Numerical modelling of esker formation in semi-circular subglacial channels

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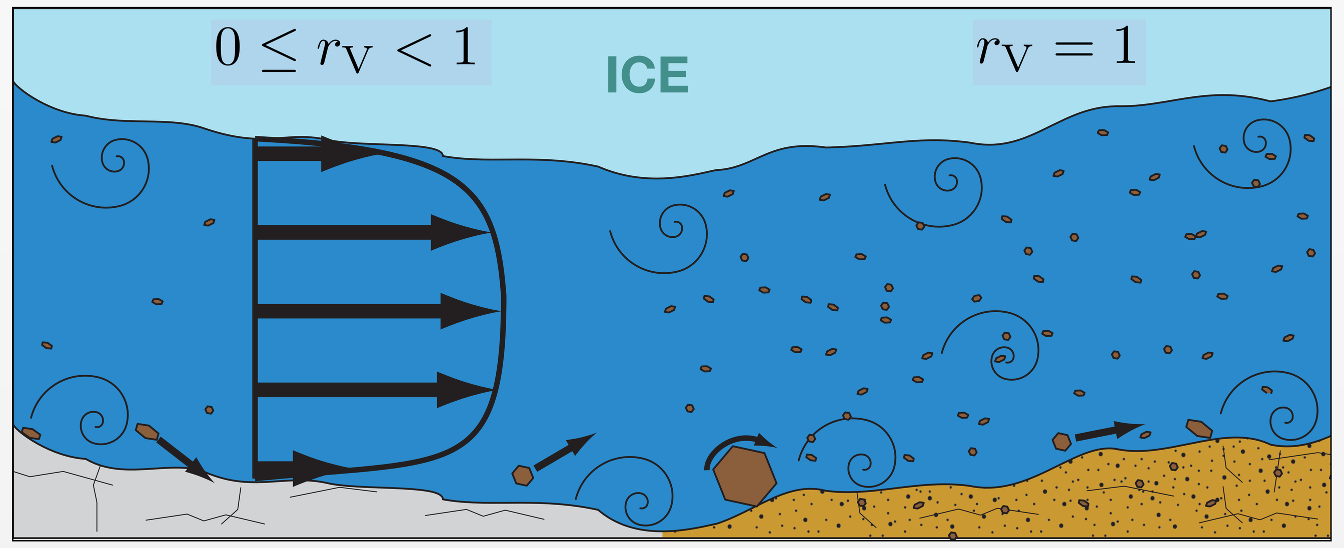
Framework for sediment transport in R-channels

Assumption:
Water flows through an R-channel fed by a moulin upstream. The bed of the R-channel is a mixed bedrock / alluvial channel and can be fully alluviated.



Mixed bedrock / alluvial channel

Numerical model:

Shear stress on the bed (Pa): $\tau_b \propto f_{bed} u_w^2$

Non-dimensional shear stress:

$$\tau^* = \frac{\tau_b}{(\rho_s - \rho_w) g D}$$

If $\tau^*/\tau_c^* \geq 1$, motion initiated.

Transport capacity per unit width (m²/s): $q_{tc} \propto D_{sed}^{3/2} (\tau^* - \tau_c^*)^{3/2}$

Volumetric rate sediment transport (m³/s): $q_t = q_{tc} r_V W_{ch}$

Sediment volume per unit length (m³/m): $V_s = (V_b + (1-\lambda)\eta_a) W_{ch}$

Channel closure by sediment deposition (m²/s): $v_s = \frac{\partial V_s}{\partial t} \frac{1}{1-\lambda}$

System of equations to solve (water conservation, evolution of channel cross-section and sediment conservation):

$$-\gamma S_{ch} \frac{\partial p_{ch}}{\partial t} = \frac{\partial Q_{ch}}{\partial x} + \frac{\Xi - \Pi}{L} \left(\frac{1}{\rho_i} - \frac{1}{\rho_w} \right) - v_{cc} - \dot{b}_{ch}$$

$$\frac{\partial S_{ch}}{\partial t} = v_{mo} - v_{cc} - v_s \qquad \frac{\partial V_s}{\partial t} = \frac{\partial q_t}{\partial x} + \frac{\partial q_{ls}}{\partial x}$$

Study summary

Motivation:
- Subglacial water flow deposits, here eskers, can help to understand present subglacial drainage systems

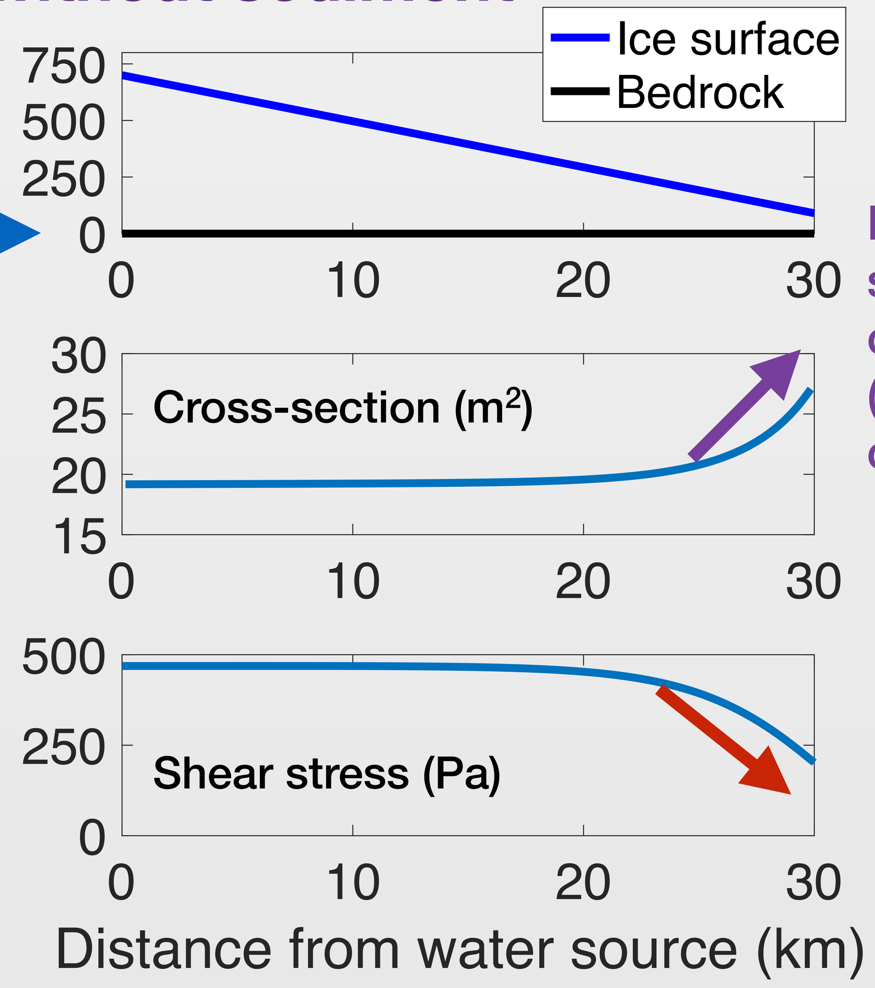
Problem:
- Little is know about sediment transport by subglacial water flow
- A better understanding of these processes would help bridge the gap between eskers and present-day subglacial drainage systems

Goal:
- Develop a numerical framework of sediment transport by water flow in R-channels and explore conditions conducive or detrimental to sediment deposition

Preliminary findings:
- Bottleneck in sediment transport is a natural feature of R-channels
- An incipient esker will form if the sediment supply exceeds the transport capacity at the terminus
- An incipient esker can form at the end of a melt-season
- The ice geometry has a significant influence on the shape of the incipient esker

Hydrology without sediment

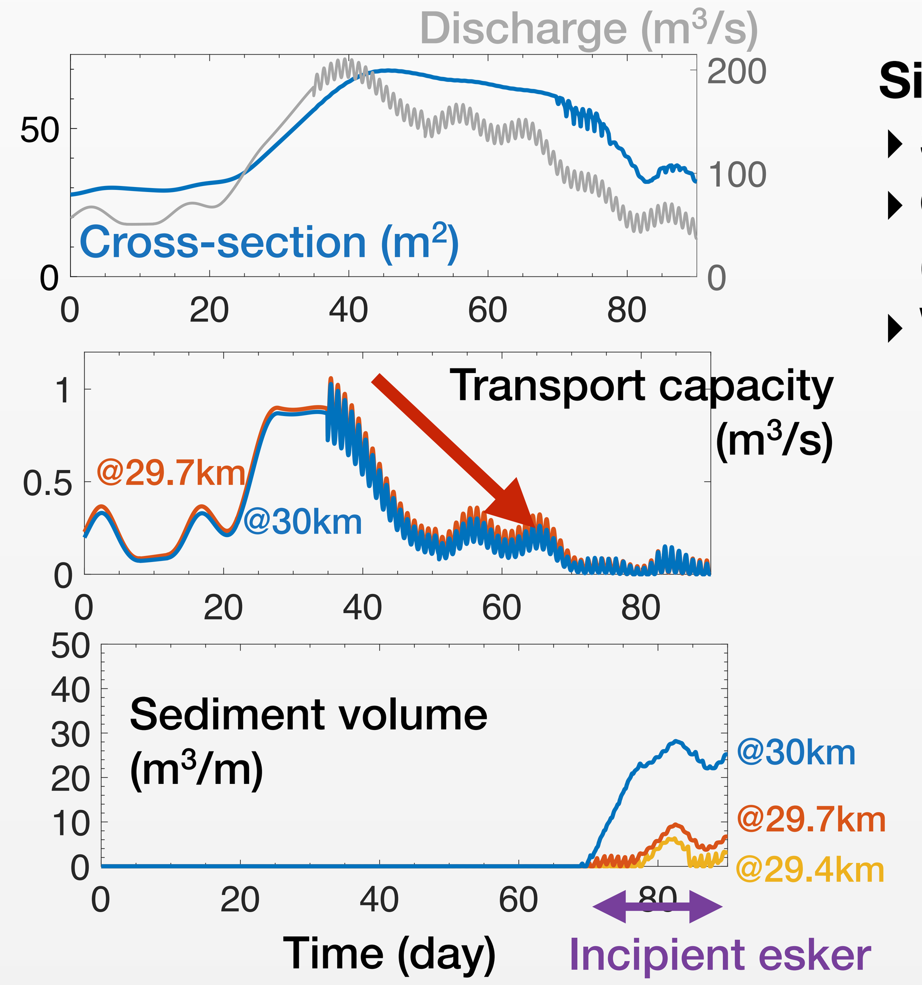
$Q_{ch} = 50\,\mathrm{m^3\,s^{-1}}$
Constant discharge fed from moulin upstream



Increase in cross section because of thinning ice (less creep closure)

Constant discharge with the changes in channel size lead to a drop in shear stress and bottleneck in sediment transport

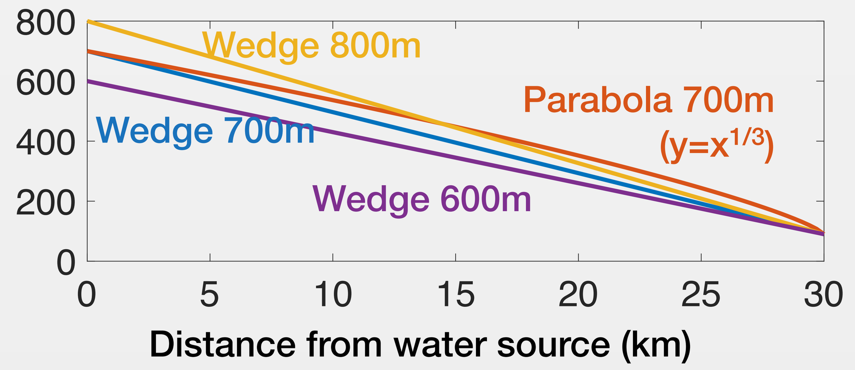
Sediment dynamics close to the terminus



Simulation set-up:
- Synthetic melt season
- Constant sediment input upstream (D_{sed} = 0.17m)
- Wedge-shape glacier

The drop in transport capacity leads to sediment accumulation close to the terminus and the deposition of an incipient esker

Ice geometry and incipient esker deposition



Simulation set-up:
- Same as above with synthetic melt-season
- Simulation run with 4 ice geometries

Results:
- Incipient esker forms for every simulation
- Steeper surface slopes lead to thicker sediment accumulation at 30 km
- Shallower surface slopes lead do deposition occurring further up-glacier

Evolution of incipient esker over time