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Numerical modelling of esker formation in semi-circular subglacial channels

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Eskers hold valuable information about past subglacial hydraulic conditions in their spatial organization, geometry, and sedimentary structures. The relations between hydraulic conditions and esker properties are nevertheless intricate as the formation of eskers has been mainly inferred from descriptive theories, about which a consensus has yet to be reached. Eskers are prevalent in areas of rigid bed and thin till cover and their formation is thought to be predominantly controlled by either water or sediment availability. In this study, we develop a 1-D numerical model of sediment transport in semi-circular bedrock-floored channels to explore the physical processes leading to esker formation. The model encompasses channel evolution by melt-opening created by the viscous heat dissipated as water flows, the creep closure of the ice walls, and changes in cross-sectional area due to sediment accumulation and removal.

We find that a bottleneck in sediment transport close to the terminus is an inherent characteristic of subglacial channels. Creep closure is reduced as the ice thins towards the terminus and hydraulic potential gradients decline, thus reducing shear stresses. This bottleneck is accentuated when water discharge drops in a well established channel. We find the conditions most conducive to sediment deposition are low ice-surface slopes within several kilometres of the terminus and water discharge fluctuations over a few to several weeks. The model also produces shear stresses large enough to transport boulders under typical melt-season conditions. Our results thus suggest that incipient eskers form toward the end of the melt season, provided water input and sediment supply are sufficient. Overall these findings corroborate the theory that eskers are formed progressively during the waning stage of an ice sheet, although we suggest that eskers are a natural manifestation of the subglacial hydraulic system in the presence of an adequate trade-off between sediment transport capacity and supply. Because sediment transport capacity by channelized subglacial water flow is driven by a combination of sediment size, ice thickness and surface slope, and the rate and volume of water input, we posit that water availability is too simplistic an indicator of the spatial organization of eskers. This model contributes to bridging the gap between different descriptive theories, toward a unifying theory for esker formation that will improve our ability to infer past subglacial hydraulic conditions.