Distribution of hydraulic damage from overpressure beneath the rapidly retreating margin of the last Fennoscandian ice sheet in Uppland, Sweden

Mikis van Boeckel[a], Adrian Hall[b], Christian Öhrling[c]

[a]Geological Survey of Norway, Trondheim, Norway, mikis.van-boeckel@ngu.no

[b]Institute of Geography, University of Edinburgh, Drummond Street, Edinburgh, Scotland, adrian.hall@ed.ac.uk

[c]Geological Survey of Sweden, Uppsala, Sweden, christian.ohrling@sgu.se

Abstract

Understanding processes that operate beneath rapidly melting ice margins is critical for predicting the responses of the ice sheets to anthropogenic global warming. Where large or rapid meltwater inputs arrive at the ice sheet bed, ice flow may temporarily accelerate, and meltwater flow mobilises and erodes sediment. Where the capacity of subglacial conduits is reached, water pressures may briefly exceed ice-overburden pressure (Pw>Pi) and water can laterally burst out of the conduit. Yet the timing and distribution of overpressure beneath former Northern Hemisphere ice sheets remains largely unknown. Here we examine patterns of overpressure development during final retreat of the Fennoscandian ice sheet across low relief, Precambrian basement terrain in Uppland, Sweden. We first integrate evidence from digital elevation models, aerial photos and field survey observations with existing map data on landforms and sediment from the Swedish Geological Survey to identify and delimit subglacial drainage pathways. We then add markers for hydraulic damage at the ice sheet bed that include rock hydrofractures, brecciated rock surfaces, and associated boulder spreads, and disrupted and partially disintegrated roches moutonnées to reveal where large volumes of subglacial meltwater reached overpressure.

Elevated areas of Uppland generally lack meltwater flow traces, retain till cover, and carry undamaged precursor rock surfaces. These are interpreted as zones of low volume, distributed subglacial drainage. In contrast, crossing meltwater corridors, 0.4-4 km wide, with up-down centerline profiles indicate high-volume and high-pressure meltwater flow. Meltwater corridors include fracture-controlled rock trenches that acted as Nye-channels, esker tunnels that functioned as Röthlisberger-channels and elongate hummock tracts that drained sheets and jets of meltwater beneath the retreating ice margin.

Hydraulic damage is scarce in zones of low volume distributed subglacial drainage. Hydraulic damage from overpressure is also absent from 1-20 km long rock trenches along the edge of the Åland Deep rock basin and from 0.5-10 km long segments of N- and R- channels. Despite availability of large volumes of meltwater in these former conduits, overpressured conditions did not develop. Here, subglacial meltwater was efficiently drained along hydraulically well-connected rock channels and crossing rock trenches. In contrast, other 4-40 km long segments of meltwater corridors carry hydraulic damage consistent with transient development of overpressure at full pipe flow. Sharp lateral and vertical boundaries to hydraulic damage are observed that are interpreted to represent the maximum local extent of sheetflow caused by overpressured sediment-laden water. Abrupt terminations and onset zones for hydraulic damage are consistent with the development of transient subglacial water pressures by sudden transfer of large volumes of supraglacial meltwater to the glacier bed as the ice margin retreats. We find that the role of overpressured meltwater is critical for understanding erosion of rock, mobilisation, transport and deposition of subglacial sediment, and formation of subglacial landforms beneath rapidly thawing ice margins.