On the Rate of Production and Transfer of Sediment from Glaciated Terrains

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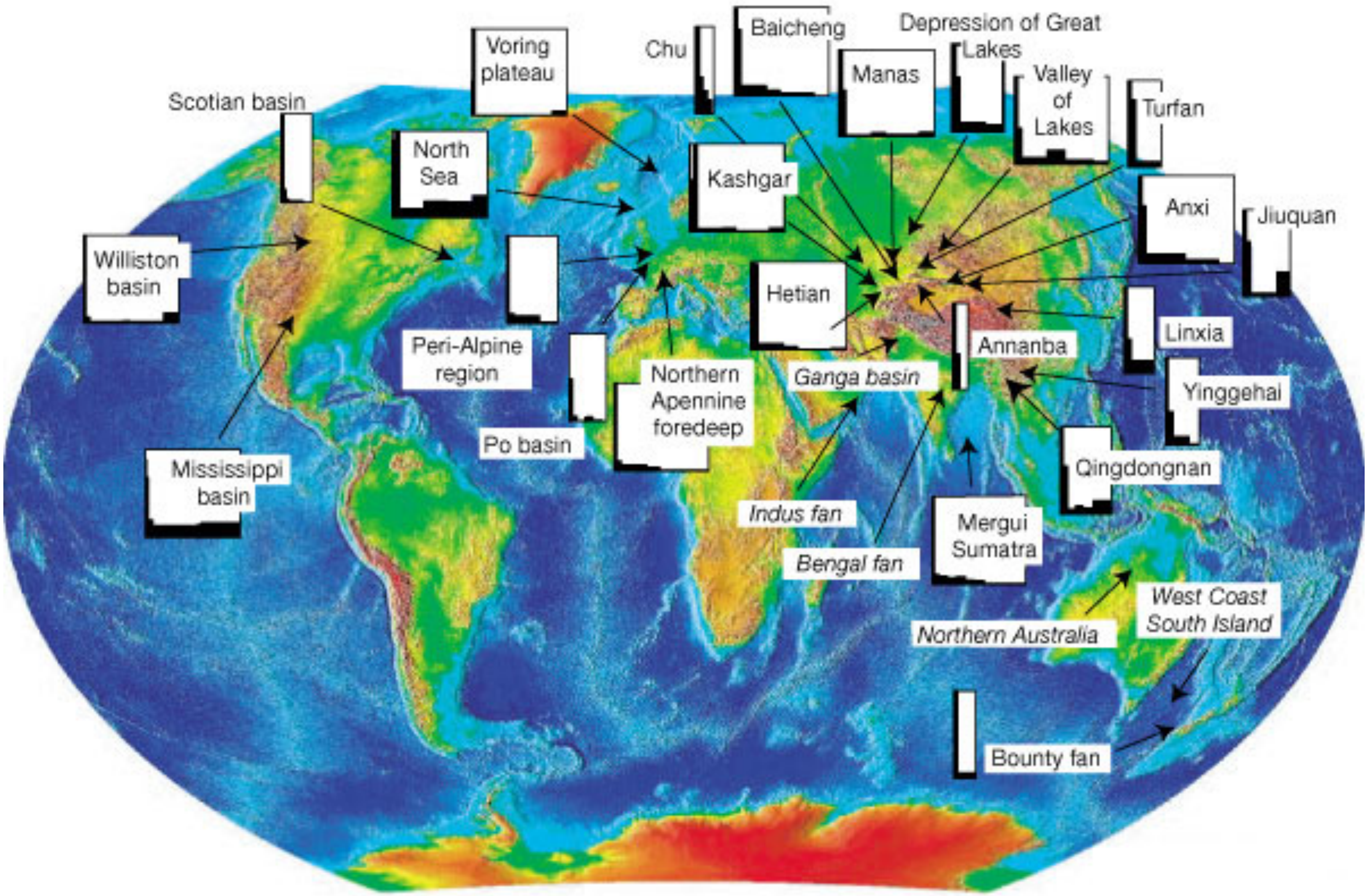
Outline

Glaciers in the global sediment system

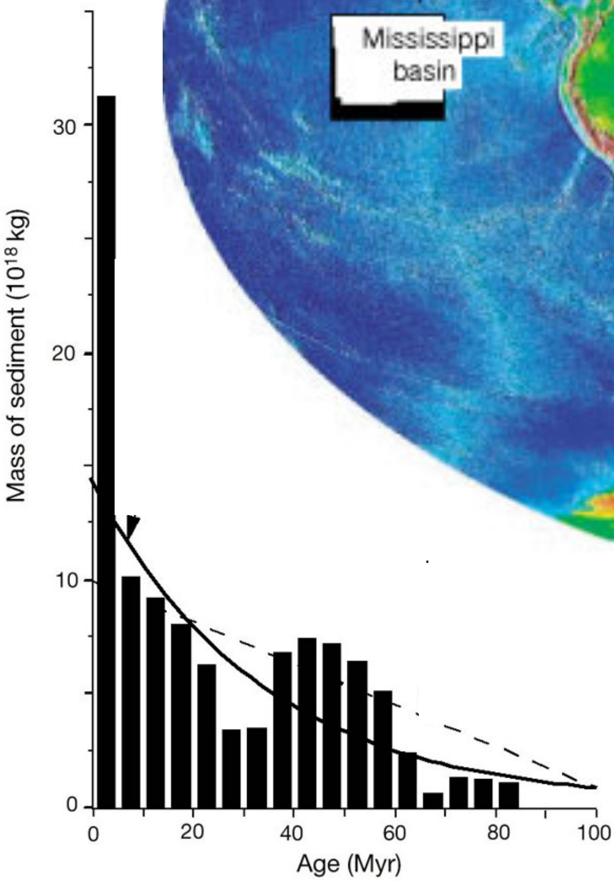
Theoretical development of glacier erosion processes

Empirical constraints on glacier erosion rates and sediment storage

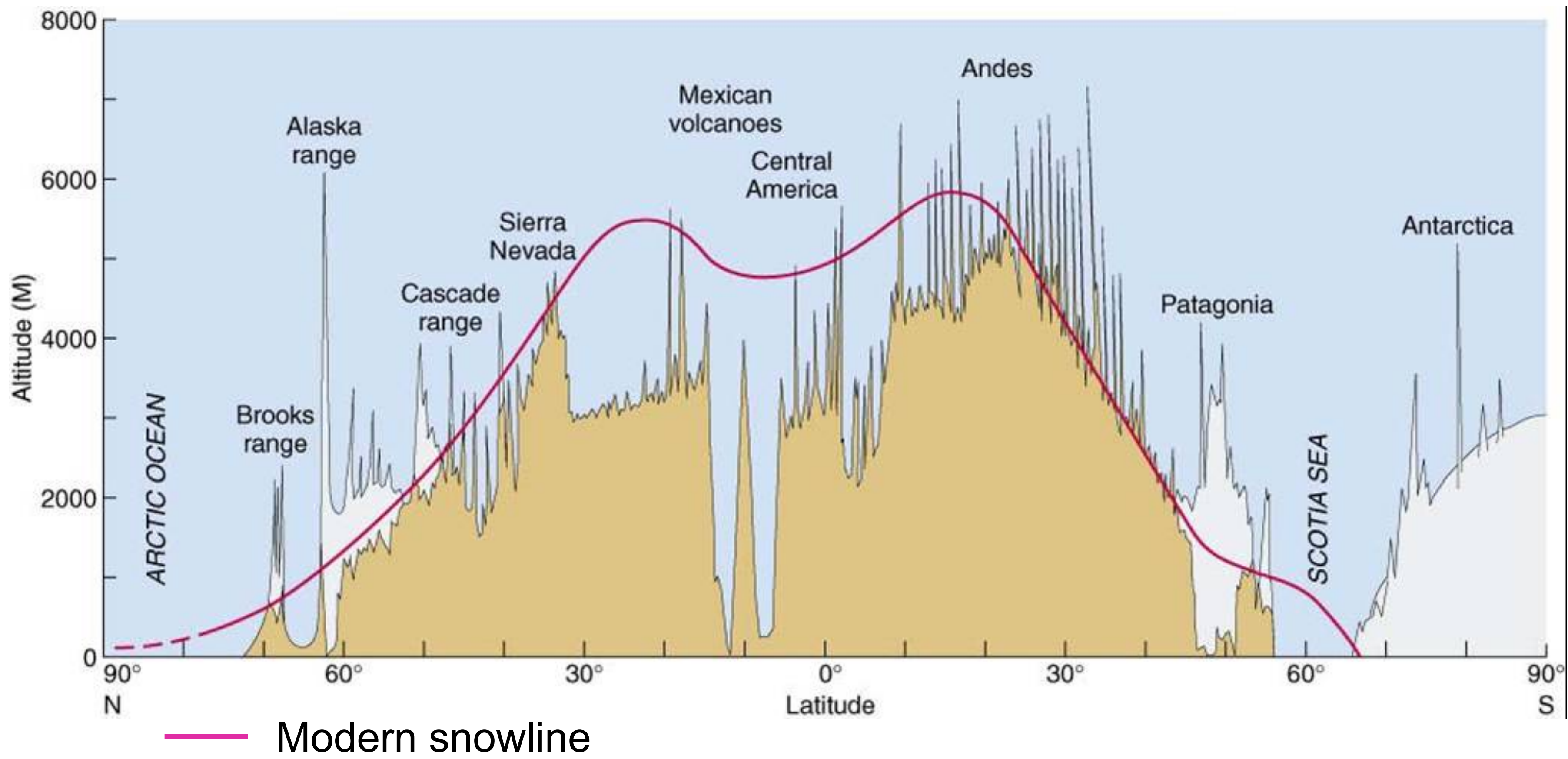
Climatic and dynamics influences on glacial sediment fluxes through time.



Peizhen et al., 2001



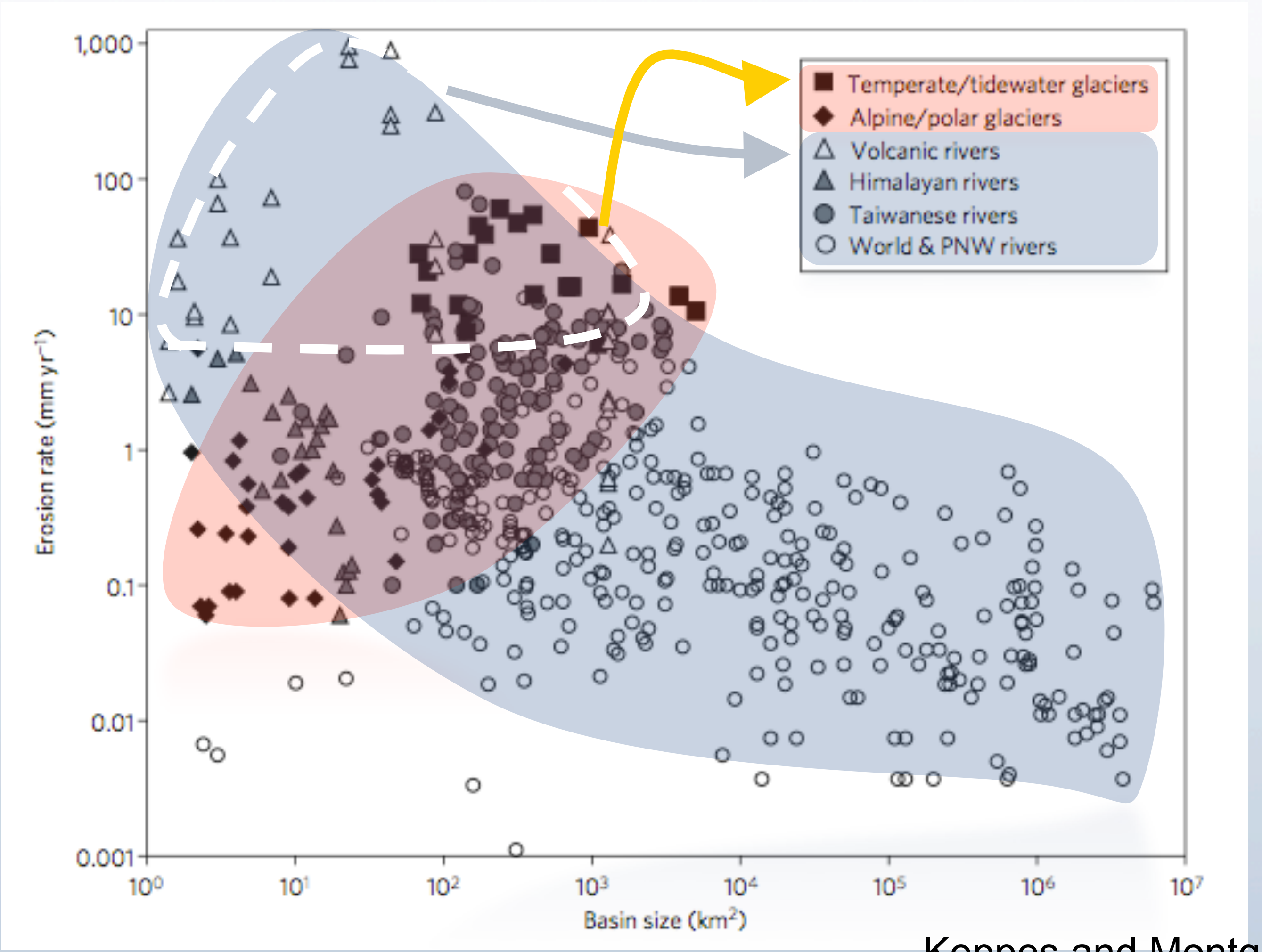
Hay et al., 1998



After Porter (1981)

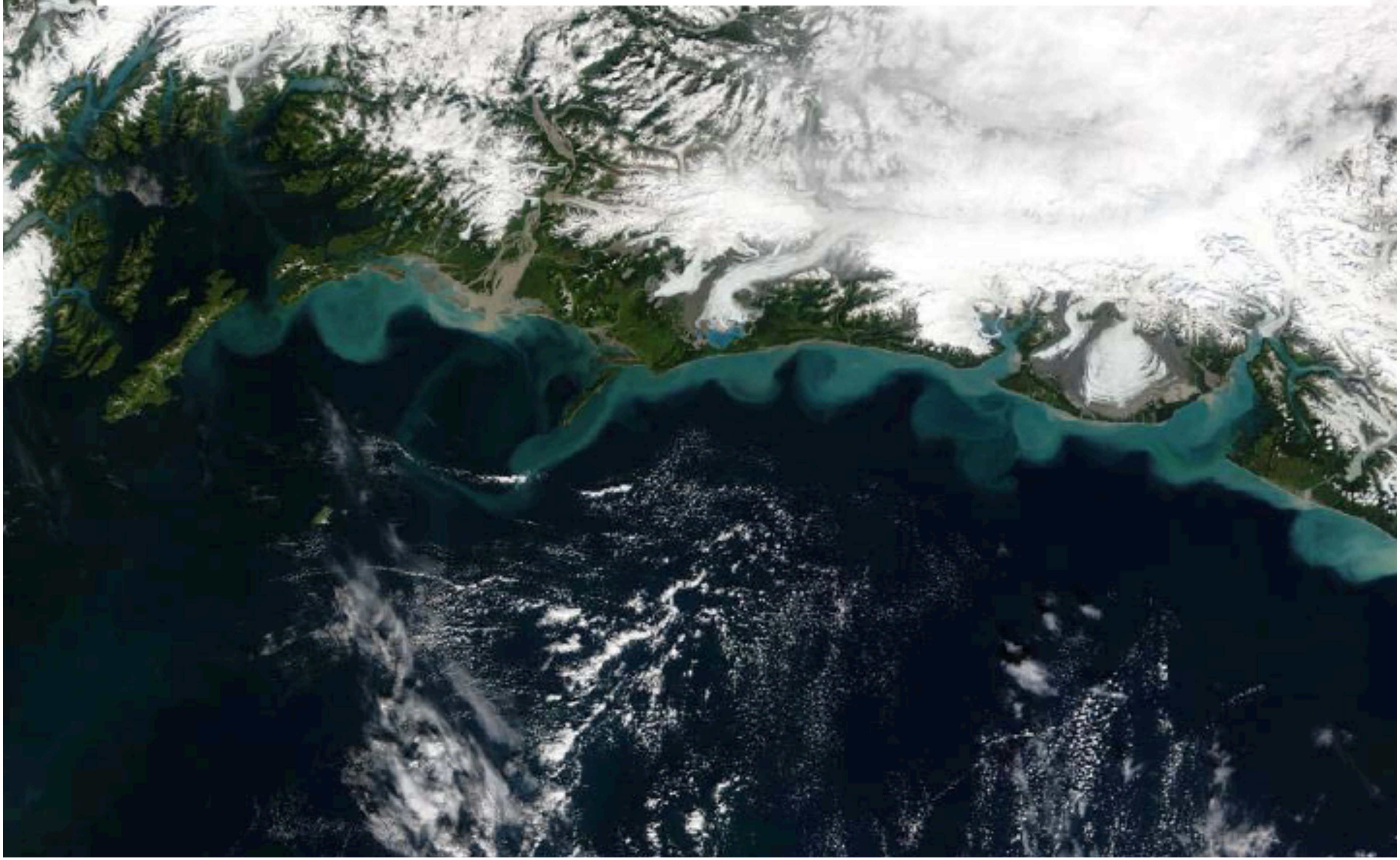
Glacial vs. Fluvial Erosion Rates

Erosion rates in glaciated and unglaciated basins span the same range of values



Koppes and Montgomery, 2009

Massive sediment plumes reflect rapid sediment evacuation from coastal mountains to the Pacific



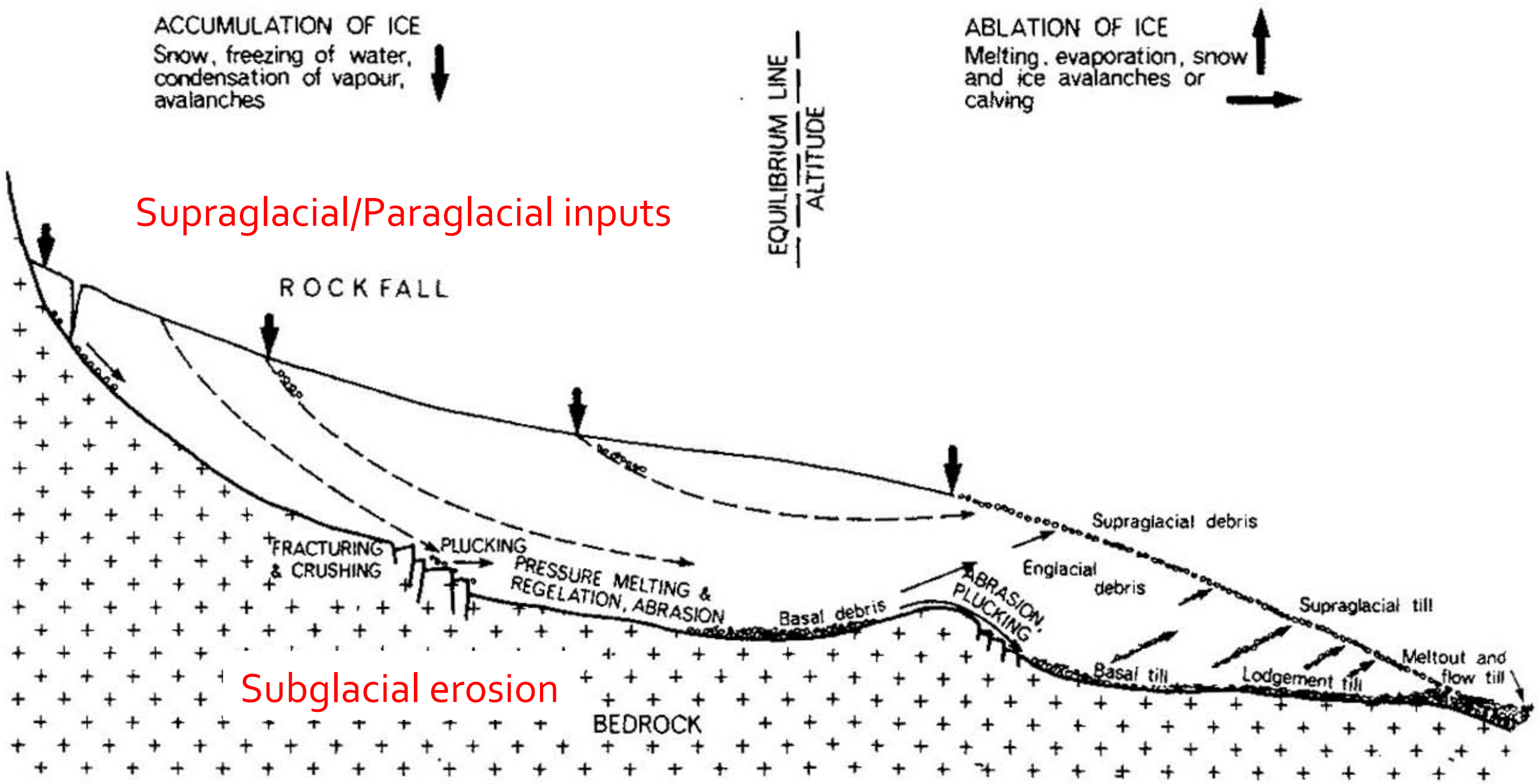


Fig. 15.11 Processes acting on and within a glacier.

Subglacial meltwater transport/erosion

(Drewry, 1986)

Glacial erosion processes

Quarrying –a.k.a. plucking: fractured bedrock, large glacial erratics. Diverse lines of evidence points to quarrying being dominant bedrock erosion processes, incl. asymmetry of erosional landform

Abrasion: dominant producer of fine sediments, but may account for < 10% of bedrock erosion.

Subglacial fluvial erosion: bulk (>90%) of sediment transport to glacier snout, but role in bedrock erosion is poorly known.

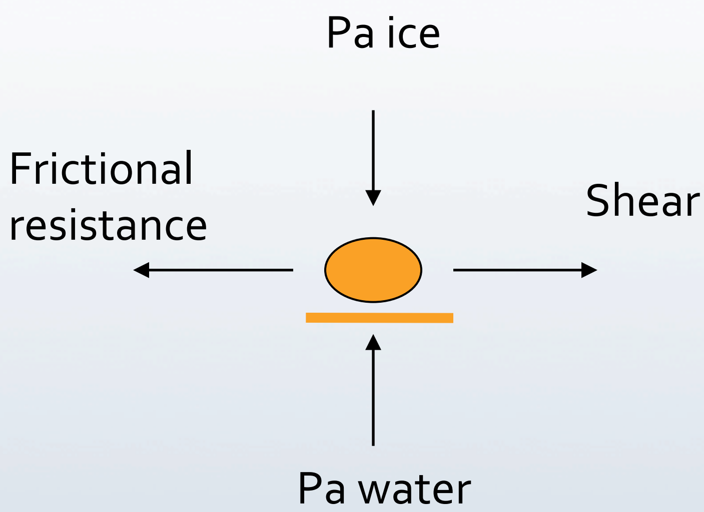
Paraglacial processes: mass wasting (from frost-activated creep to massive landslides) of supraglacial slopes and fluvial incision of pro-glacial sediments can be locally important.

Abrasion: dominant producer of fine sediments, but may account for < 10% of bedrock erosion.

Photo Credit: Michele Koppes

Theories of glacial abrasion

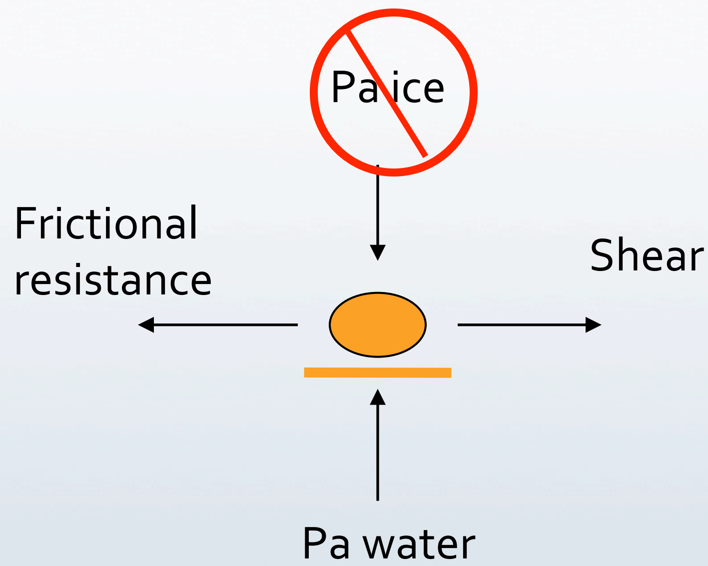
Boulton (1979)



Erosion is a function of:

1. Ice thickness (overburden)
2. Permeability of substrate

Hallet (1979)



Erosion is a function of:

1. Ice speed
2. Basal melting

Factors affecting rate of abrasion

- number of cutting tools: rock fragment concentration
- fragment (ice) velocity

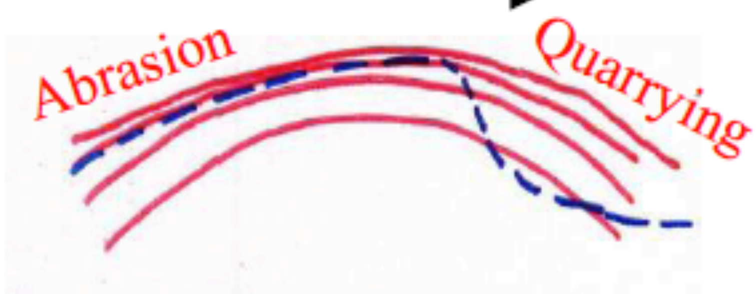
} Flux of fragments

- lithology and shape of fragments
- shape of the bed (including erosion shadows)
- effective contact force

Quarrying –a.k.a. plucking: fractured bedrock, large glacial erratics. Diverse lines of evidence points to quarrying being dominant in bedrock erosion

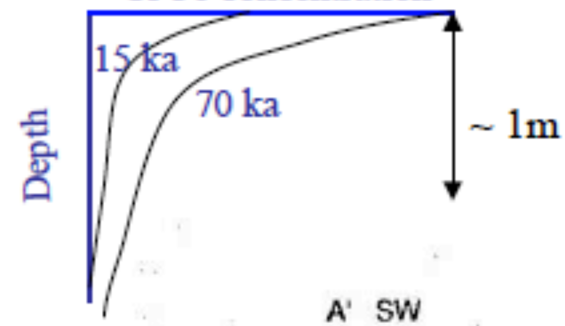
Looking 20 m. upglacier under Grinnell Glacier (photo courtesy of B. Hallet)

Relative importance of abrasion and quarrying



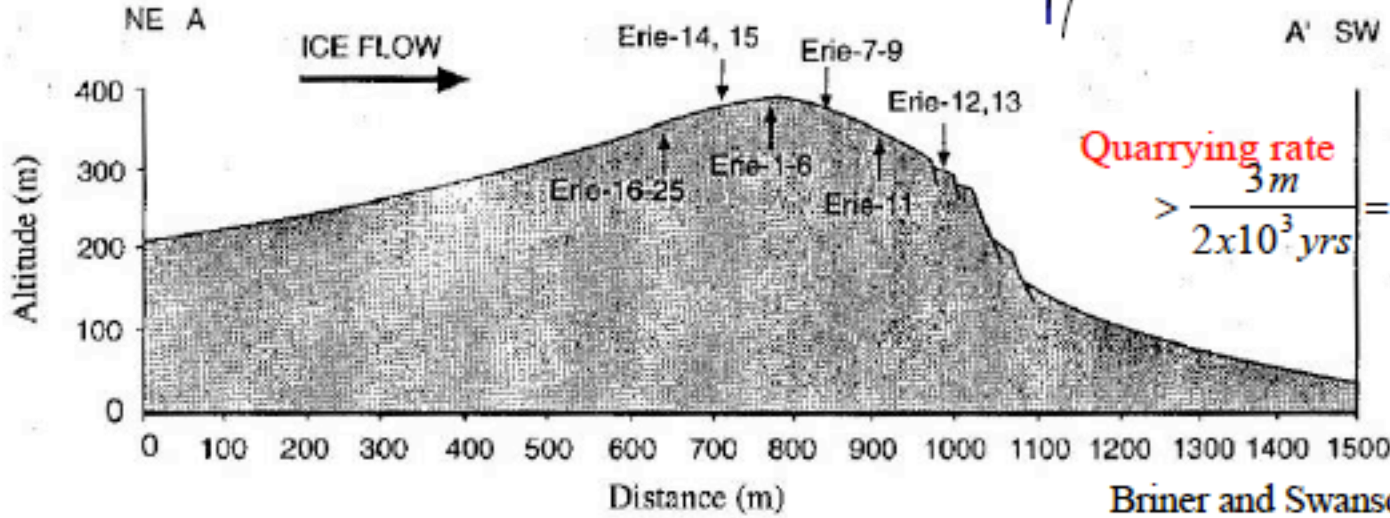
Asymmetry of exfoliating granite domes

R. Jahns (1943) recognized that more was missing from quarried side.



Abrasion rate

$$< \frac{0.3\,m}{2x10^3\,yrs} = 0.15\frac{mm}{yr}$$



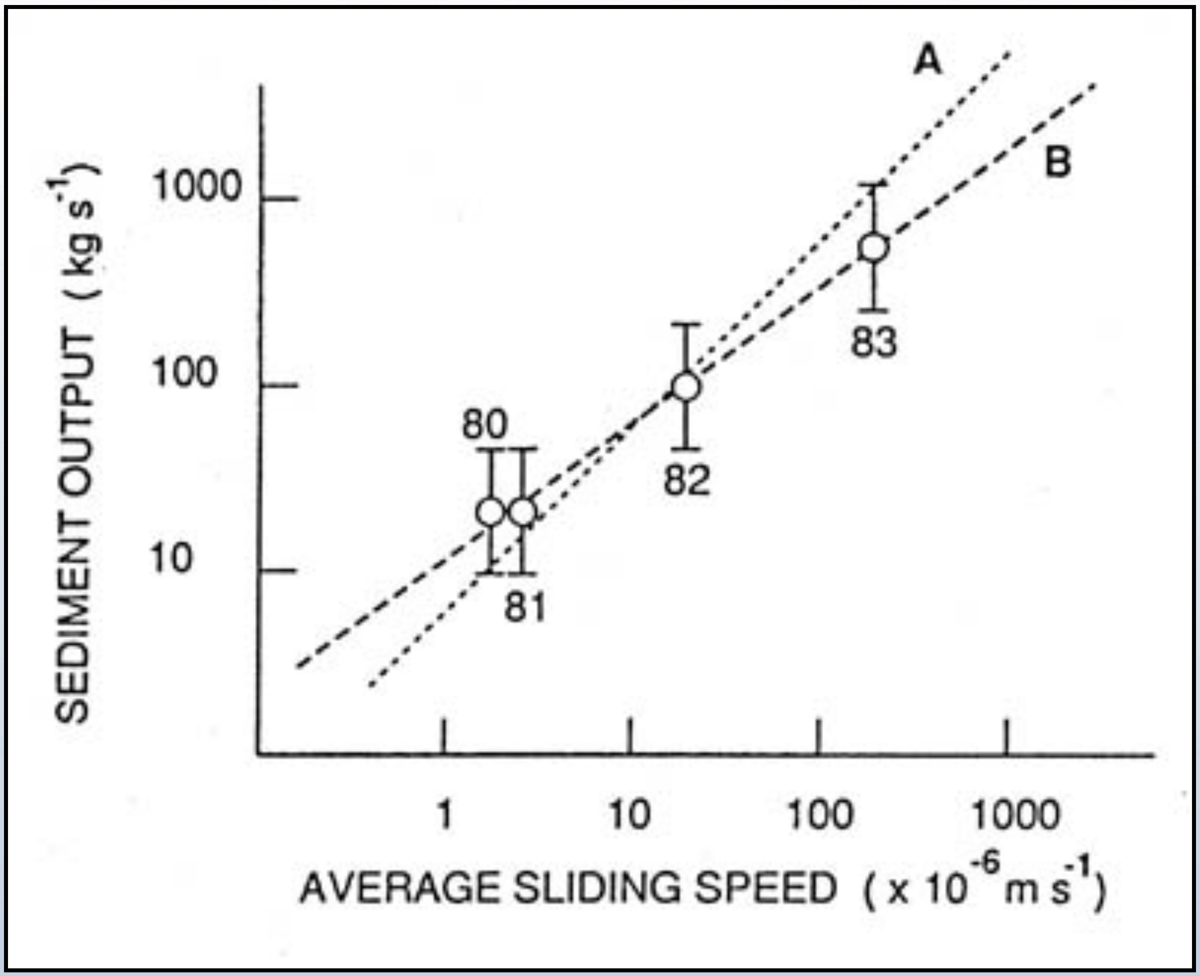
Quarrying rate

$$> \frac{3\,m}{2x10^3\,yrs} = 1.5\frac{mm}{yr}$$

Briner and Swanson, 1998

Erosion is a function of ice recession

Variegated Glacier during surge cycle
(Humphrey and Raymond, 1994)



$$Q_S = k\overline{U}_i$$

Overall glacial erosion rates depend on:

•Basal temperature (negligible if ice is frozen to the bed)

• Glacial extent (% of basin under ice)

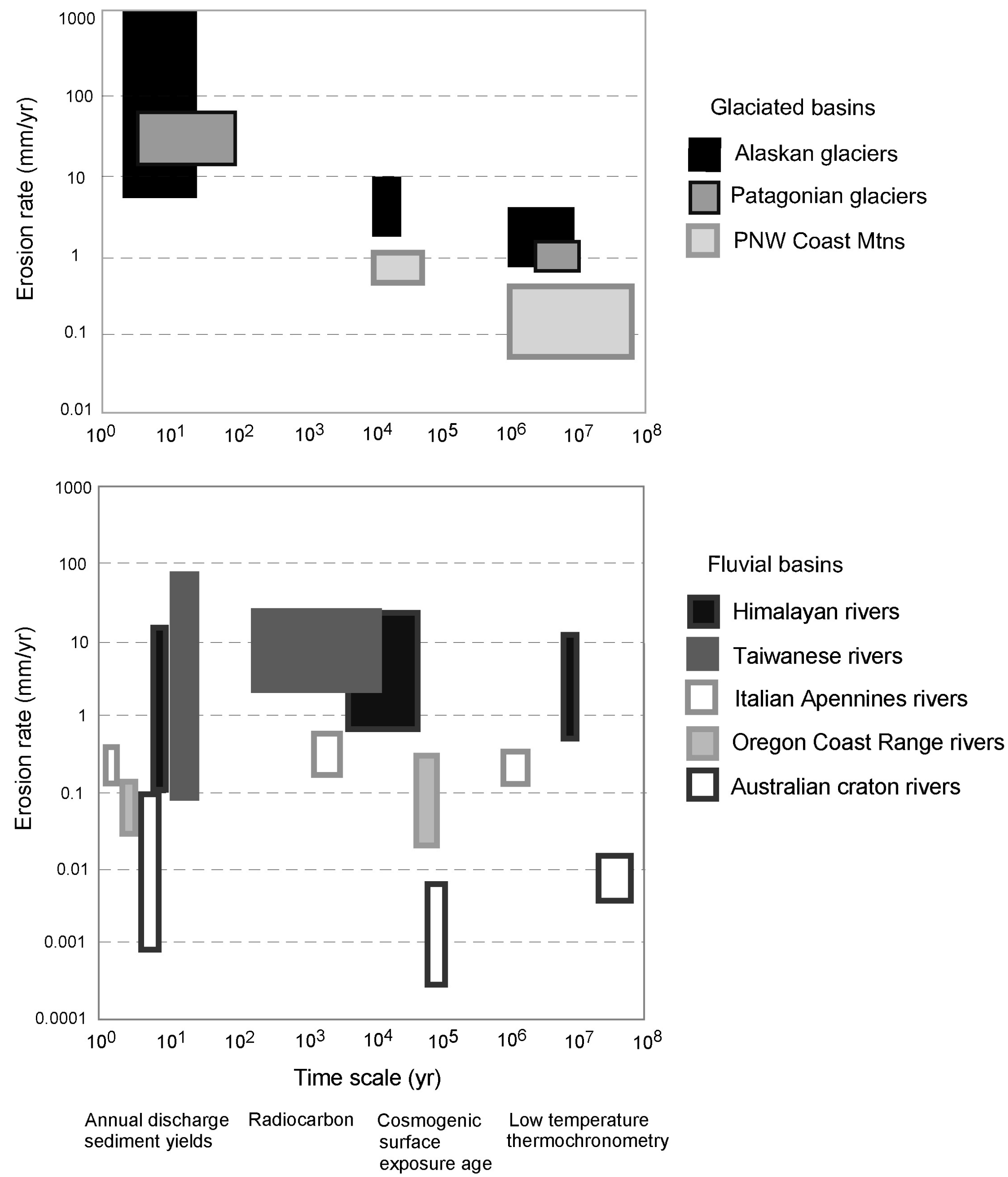
•Bedrock characteristics (lithology, structure, micro-& macro-cracks)

•Tectonic setting (fractures, pervasive damage, strain rates)

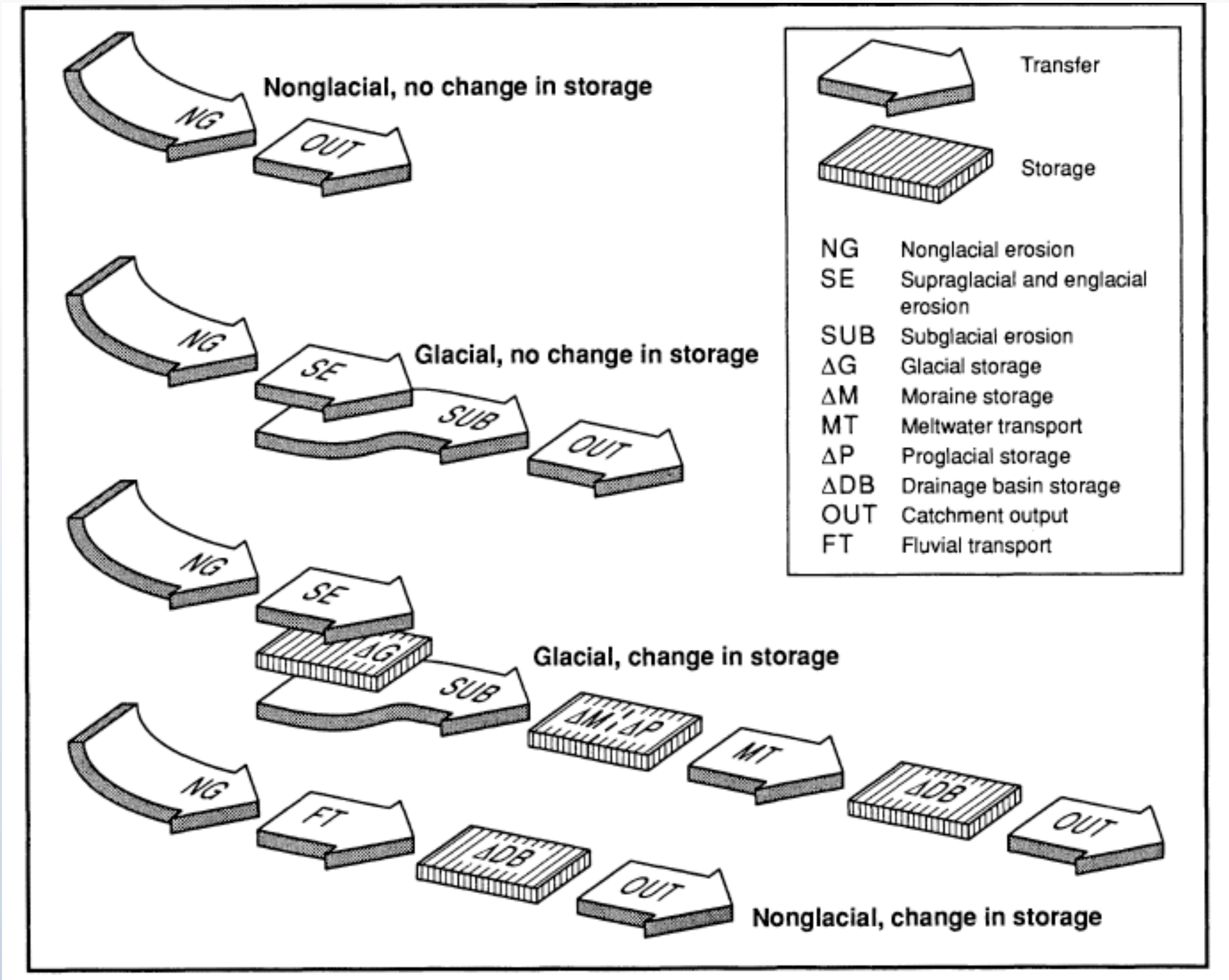
•Weathering is NOT required for glaciers to erode.
For example, in SE Alaska rates are high and the area has been under ice for >5 Myr.

Erosion Rates

Erosion rates from glaciated basins appear to decrease with increasing time scale … why?



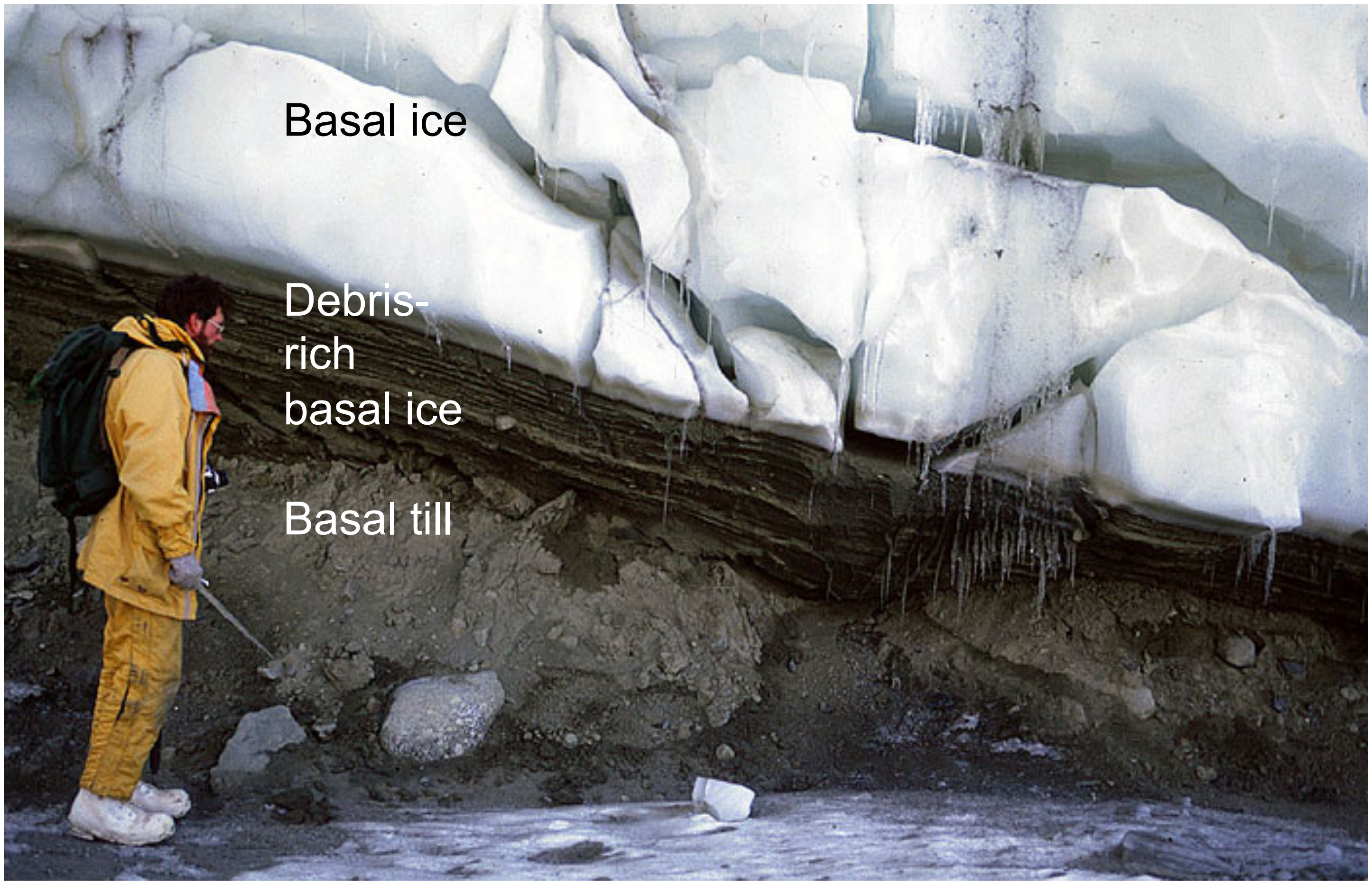
Koppes and Montgomery, 2009



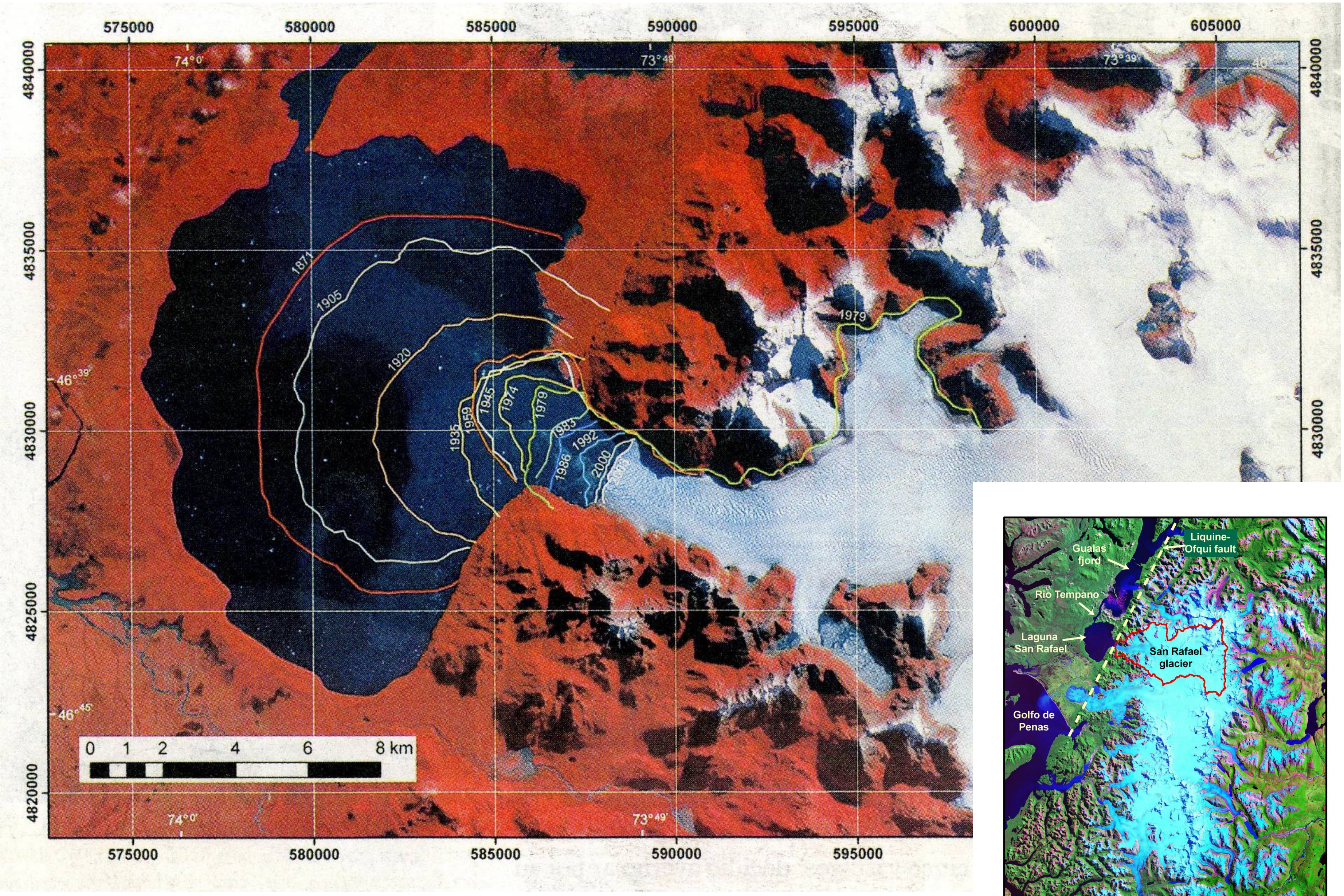
From Harbor & Warburton, 1993

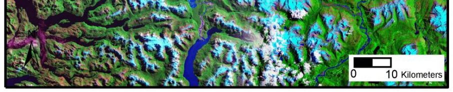
Storage

Subglacial till layers are typically < 1 m. thick (e.g., Kamb et al., 1985)
Englacial and supraglacial debris concentrations do not exceed 10% per unit volume of ice (Lawson et al., 1996)



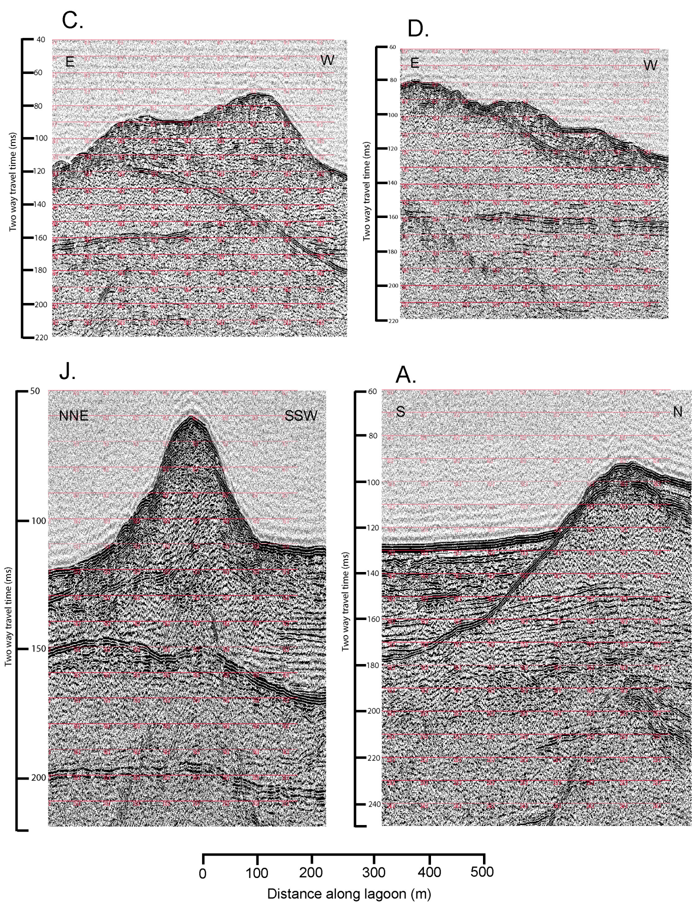
(Photo M. Hambrey, 1984)

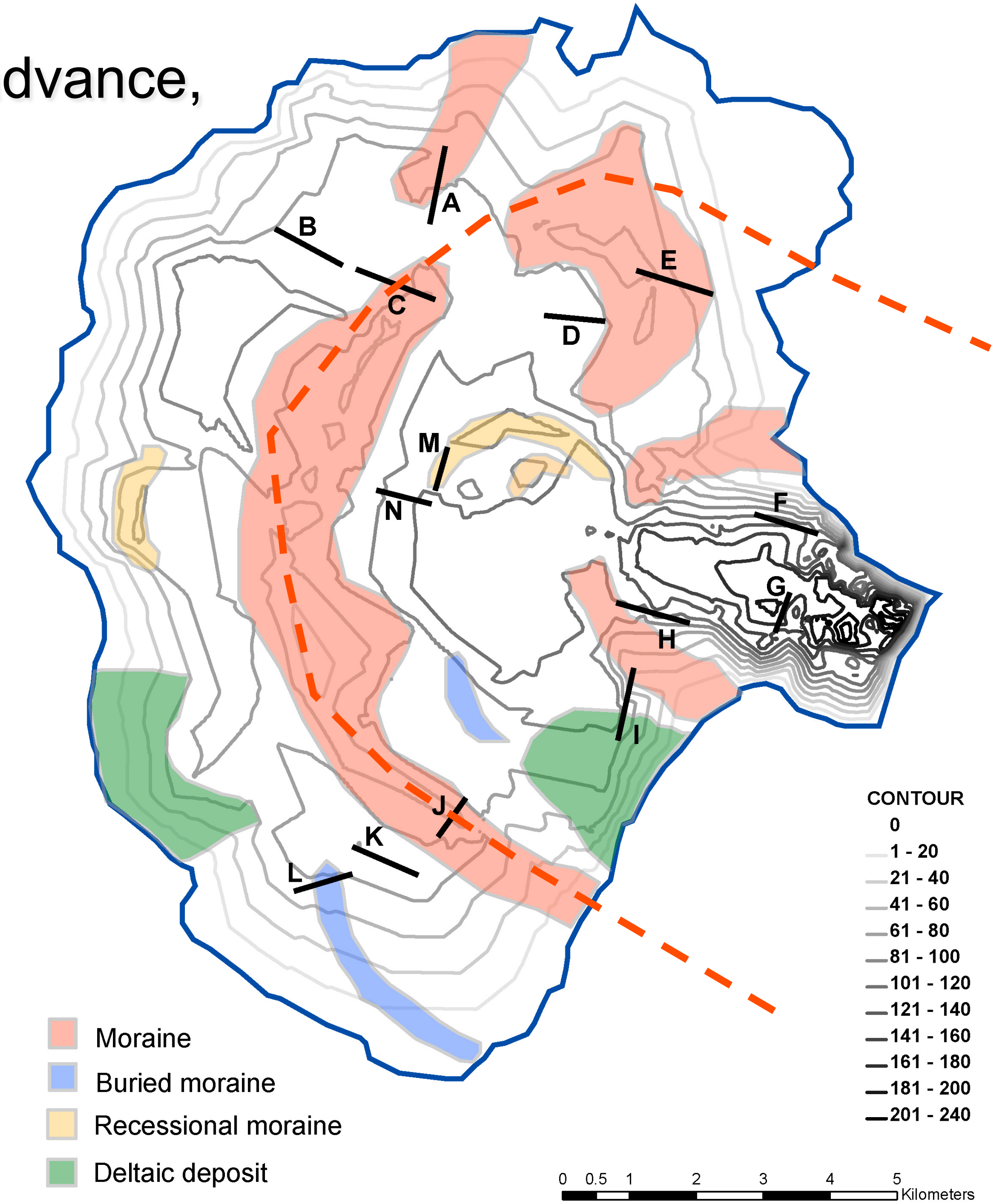




From Rivera et al. (2007)

Extent of Little Ice Age advance, San Rafael Glacier





Koppes et al., 2010

Erosion rates during LIA advance and retreat, San Rafael Glacier

Advance (early 1800's)
< 7 ± 2 mm/yr

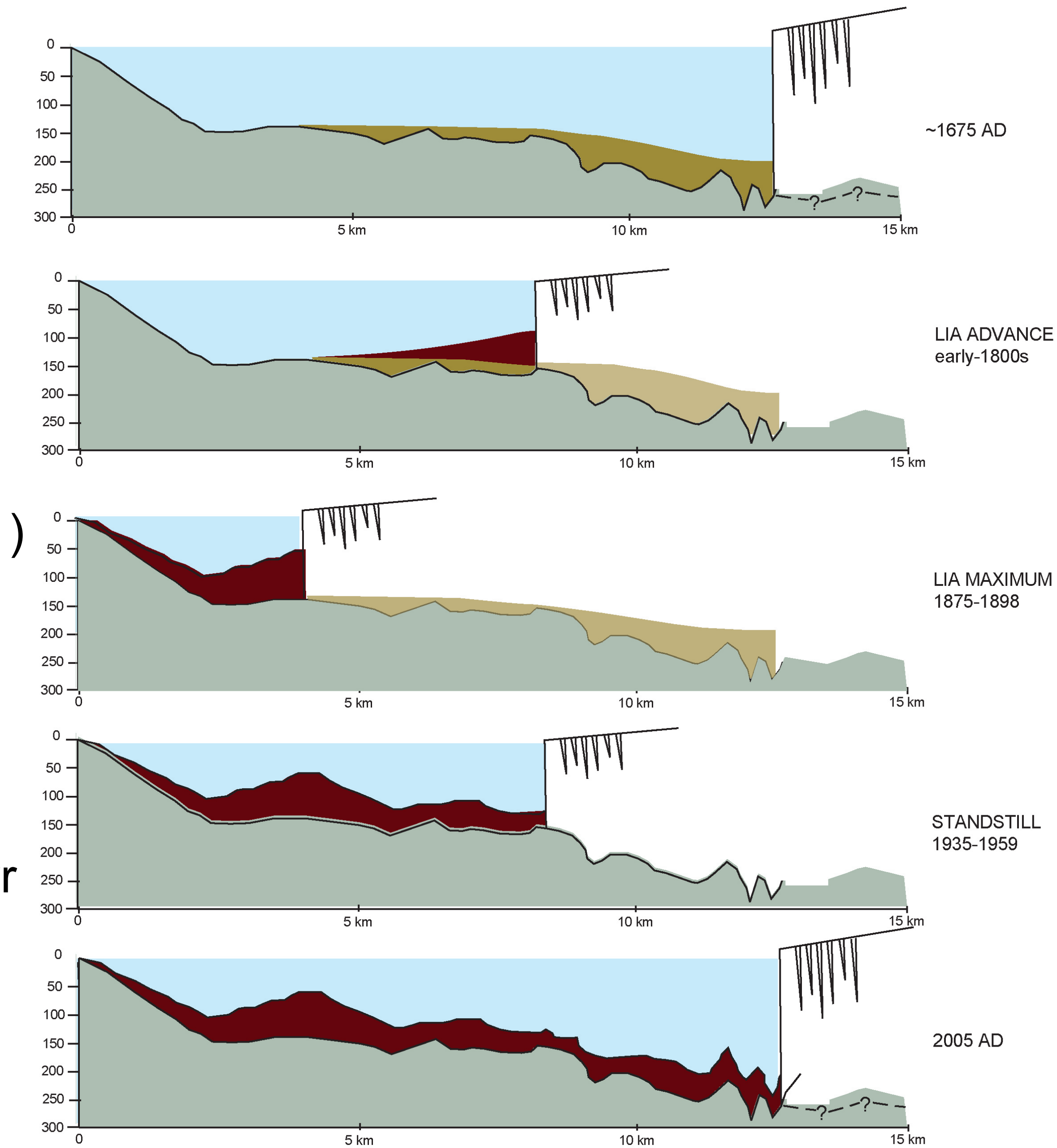
LIA standstill (1871-1905 A.D.)
= 34 ± 12 mm/yr

Start of fast retreat (1905-1921)
= 68 ± 26 mm/yr

End of retreat (1959-2005)
= 16 ± 12 mm/yr

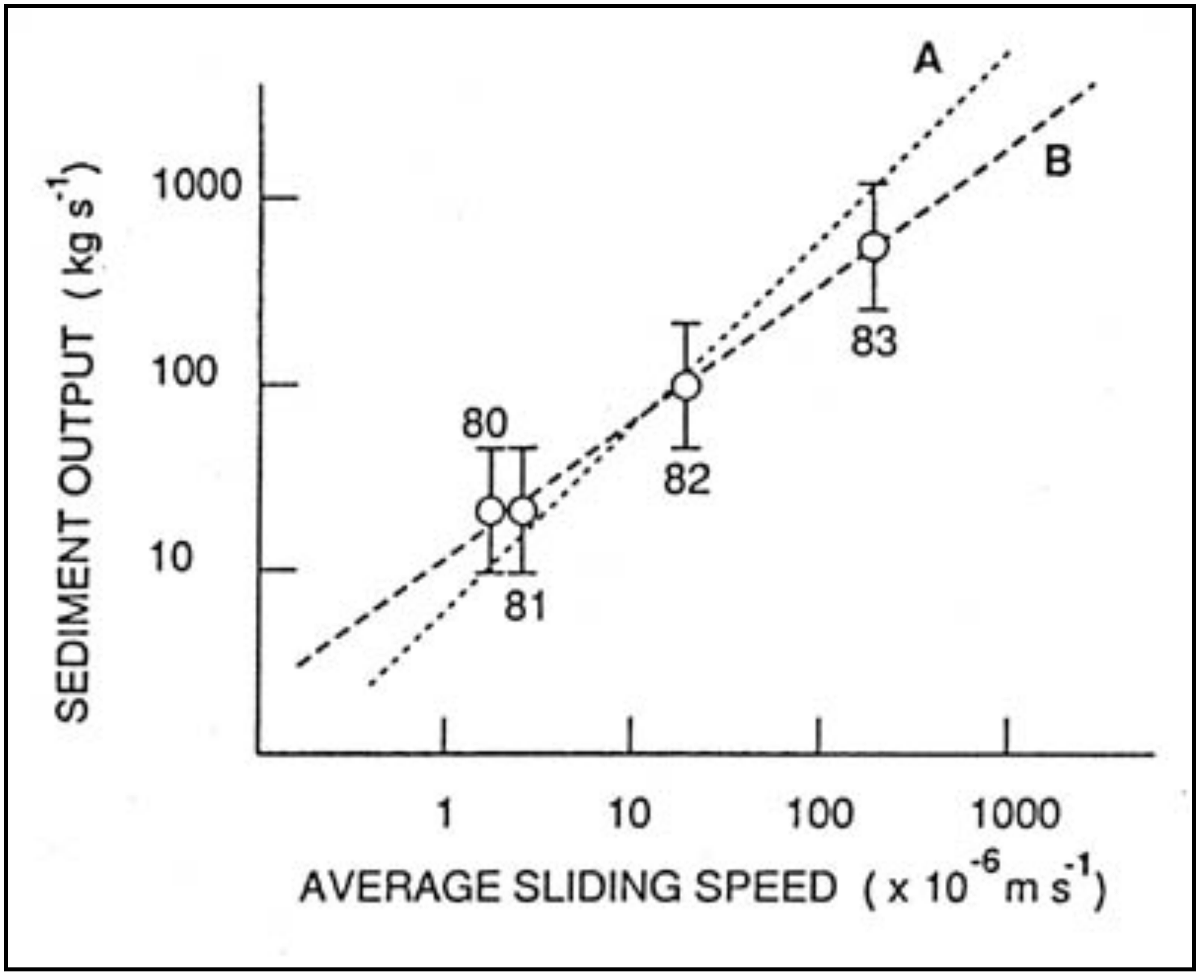
Average retreat = 23 ± 9 mm/yr

Erosion rate from AFT
= 1.3 mm/a



Variegated Glacier during surge cycle

(Humphrey and Raymond, 1994)



$$Q_S = k\overline{U_i}$$

Summary

- Erosion of glaciated landscapes is a function of climate –balance of the internal dynamics and thermal regimes of the glaciers
- Glacial erosion and sediment production is driven by ice speed and ice flux. It is greatest during periods of rapid retreat and ice acceleration
- Recent, centennial erosion rates from temperate glaciers are 1-2 orders of magnitude greater than million-year denudation rates,
- Erosion by temperate ice is up to 2 orders of magnitude greater than by cold-based ice
- Upland and subglacial storage is negligible in the long term