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Implications of sediment transport by subglacial water flow for interpreting contemporary glacial erosion rates

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The role of glaciers in landscape evolution is central to the interactions between climate and tectonic forces at high latitudes and in mountainous regions. Sediment yields from glacierized basins are used to quantify contemporary erosion rates on seasonal to decadal timescales, often under the assumption that subglacial water flow is the main contributor to these yields. Two recent studies have furthermore used such sediment fluxes to calibrate a glacial erosion rule, where erosion rate scales with ice sliding speed raised to a power greater than one. Subglacial sediment transport by water flow has however seldom been studied, thus the controls on sediment yield from glacierized basins remain enigmatic. To bridge this gap, we develop a 1-D model of morphodynamics in semi-circular bedrock-floored subglacial channels. We adapt a sediment conservation law from the fluvial literature, developed for both mixed bedrock / alluvial and alluvial conditions, to subglacial channels. Channel evolution is a function of the traditional melt-opening due to viscous heat dissipation from the water flow, and creep closure of the overlying ice, to which we add the closure or enlargement due to sediment deposition or removal, respectively.

Using a simple ice geometry representing a land-terminating glacier, we find that the shear stresses produced by the water flow on the bed decrease significantly near the terminus. As the ice thins, creep closure decreases and large hydraulic potential gradients cannot be sustained. The resulting gradients in sediment transport lead to a bottleneck, and sediment accumulates if the sediment supply is adequate. A similar bottleneck occurs if a channel is well established and water discharge drops. Whether such constriction happens in space of time, in the presence of a sufficiently large sediment supply sediment accumulates temporarily near the terminus, followed shortly thereafter by enhanced sediment transport. Reduction in the cross-sectional area of the channel by sediment storage leads to enhanced shear stresses and transport rates. As a result, assuming a constant sediment input and a seasonal water forcing sediment delivery to the proglacial environment undergoes two phases determined by a combination of meltwater discharge and channel development. In the stage of the melt season dominated by channel growth and increasing discharge, the sediment yield is virtually constant and matches the input. In contrast, during the stage dominated by channel closure and decreasing discharge the sediment yield exhibits daily fluctuations caused by temporary sediment storage in the channel.

Our findings thus suggest that contemporary sediment yields may be controlled by the dynamics of subglacial water flow in the vicinity of the terminus. This provides a new perspective for the interpretation of proglacial sediment fluxes, fluxes which are central to refining glacial erosion laws utilized in landscape evolution models.