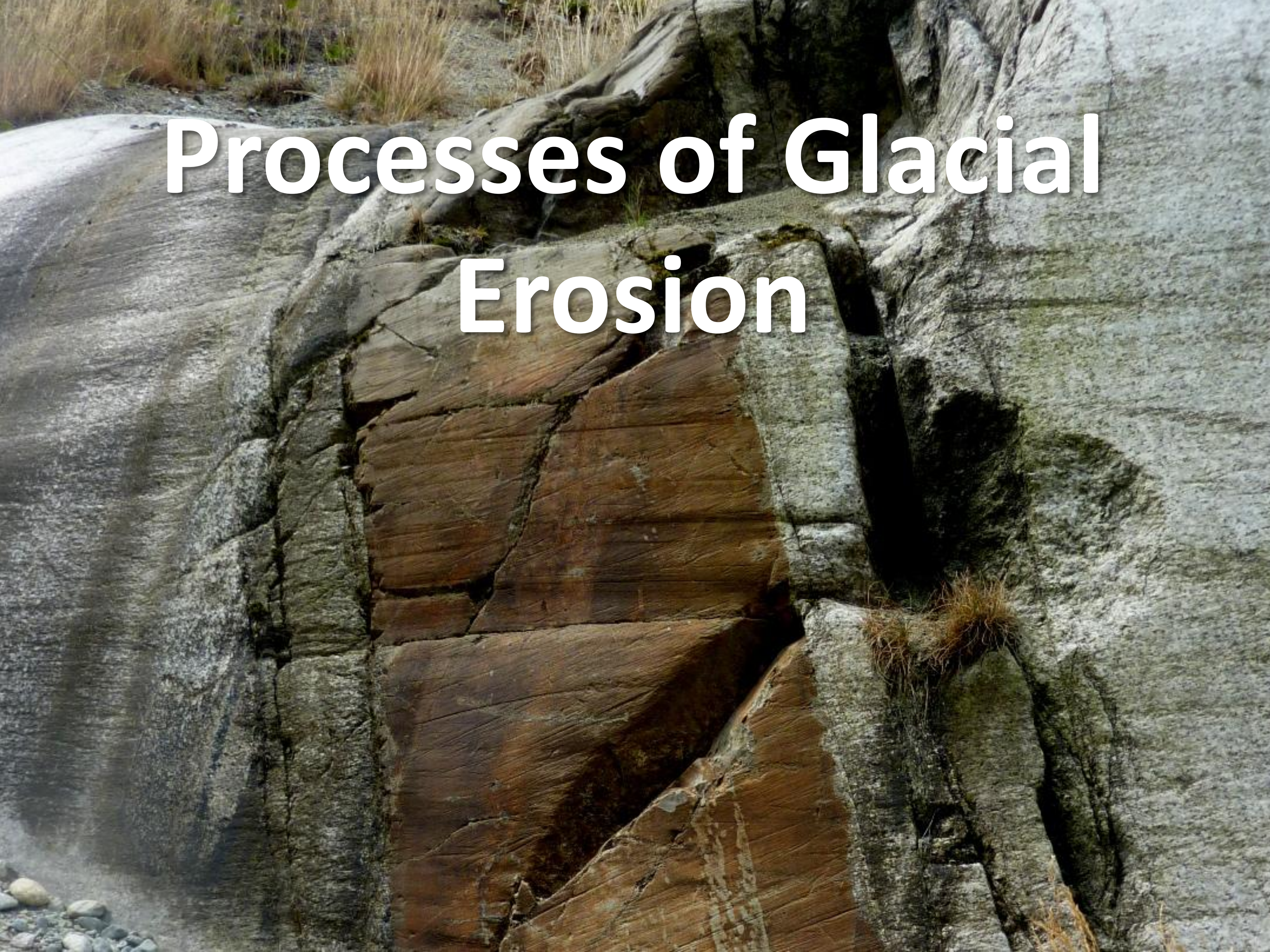
Processes of Glacial Erosion



Topics

Erosional processes

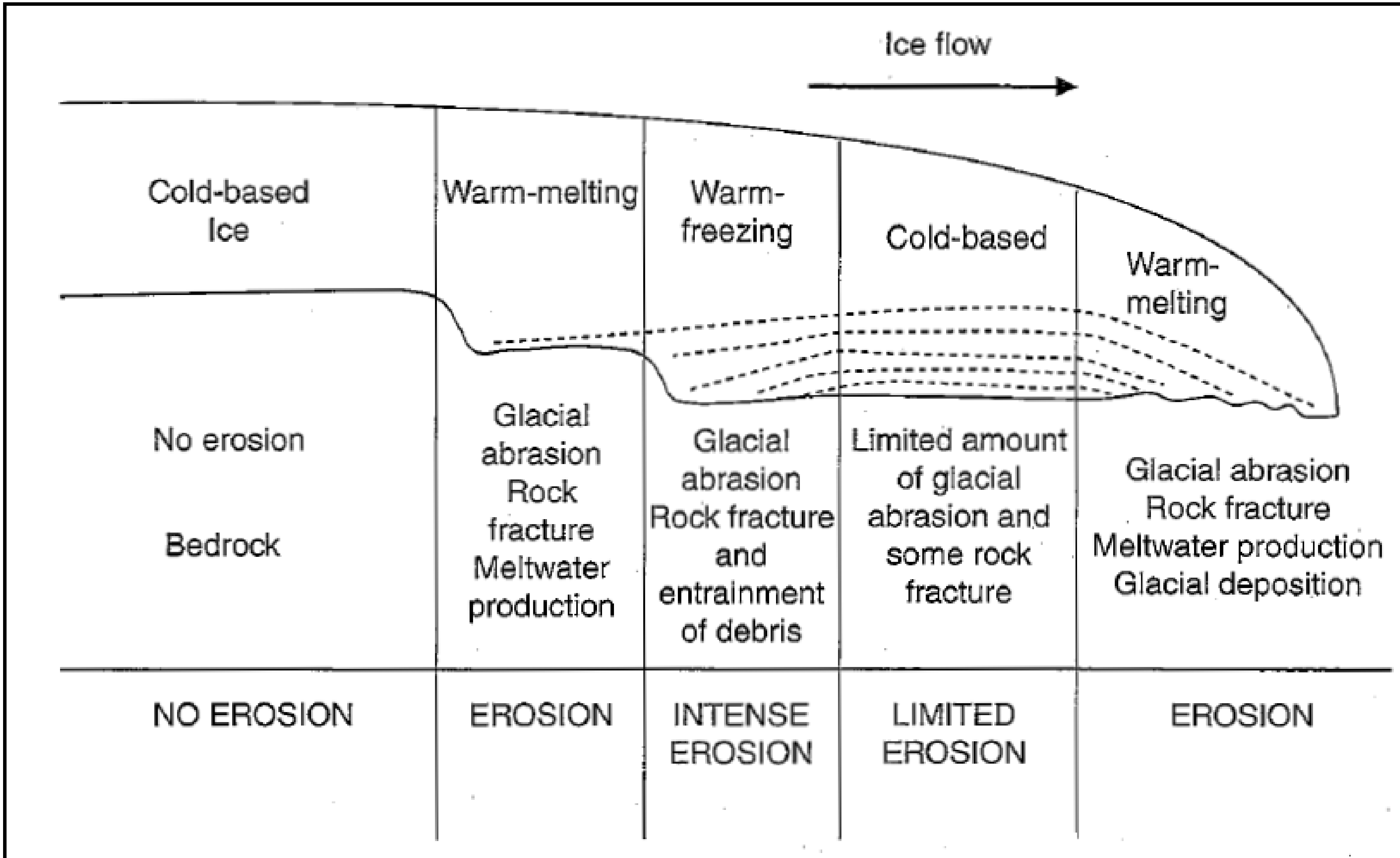
- conditions under which glaciers erode their bases
- models and mechanisms of erosion
- glacial quarrying
- particle entrainment

Erosional features

- micro-scale erosional features (striae etc.)
- meso-scale (e.g., roches moutonée, whalebacks)
- macro-scale (rock drumlins, cirques, U-valleys, arêtes etc.)
- rates of erosion (glaciers vs rivers)

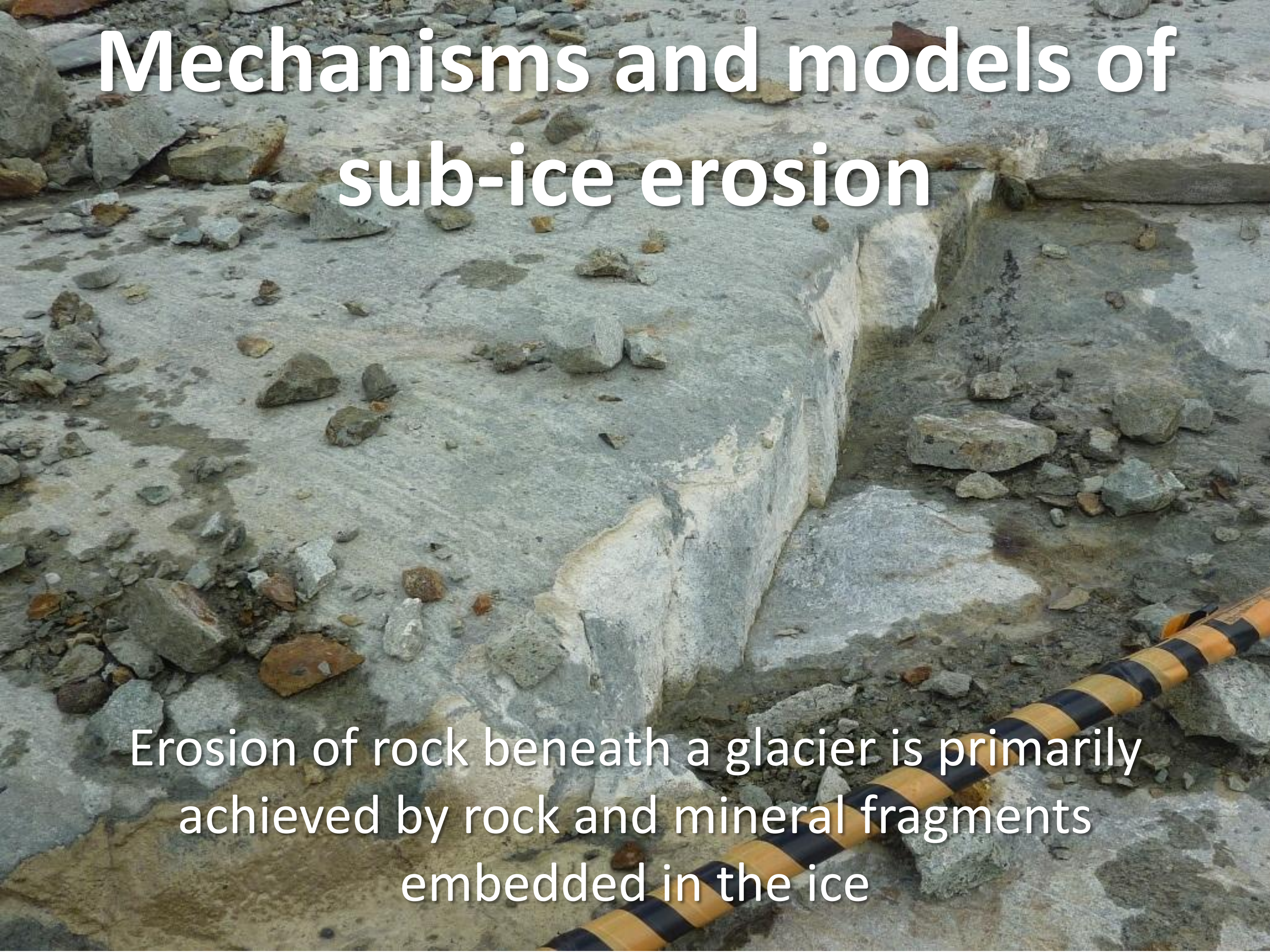
Conditions under which glaciers erode their bases effectively

- Glaciers with frozen bases do not generally slide along the ice-bed interface, and therefore do not erode their bases.
- In general greatest erosion is associated with warm-based glaciers that have basal melting.
- Transition from warm to cold (or water to ice) will contribute to quarrying.
- Fast-flowing glaciers are likely to erode more effectively than slow glaciers.
- Fluctuations in water pressure will promote quarrying
- In areas glaciated several times most of the glacial erosion may be completed during the first phase of glaciation.



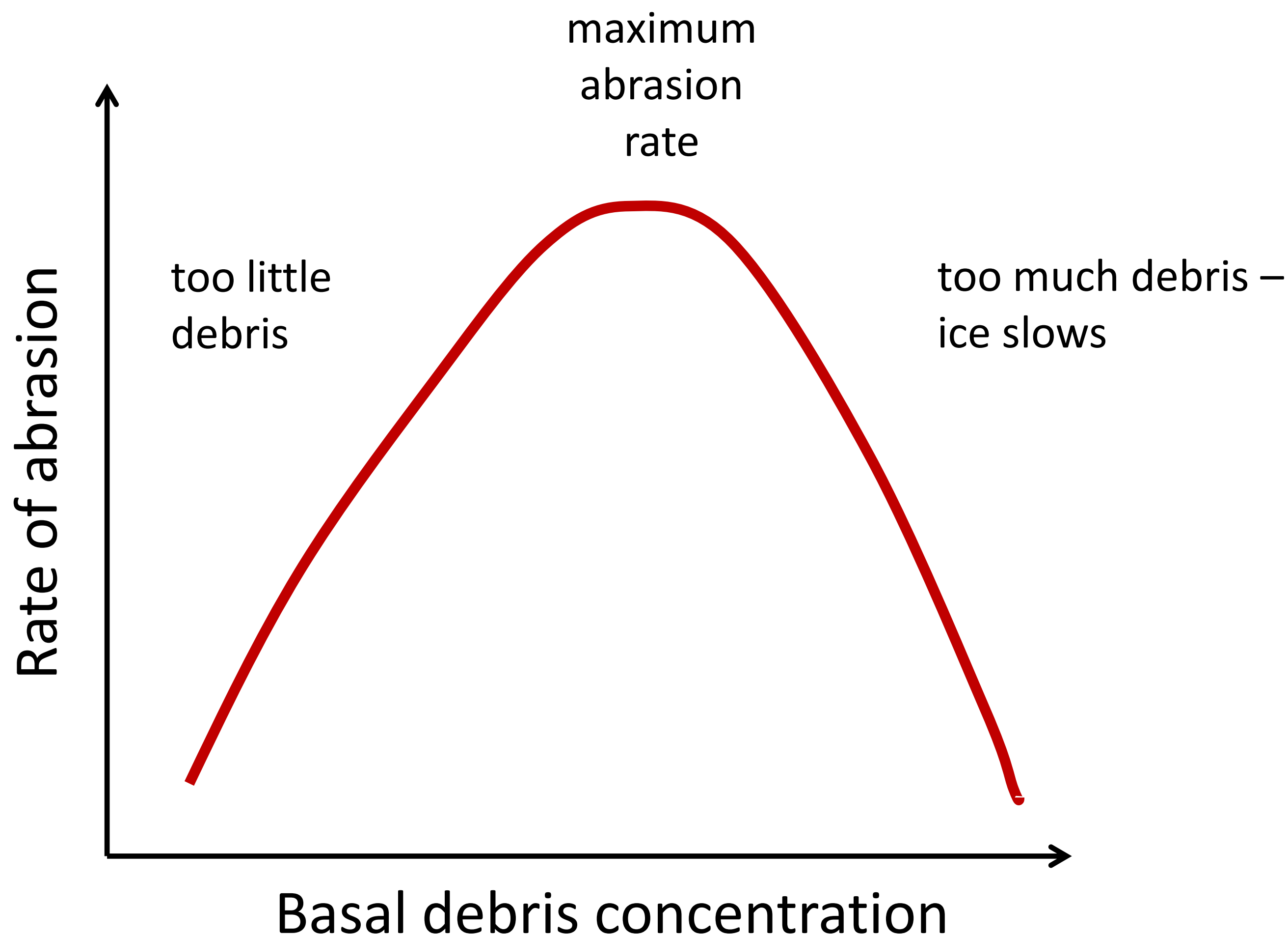
After Bennett and Glasser, 2009

Mechanisms and models of sub-ice erosion



Erosion of rock beneath a glacier is primarily achieved by rock and mineral fragments embedded in the ice

Abrasion rate vs ice-debris concentration

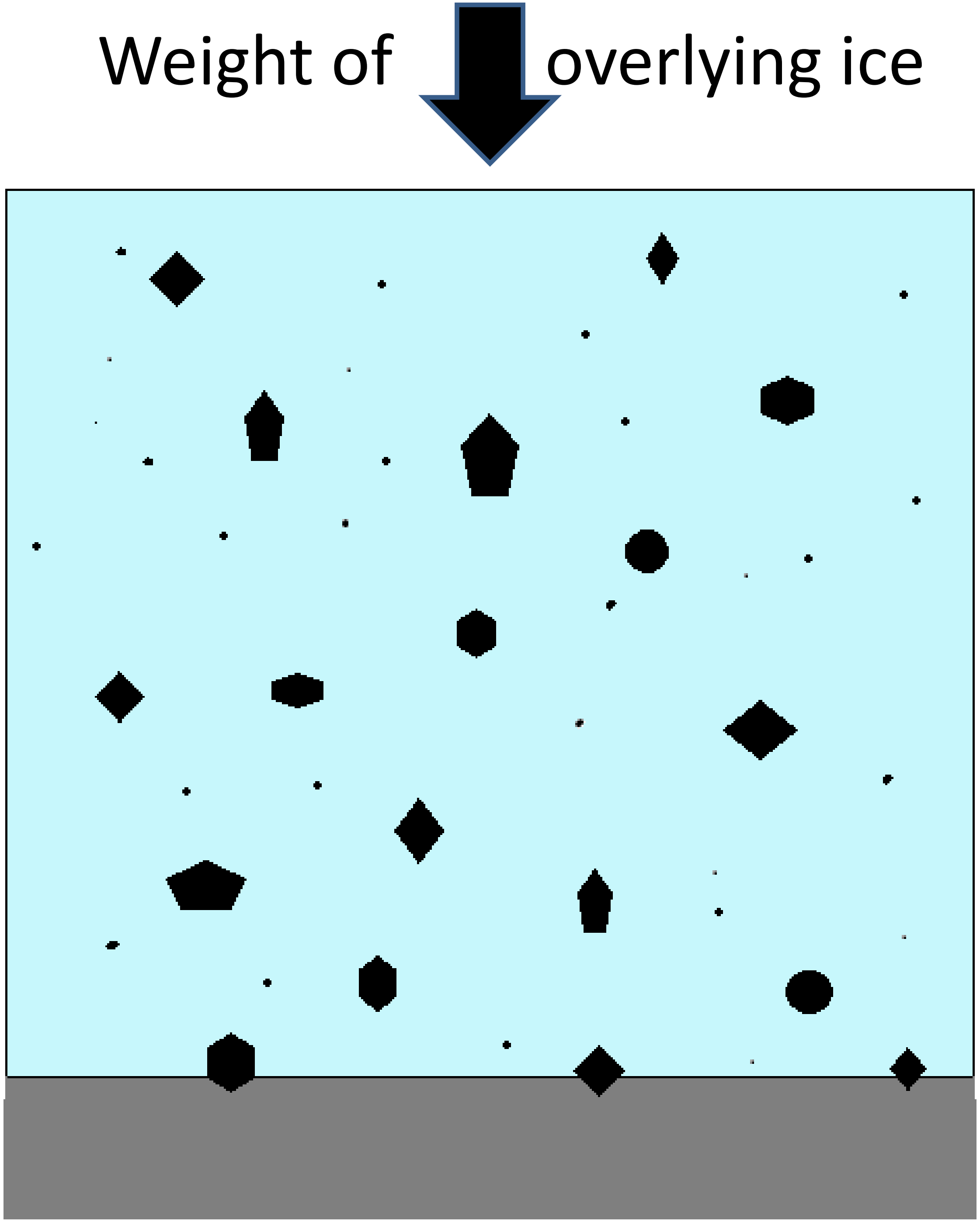


Modified after Bennett and Glasser, 2009

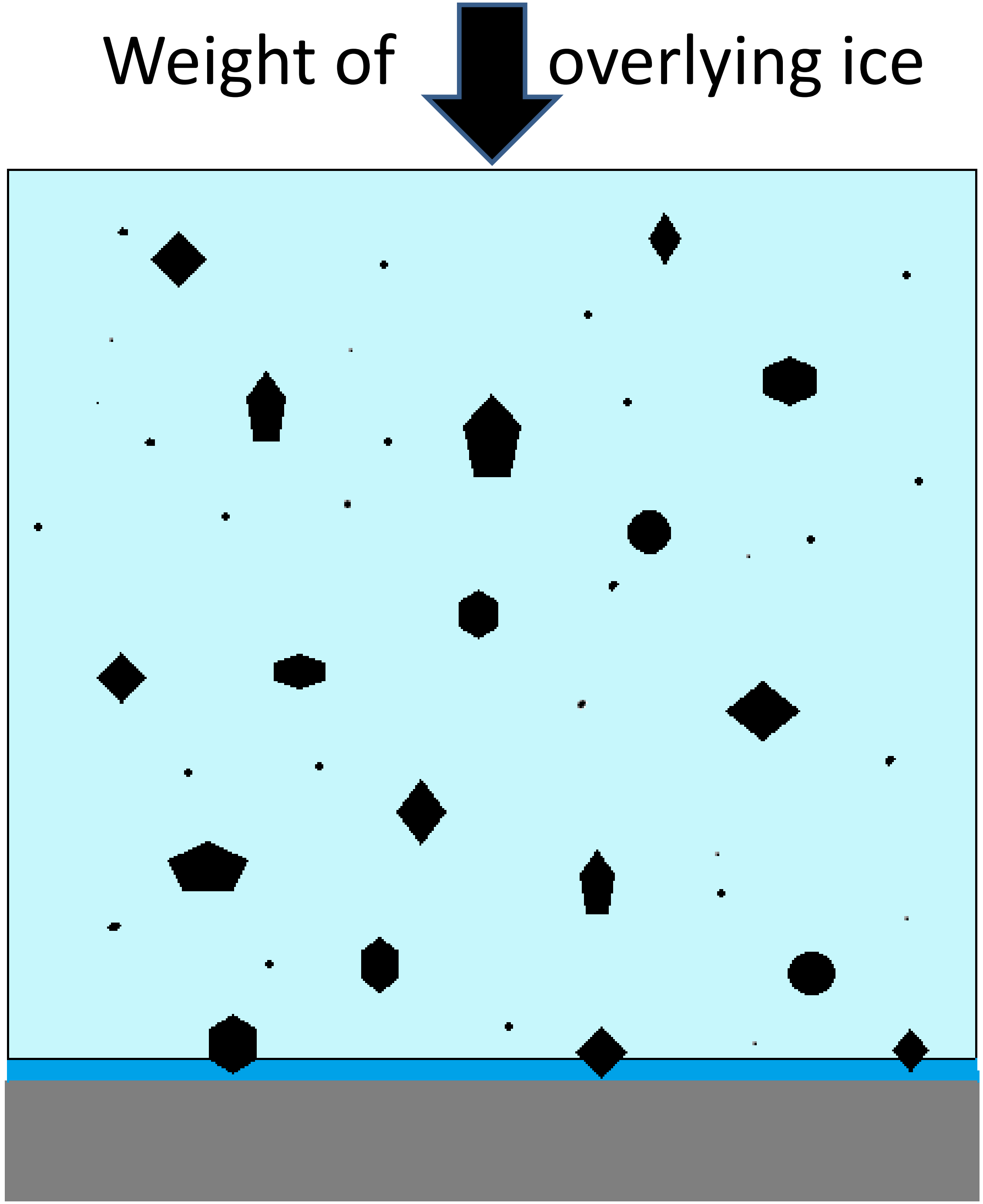
Boulton model

- “effective normal pressure” (weight of overlying ice minus basal water pressure) will affect the rate of abrasion
- increasing basal water pressure increases the rate of basal sliding but decreases the effective normal pressure
- ice with more rock fragments is more effective at abrading rock, but tends to move slower than “clean” ice
- abrasion and lodgement (deposition of till) are part of a continuum

After Bennett and Glasser, 2009



Weight of overlying ice



Water under pressure facilitates flow but reduces the effective normal pressure of the ice

Boulton model

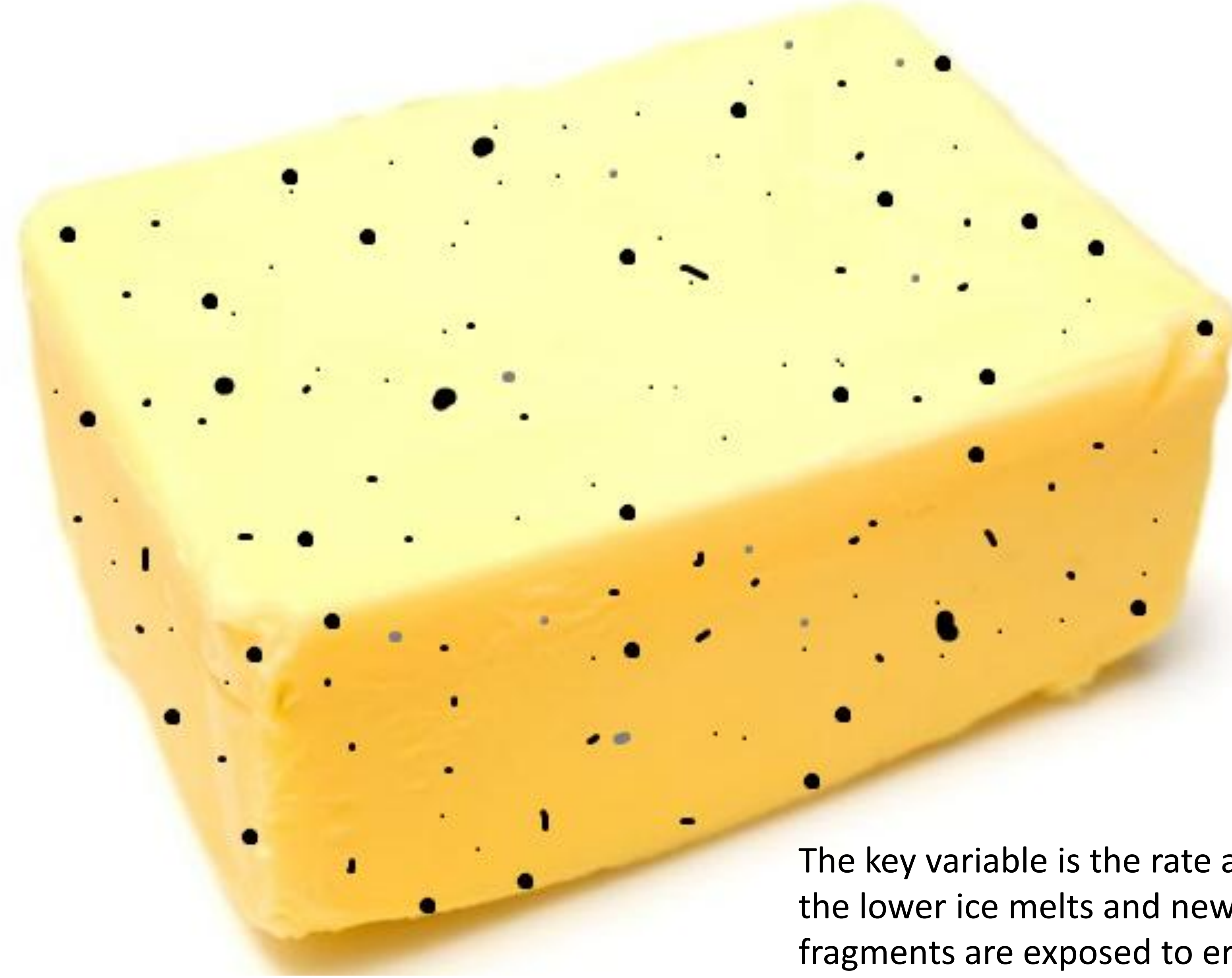
The key variable is how hard you push down on the sander.

Hallet model

- "effective normal pressure" is not important because the rock clasts are "floating" in the ice and are not necessarily pushed down by the ice because of the ice is so much weaker than the rock fragments
- pressure of fragments against the bed is determined by the rate of flow towards the bed
- that rate is controlled by the rate of melting at the ice-bed interface
- basal melting is favoured by (i) rapid flow, (ii) thick ice and (iii) high surface T

After Bennett and Glasser, 2009

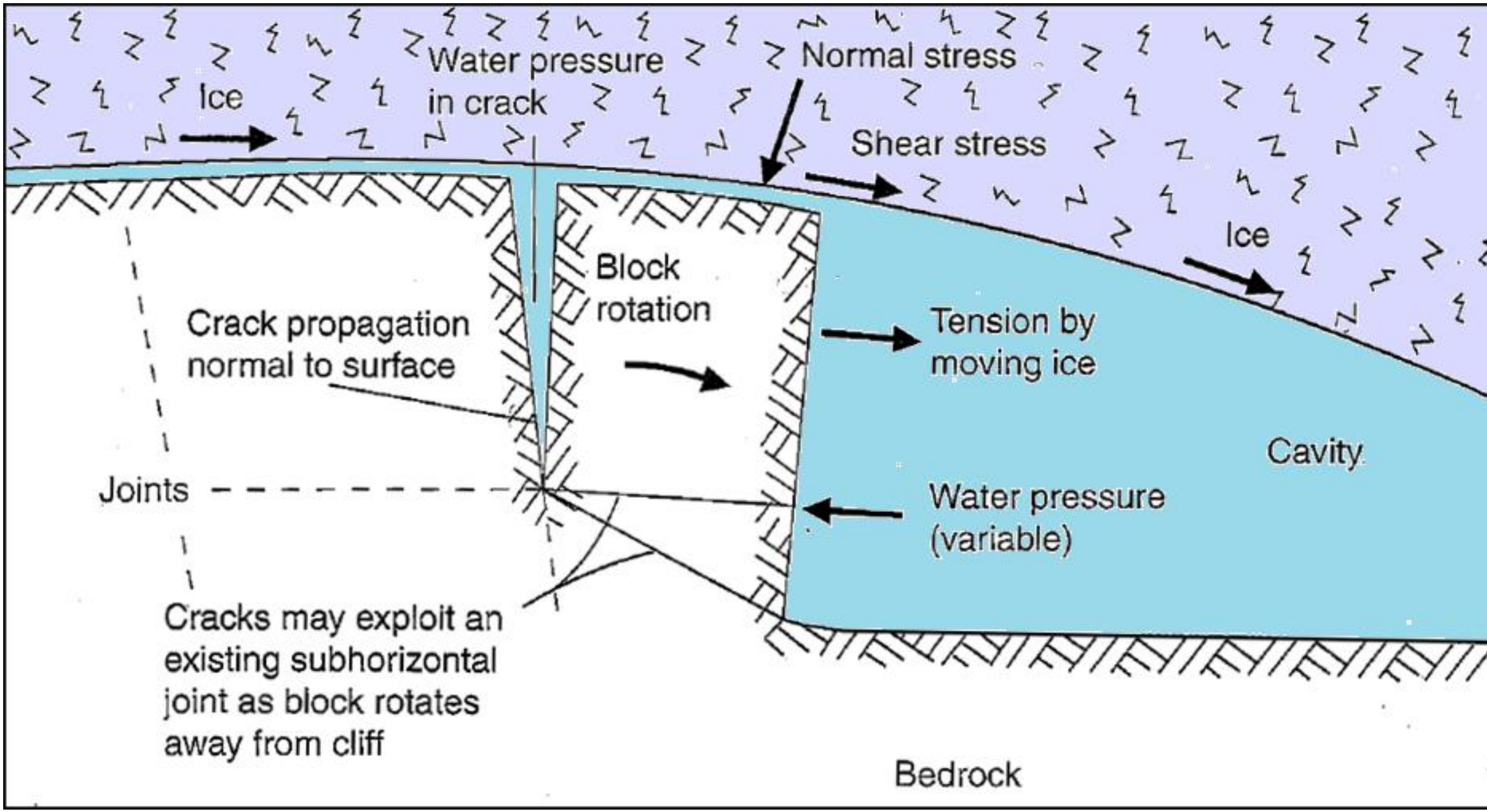
Hallett model



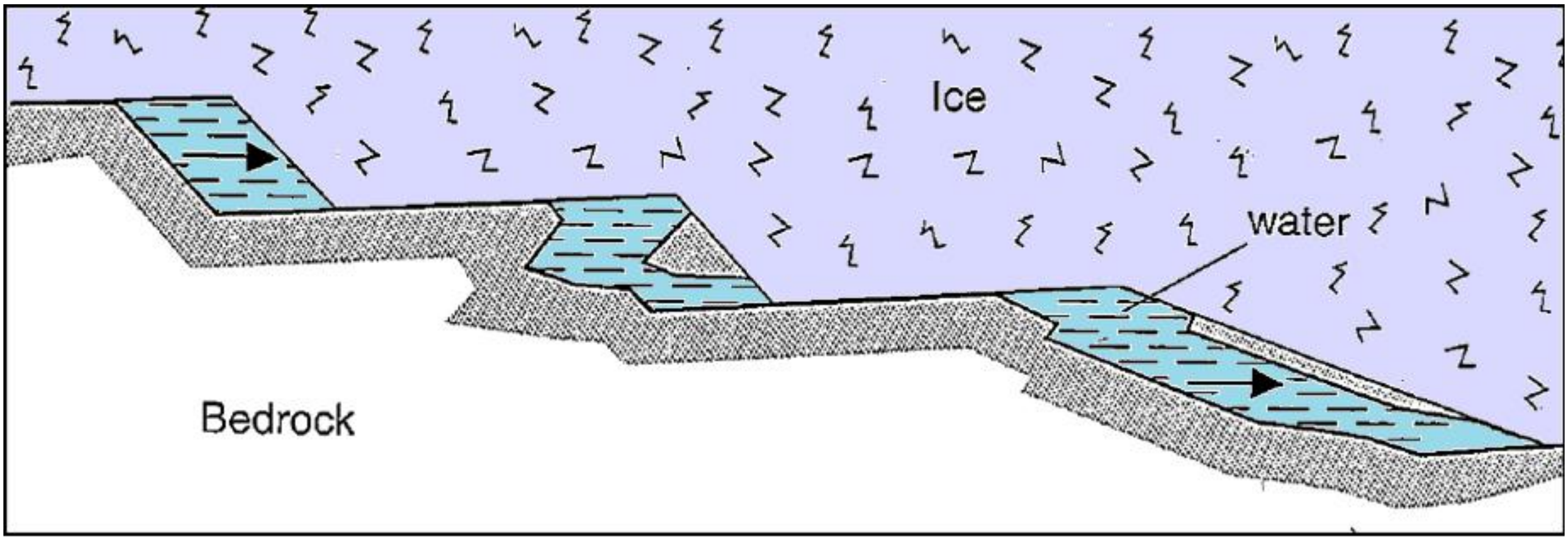
The key variable is the rate at which the lower ice melts and new rock fragments are exposed to erode the rock below.

Glacial Quarrying

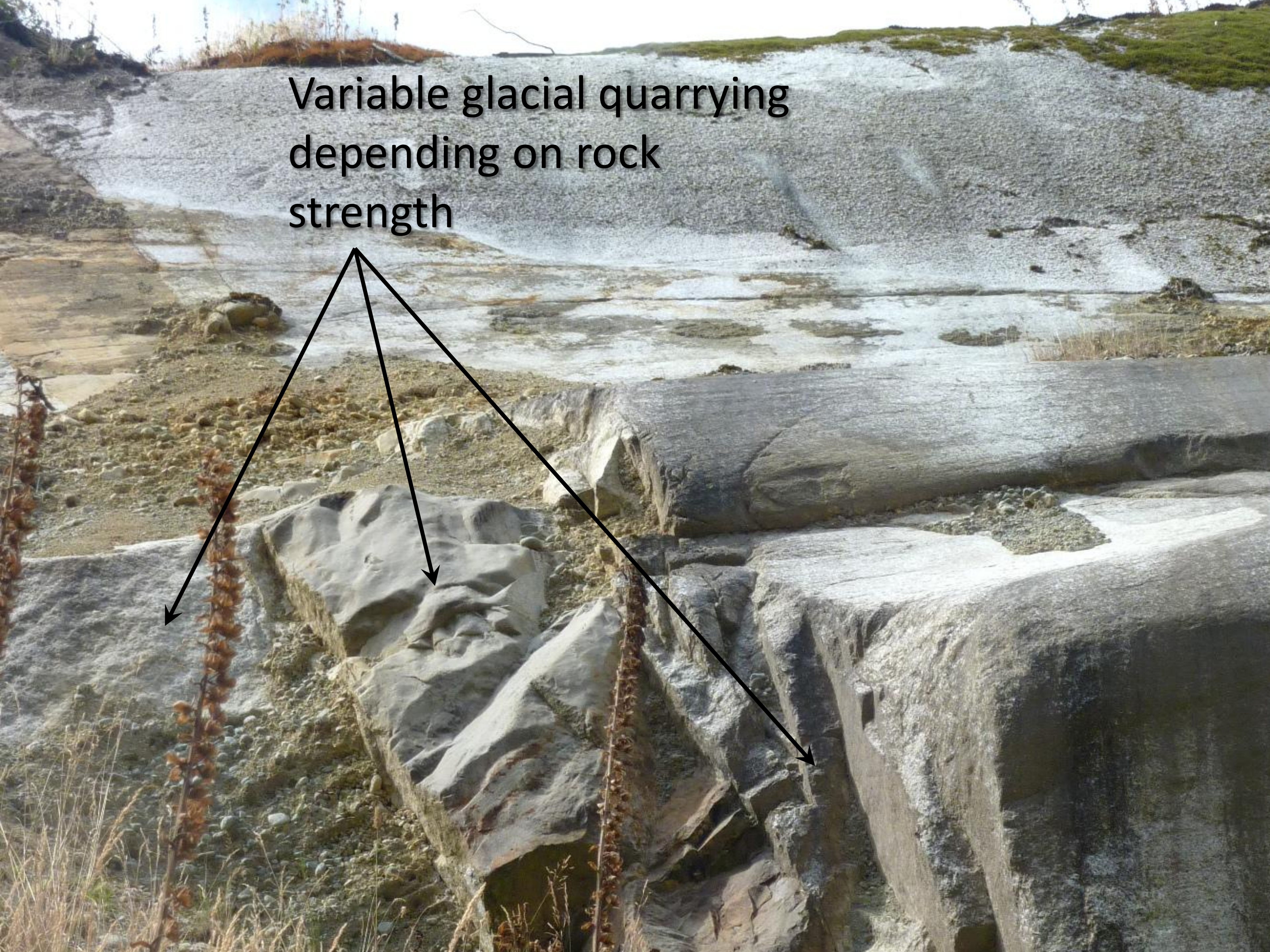
- Removal of large pieces from bedrock
- Starts with fracturing (may or may not be initiated by glacial processes)
- Water pressure changes may be important
- Freeze-thaw cycles are probably not important but freezing of water due to P changes are
- The presence of basal cavities is important

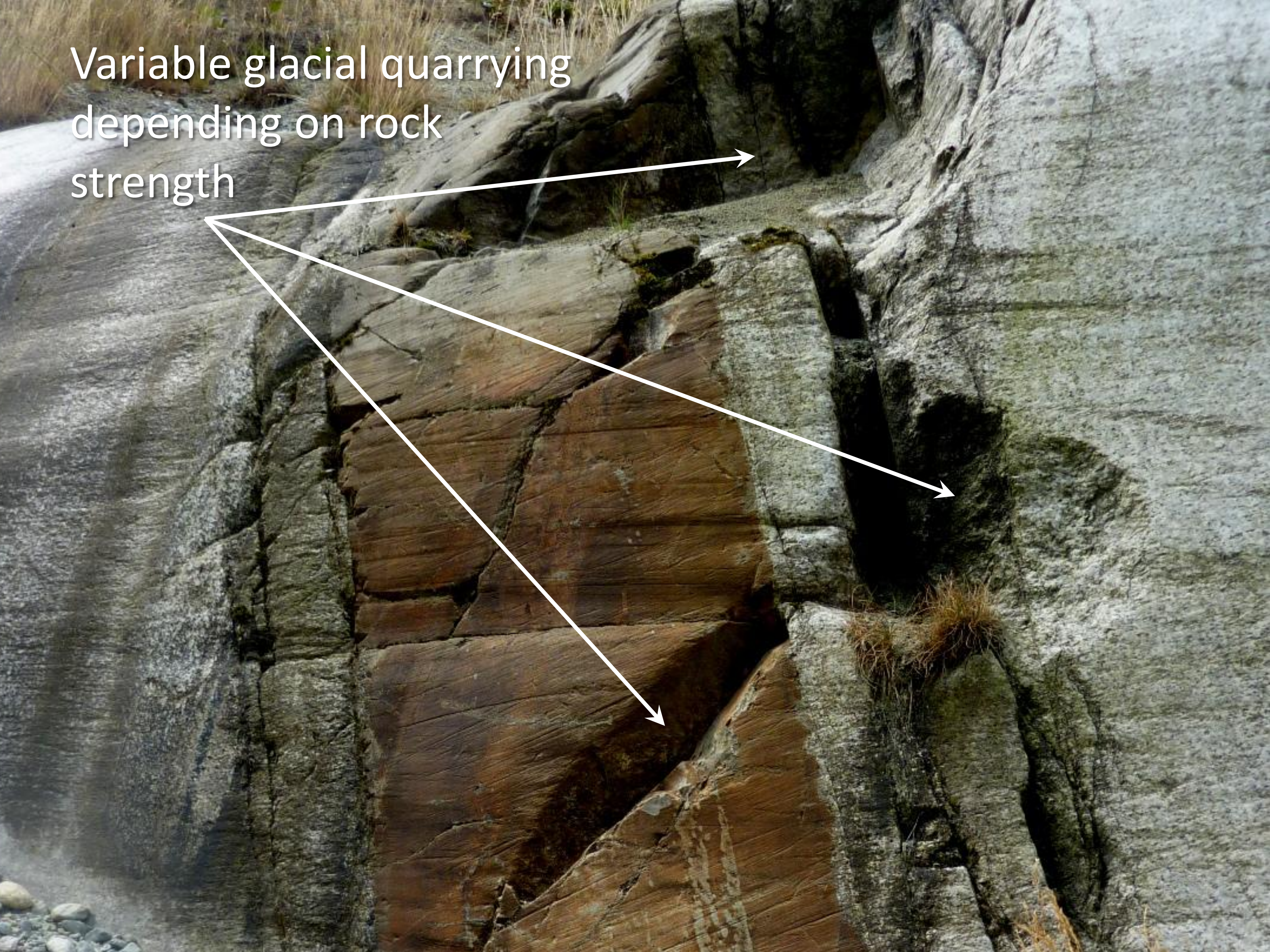


After Bennett and Glasser, 2009



After Bennett and Glasser, 2009


Variable glacial quarrying
depending on rock
strength

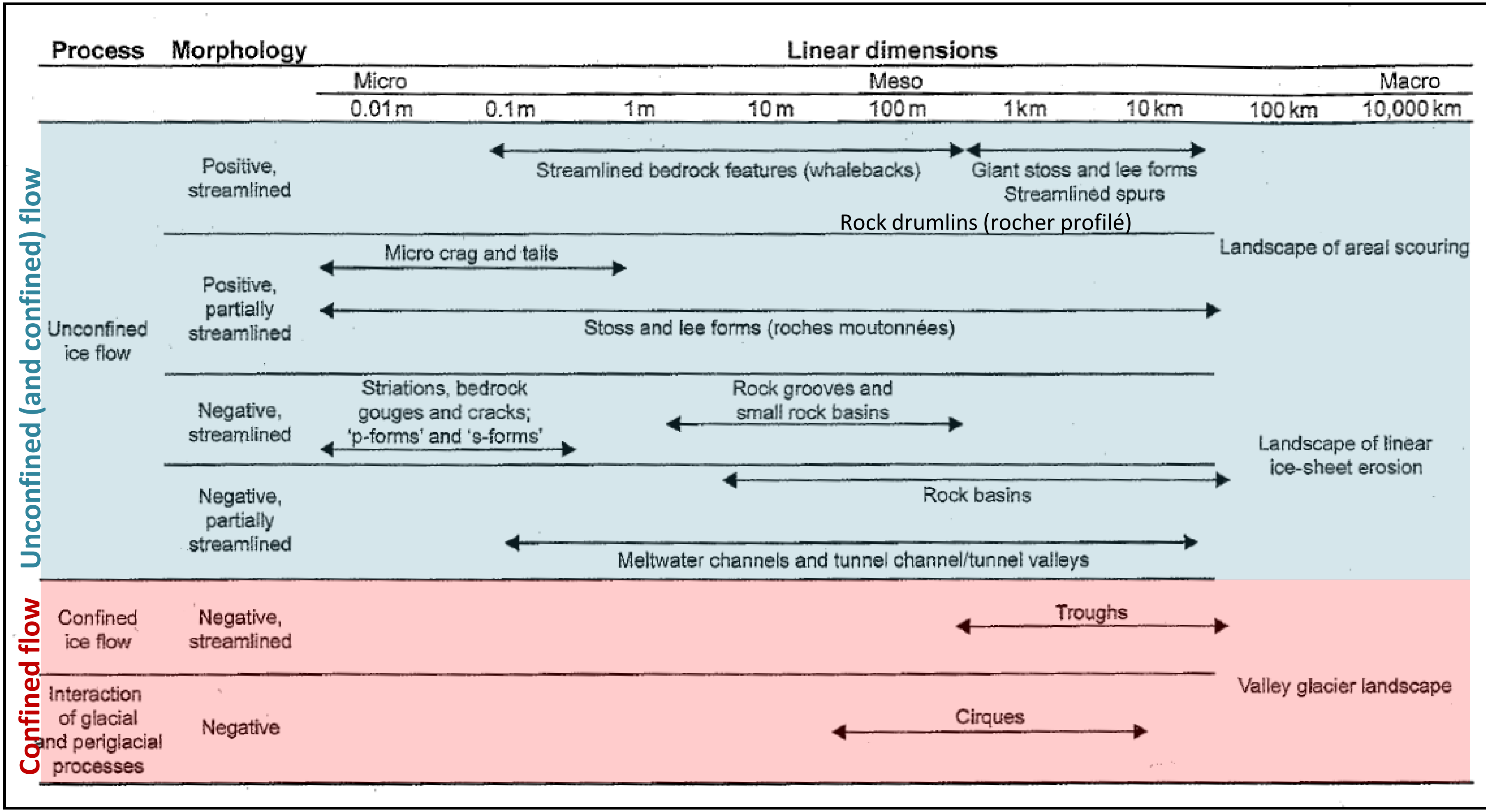

Variable glacial quarrying depending on rock strength


Glacial quarrying

Rock and debris entrainment

- Freezing of water onto the base of the glacier, trapping debris (various mechanisms exist for water at the ice-bed contact to freeze onto the overlying ice and incorporate rock fragments into the glacier)
- Thrust faults within the ice can push debris up into the glacier

Glacial erosional features



After Bennett and Glasser, 2009


Micro-scale erosional features
• striations
• micro crag and tails
• crescentic fractures and gouges
• chatter marks

Striae

- Type 1: become wider and deeper down-ice and then end suddenly as a deep gouge
- Type 2: start thin, steadily widen, thin again
- Type 3: start abruptly as deep gouges, then thin out

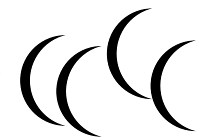
Nick

Micro crag-and-tails

Erosional features related to resistant areas (e.g., hard minerals) within a rock surface

Finlayson Pt., Victoria (http://www.geocaching.com)

Friction cracks

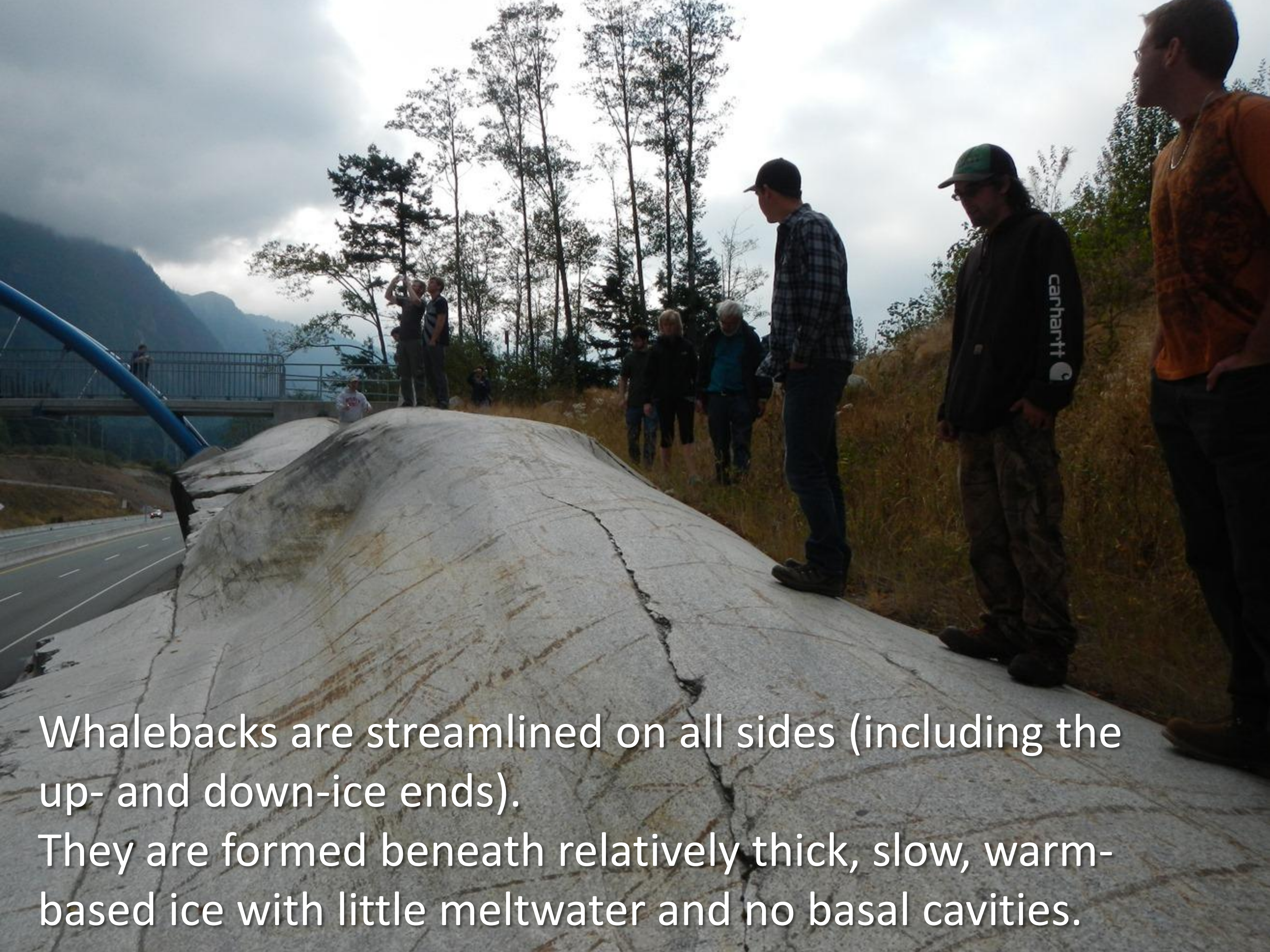
- Crescentic fractures: convex up-ice → 
- Crescentic gouges
- Chatter marks (irregular fractures)


Crescentic fractures
Ice flow
http://dorothyspctblog.blogspot.ca

Crescentic gouges at Squamish

Meso-scale erosional features

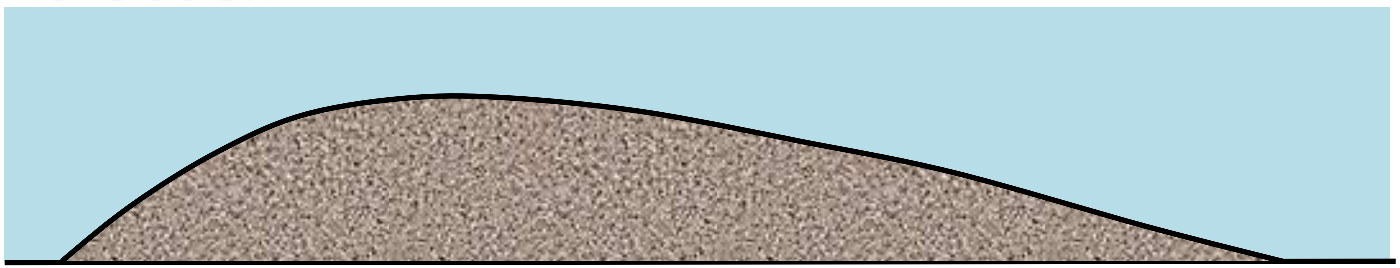
- whalebacks
- roches moutonées
- grooves
- melt-water channels



Whalebacks are streamlined on all sides (including the up- and down-ice ends).
They are formed beneath relatively thick, slow, warm-based ice with little meltwater and no basal cavities.

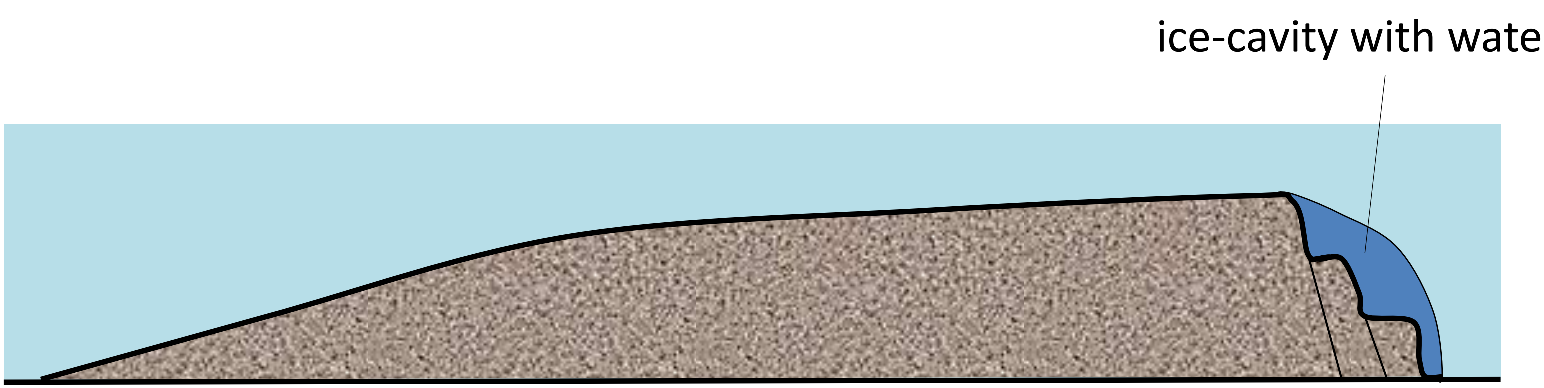
Roches moutonées are streamlined at their up-ice end and quarried at their down-ice end. They are formed beneath warm-based ice with abundant basal melt-water, with fluctuations in water pressure and with basal cavities. The existence of basal cavities <u>may</u> imply thin ice.

Whaleback



ice flow

Roche moutonée

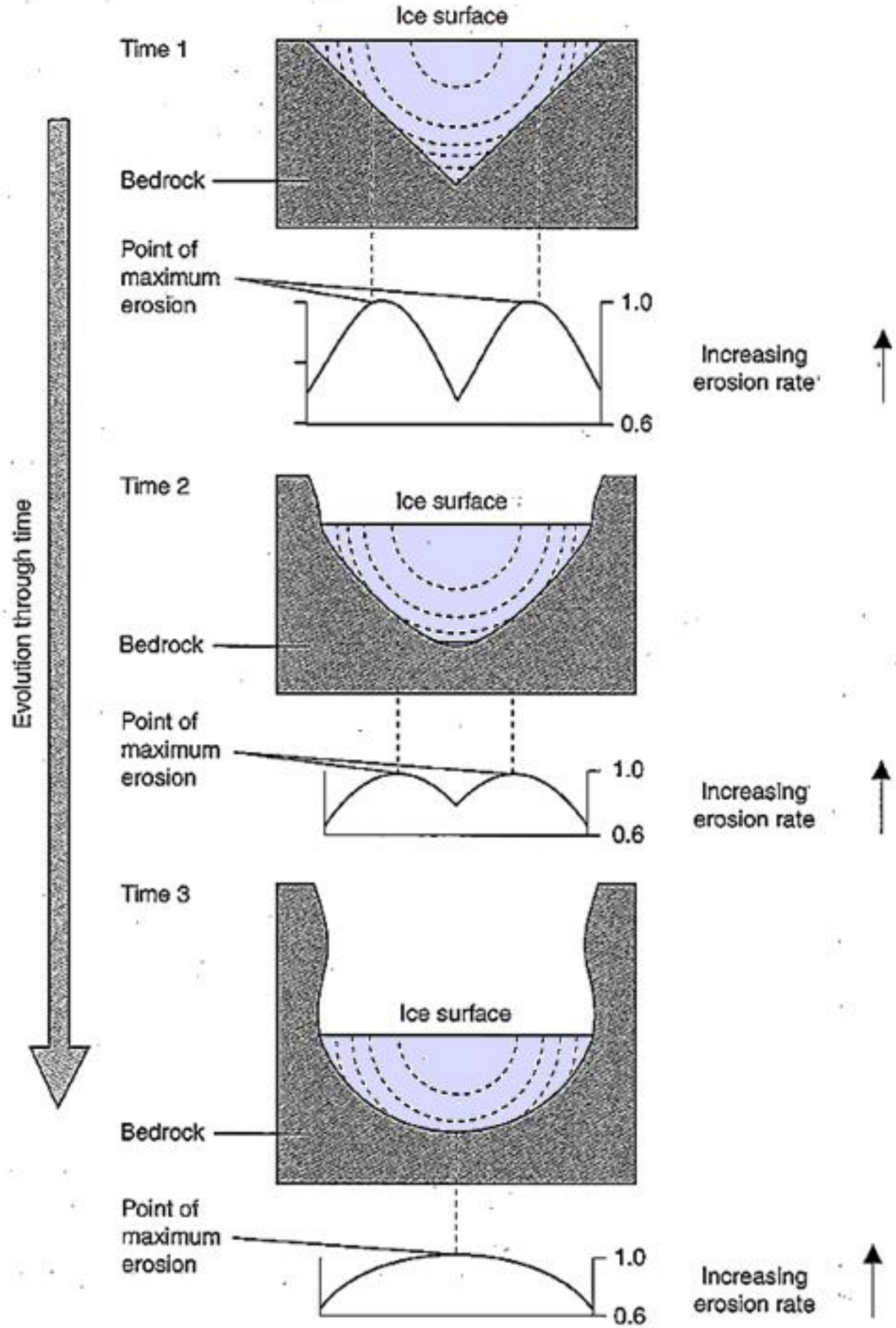


Macro-scale erosional features

- U-shaped valleys
- cirques, arêtes & horns
- rock drumlins
- areal scouring

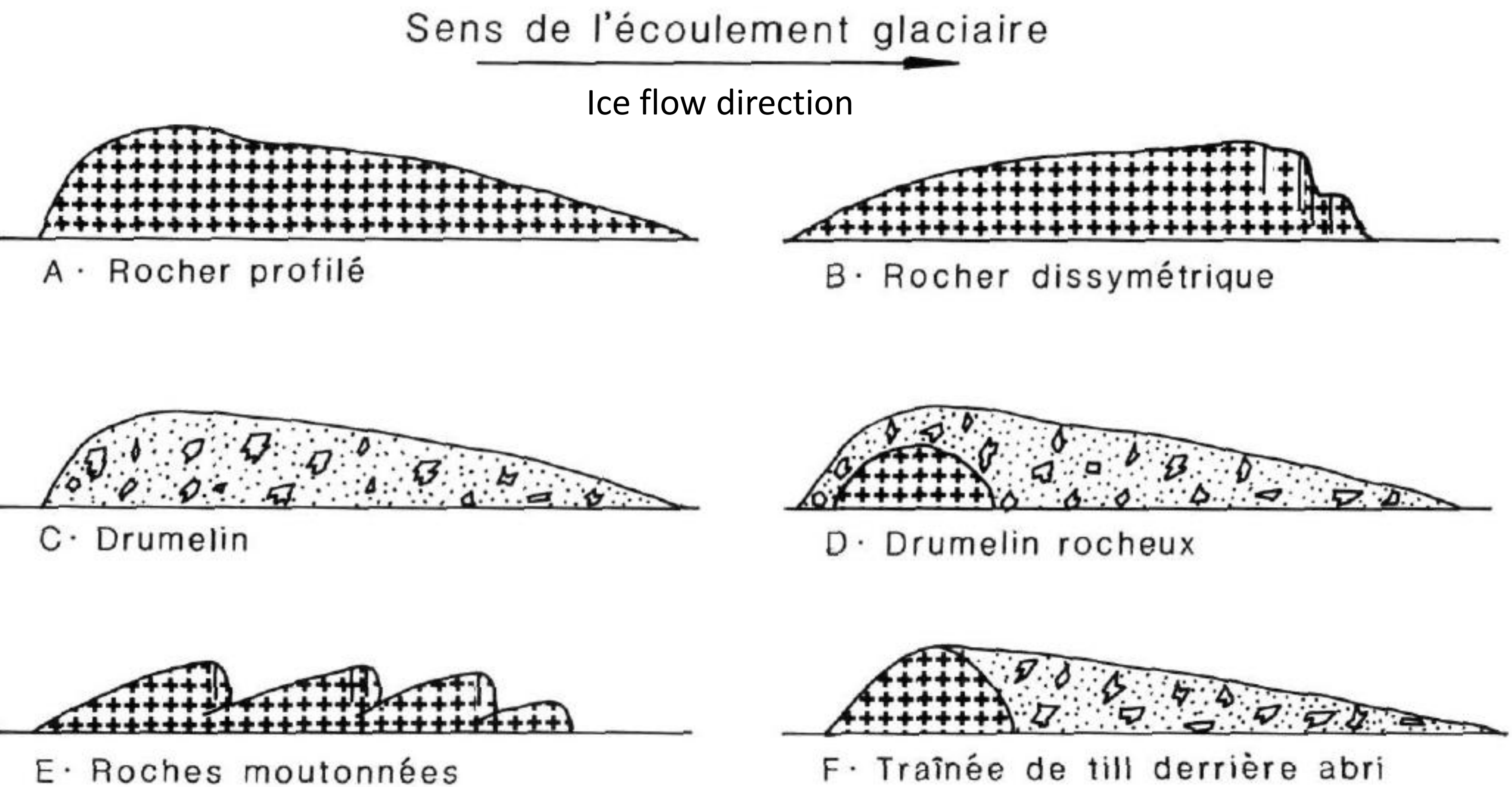

Fitzsimmons Ck. valley
Whistler-Blackcomb

Hanging Valleys at Woodfibre, Howe Sound



After Bennett and Glasser, 2009

Many of the meso- to macro-scale erosional features of the Howe Sound area have shapes like this. The implications are a thick warm-based glacier without: basal cavities, abundant basal melt-water, or fluctuations in water pressure.



Jean-Claude Dionne , Géographie physique et Quaternaire, vol. 38, n° 1, 1984, p. 69-74.

Areal Scouring
Hottah Lake area, NWT
(http://www.nwtgeoscience.ca)

The relative efficacy of fluvial and glacial erosion over modern to orogenic timescales

Michele N. Koppes & David R. Montgomery

Abstract

Since the late nineteenth century, it has been debated whether rivers or glaciers are more effective agents of erosion. The dramatic landscapes associated with glaciated terrain have often led to the argument that glaciers are more erosive than rivers, and recent studies have documented the topographic signature of an ice-controlled limit of mountain height known as the ‘glacial buzz-saw’. Here we present a new global compilation of erosion rates, which questions the conventional view of glaciers and erosion. In regions of rapid tectonic uplift, erosion rates from rivers and glaciers both range from 1 to over 10 mm yr^{-1}, indicating that both are capable of generating erosion rates matching or exceeding the highest rates of rock uplift. Moreover, a comparison of erosion rates over timescales ranging from 10^1 to 10^7 years indicates that glacial erosion tends to decrease by one to two orders of magnitude over glacial cycles, whereas fluvial erosion rates show no apparent dependence on time. We conclude that tectonics controls rates of both fluvial and glacial erosion over millennial and longer timescales and that the highest rates of erosion (>10 mm yr^{-1}) generally result from a transient response to disturbance by volcanic eruptions, climate change and modern agriculture.

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