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Concentrated englacial shear over rigid basal ice, West Antarctica: implications for modelling and ice sheet flow

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Basal freeze-on, deformation and ice crystal fabric re-organisation have been invoked to explain thick, massive englacial units observed in the lower ice column of both the Antarctic and Greenland ice sheets. Whilst recognised as having very different rheological properties to overlying meteoric ice, studies assessing the impact of these basal units on the large-scale flow of an ice sheet have so far been limited.

We report the discovery of a previously unknown, extensive (100 km long, more than 25 km wide, and up to 1 km thick) englacial unit of near-basal ice beneath the onset zone of the Institute Ice Stream, West Antarctica. Using radio-echo sounding observations, we describe the form and physical characteristics of this englacial unit, and its impact on the stratigraphy and internal deformation of the overlying ice.

The lower englacial unit, characterised by a highly-deformed to massive structure, is inferred to be rheologically distinct from the overlying ice column. The overlying ice contains a series of englacial 'whirlwind' features, which are traceable and exhibit longitudinal continuity between flow-orthogonal radar lines. In our data, these whirlwinds are the representation of englacial layer buckling, and therefore provide robust evidence for enhanced ice flow. The interface between the primary ice units is sharp and abrupt, and at a macro-scale is characterised by a series of high-amplitude long-wavelength undulations. Immediately above this interface, whirlwind features are deformed and display evidence for flow-orthogonal horizontal shear, consistent with the deformation of the overlying ice across the basal ice unit. This phenomenon is not a local process, it is observed above the entirety of the currently mapped extent of the basal ice, nor is it dependent on flight orientation, the direction of shear is consistent regardless of flight orientation.

These findings have clear significance for our understanding and ability to realistically model ice sheet flow. Our observations suggest that, in parts of the onset zone of the Institute Ice Stream, the flow of the ice sheet effectively ignores the basal topography. Instead, enhanced ice flow responds to a pseudo-bed, with internal deformation concentrated and terminating at an englacial rheological interface between the upper ice sheet column and the massive basal ice. Although we cannot entirely rule out basal accretion as the cause of the strong englacial interface and thick basal layer, discrete englacial shearing acting to realign ice crystals, may be the best explanation for the basal unit in this case.

Our results demonstrate that we will, at the very least, need to adapt numerical models of those parts of the ice sheet with extensive and thick basal ice units, and that we may even need to carefully reconsider existing schematic models of ice flow, to incorporate processes associated with concentrated englacial shear.