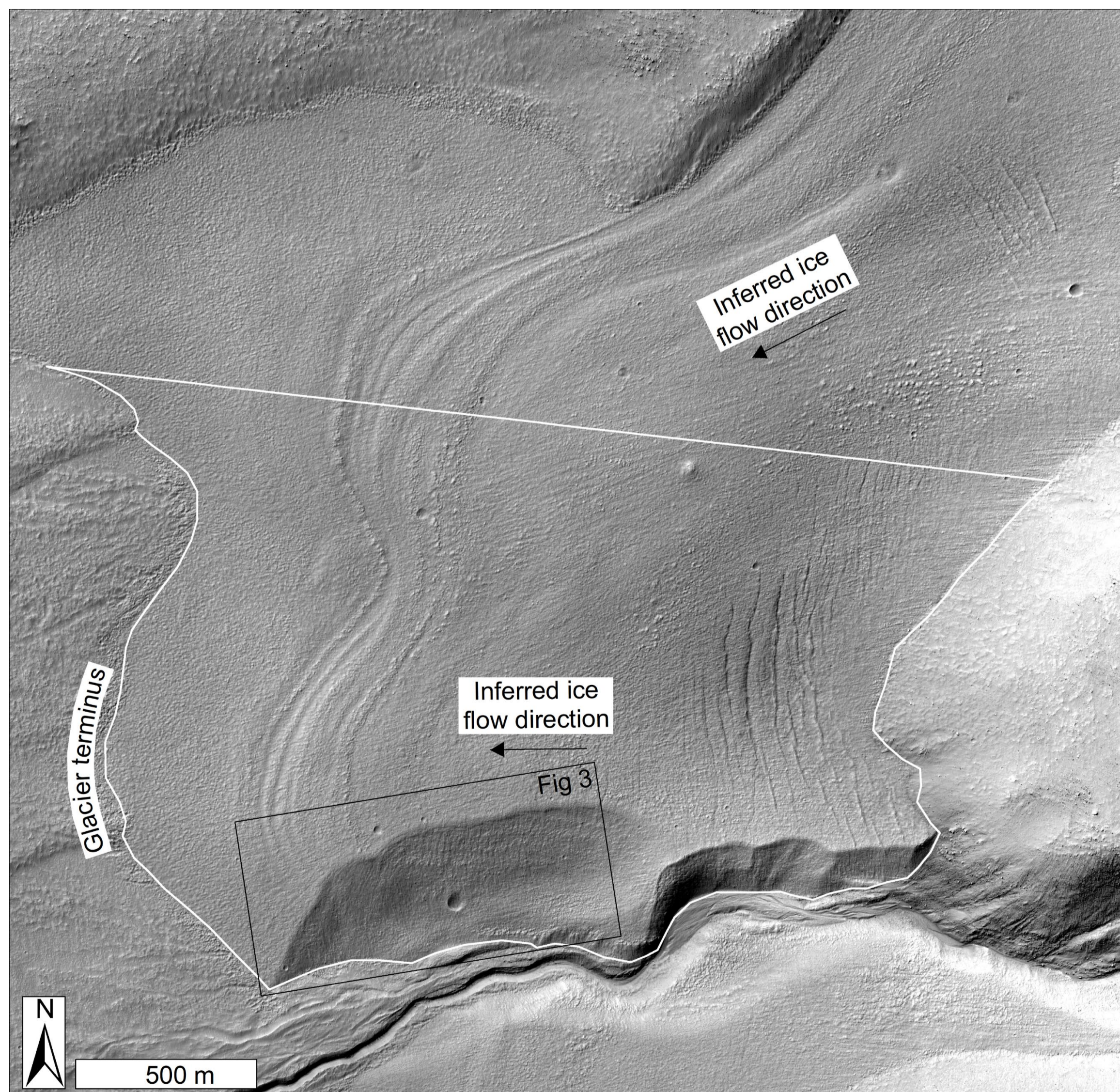


Fig 2: Arcuate flow-transverse structures on the surface of the glacier, intersected by a gully incised subparallel to ice flow direction (right to left). Black box is extent of Fig 3. White line shows extent of model domain in Fig 5. HiRISE image ESP_051036_1370.

- The flowlines (Fig 2) appear to have formed by **flow compression**.
- The internal structures (Fig 3) **dip up-glacier (NE)** at $\sim 20^\circ$ from the bed, which dips $\sim 12^\circ$ 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].

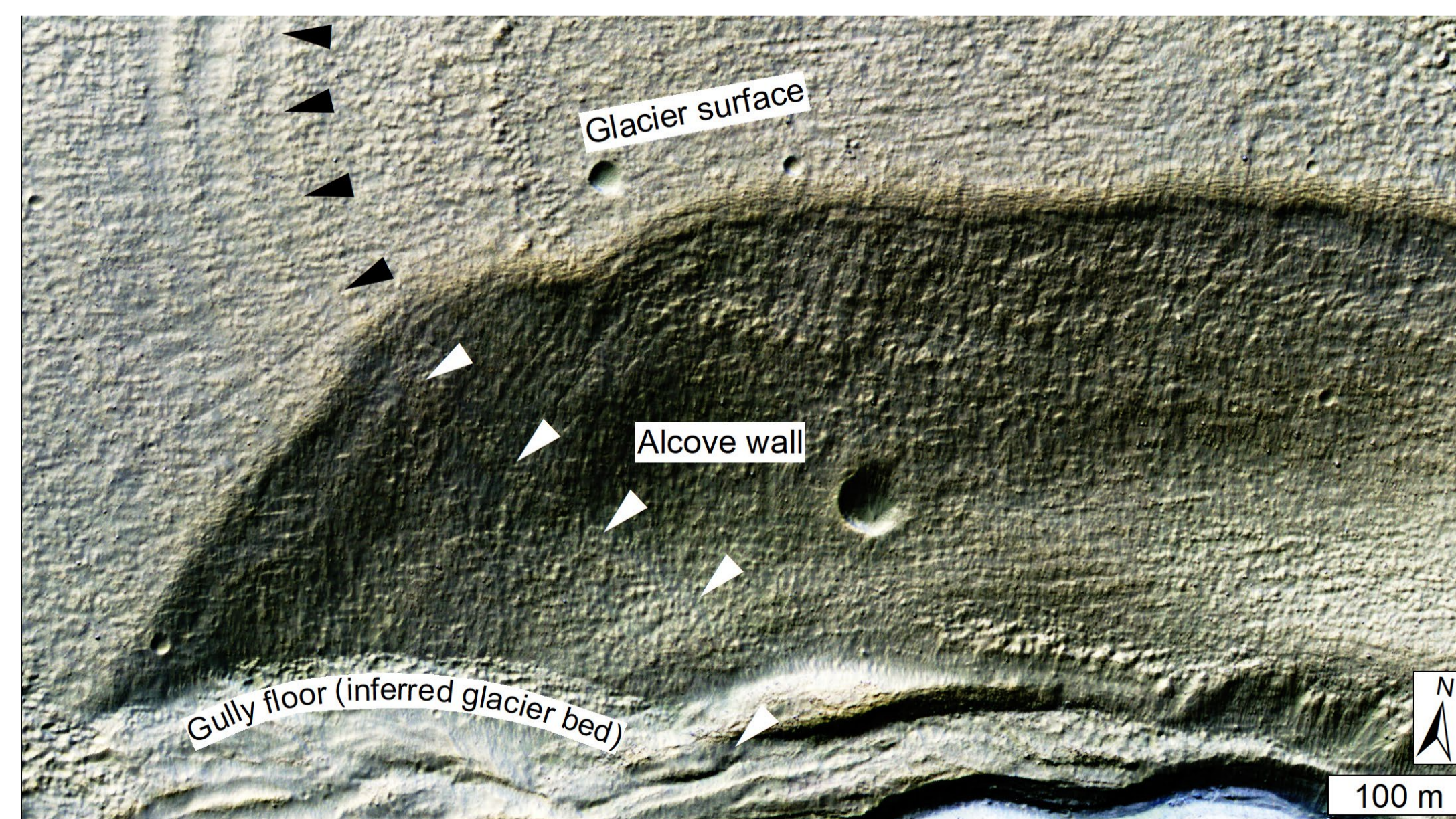


Fig 3: HiRISE merged IRB image ESP_051036_1370 showing the colour signature of the DCG-internal structures (e.g. white arrows), and associated surface foliations (black arrows)

On Earth, similar up-glacier-dipping internal structures often transport basal and en-glacial debris to glacier surfaces [e.g., 3–4].

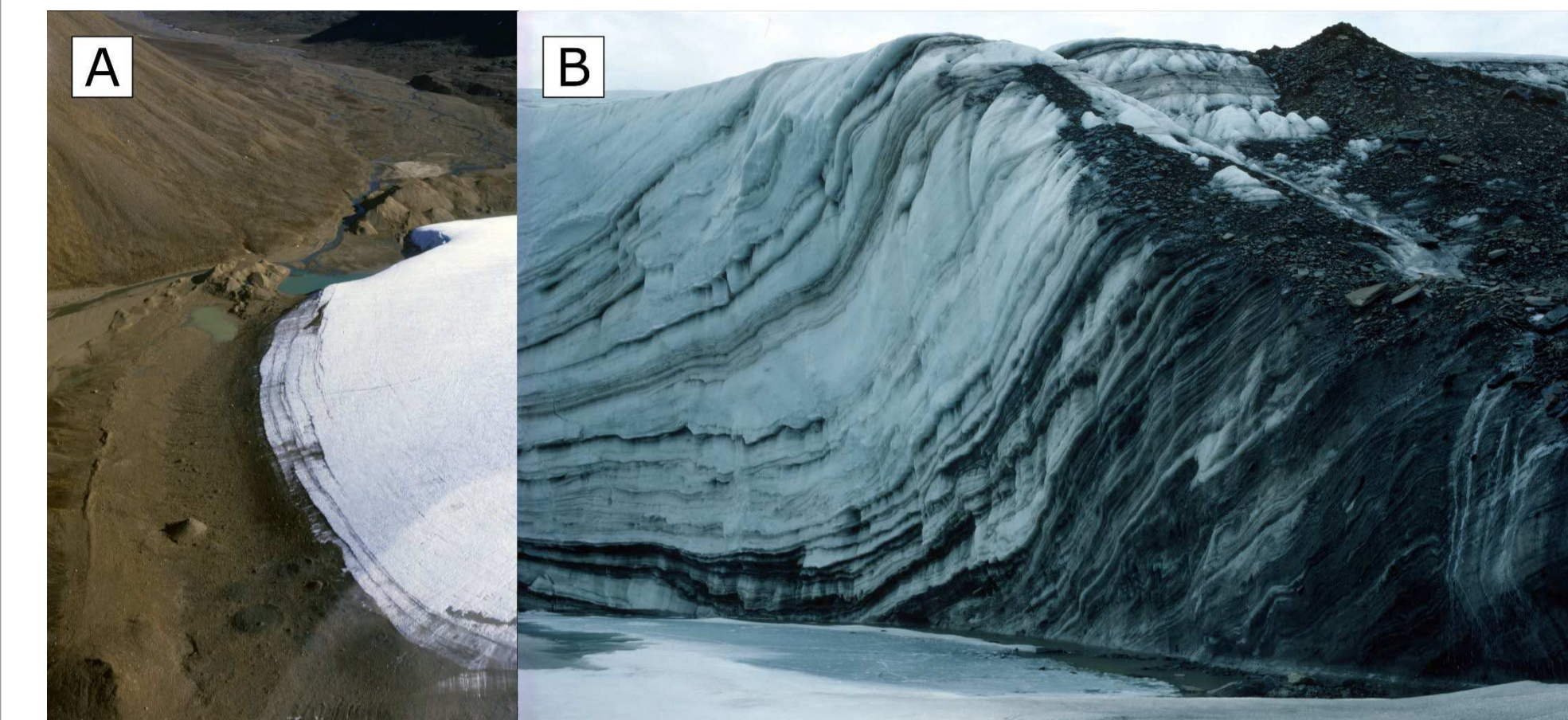


Fig 4: (A) Aerial view of glacier flow compression lines, NW Ellesmere Island. (B) Cliff exposure of up-glacier-dipping structures transporting basal debris to the surface features in A [5]. Images provided by D.J.A. Evans.

- **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 DCG-surface flowlines**.

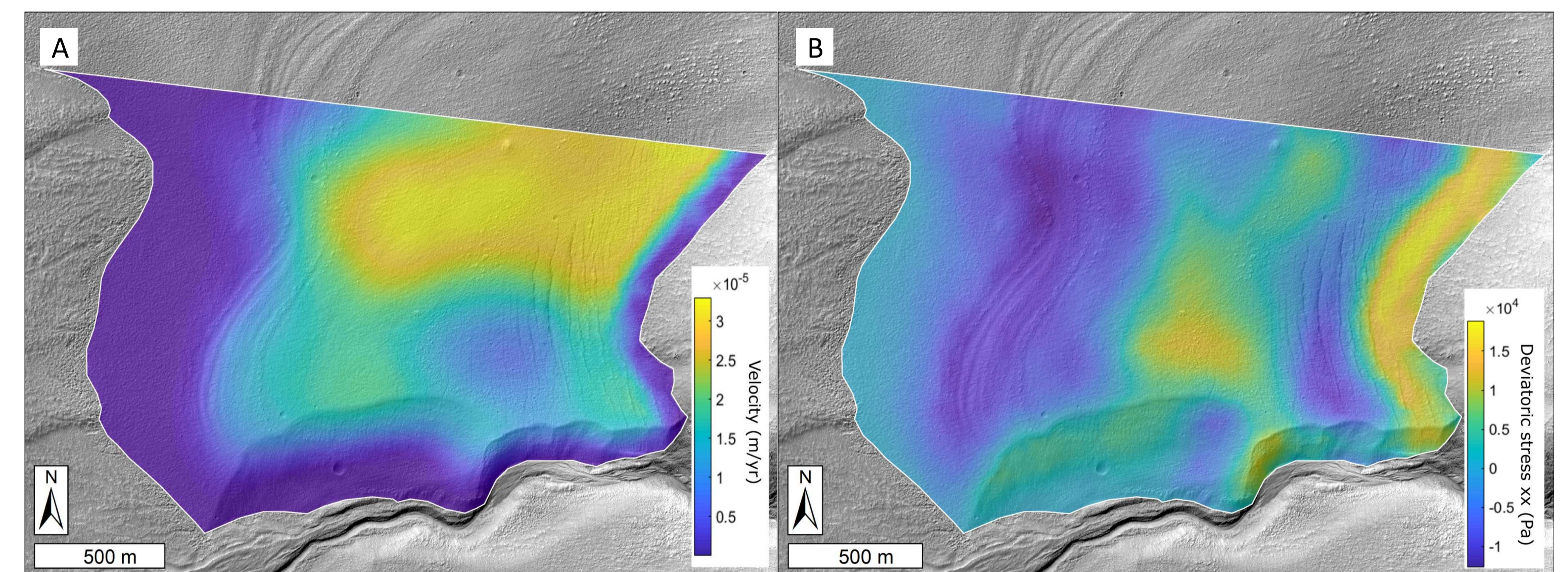


Fig 5: Reconstructed velocity (panel A) and horizontal deviatoric stress (panel B) for the surface of the gully-incised DCG. Negative deviatoric stresses indicate longitudinal flow compression. Extent of model domain shown by white line in Fig 2. Basemap is HiRISE image ESP_051036_1370.

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**.