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Megascale glacial lineations under Thwaites Glacier, West Antarctica

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Megascale glacial lineations (MSGLs) are kilometer-scale, or longer, flow-parallel subglacial ridges that are commonly found in previously glaciated terrain. Although a relatively ubiquitous subglacial landform, there is no widely-accepted formation mechanism, partially due to few observations of active MGSLs forming and evolving under currently streaming ice flow. Previously posited formation mechanisms include subglacial water erosion into soft beds, keels of ice plowing troughs into soft sediment, and various bed instability mechanisms, where variations in normal stress due to varying topography or sediment rheology result in some balance of excavation of troughs and construction of ridges in the sediment. Recent work has suggested that ribbed moraines, drumlins, and MSGLs form a continuum of subglacial landforms (Barchyn et al., 2016). Under this hypothesis, all of these landforms are formed by pressure gradient-driven flux into a subglacial cavity, but the length and form of the landform are dictated by the size of the cavity and availability of the sediment, which are functions of ice speed, obstacle size and nature (whether topographical or rheological), and subglacial pressure gradient. Data to assess this hypothesis were previously unavailable, as detailed subglacial topography under an area of currently streaming ice flow with similar geology but variable ice speed was needed.

Here we present two detailed gridded subglacial topographies from Thwaites Glacier, West Antarctica obtained from ice-penetrating radar measurements. One grid is located $\sim$170 km downstream from the ice divide where ice is moving $\sim$100 m/yr. The second grid is located $\sim$300 km downstream of the ice divide where the ice is moving $\sim$350 m/yr. Despite a somewhat similar subglacial setting, no subglacial lineations are observed in the upstream grid, while extensive multiscale subglacial lineations are observed in the downstream grid. This suggests that MSGLs are formed only under fast-flowing (>150 m/yr) ice, which agrees with the landform-continuum formation hypothesis. Where lineations are present in our downstream grid, they occur downstream of bumps in bed topography. We suggest that under steady-state conditions the water pressure in these subglacial cavities is approximately equal to the water pressure at the downstream end of the cavity. Then cavity (and thus lineation) length will be a function of the pressure gradient between the cavity and the surrounding grounded ice. Thus, given knowledge of surface topography and ice thickness, cavity closure rates via ice creep, basal ice velocity, and lineation length, pressure gradients driving till into the cavity can be calculated (i.e. for a 0.1% surface slope, a 10-km long cavity results in a 1 bar pressure drop at the upstream end of a cavity relative to the glaciostatic pressure). We apply this simple model of cavity pressure to our observed lineation lengths under Thwaites Glacier to calculate subglacial water pressure variation, and discuss complications, such as stress reduction via bridging, which may result in deposition of especially soft sediments on lineation peaks and water routing along and into lineation axes.