

Glacier and ice sheet reconstruction



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Glaciers erode rock and move sediment around



Glacier and ice sheet reconstruction

What can erosional and depositional landforms tell us about the...

- Extent*
- Thickness*
- Flow direction*
- Basal thermal regime*
- Surface slope*
- Hydraulic gradients*
- Basal shear stresses*

... of former glaciers?

What climate was needed to produce these glaciers?

- Equilibrium-line altitude*
- Summer (ablation season) temperatures*
- Winter accumulation*
- Snow-bearing winds*
- and more that Gerard Roe will be talking about*

Glacial erosion - polished and striated bedrock



Half Dome, Yosemite National Park, Calif.



Exfoliation or Sheetting Granite Domes.

Granite sheets thicken with depth

<http://gigapan.com/galleries/7749/gigapans/52181>

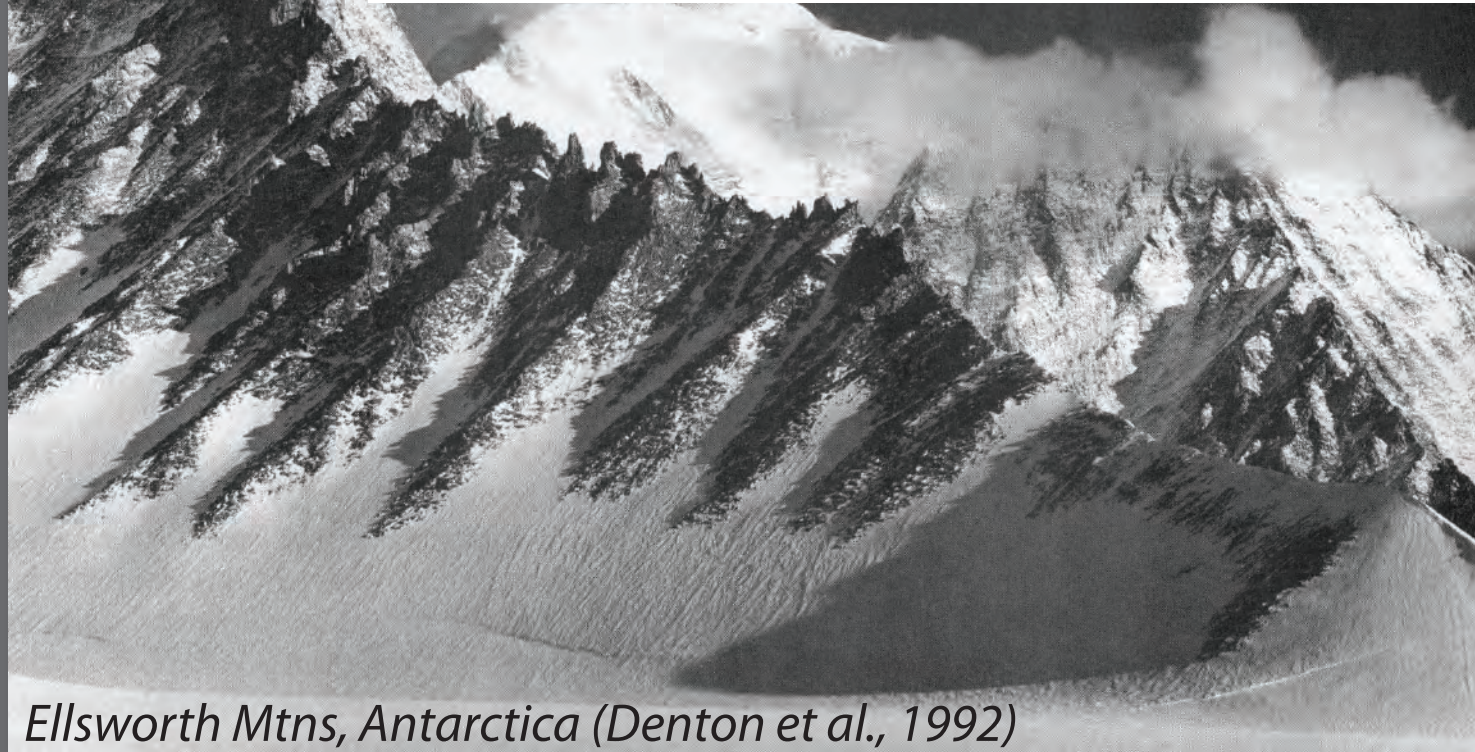
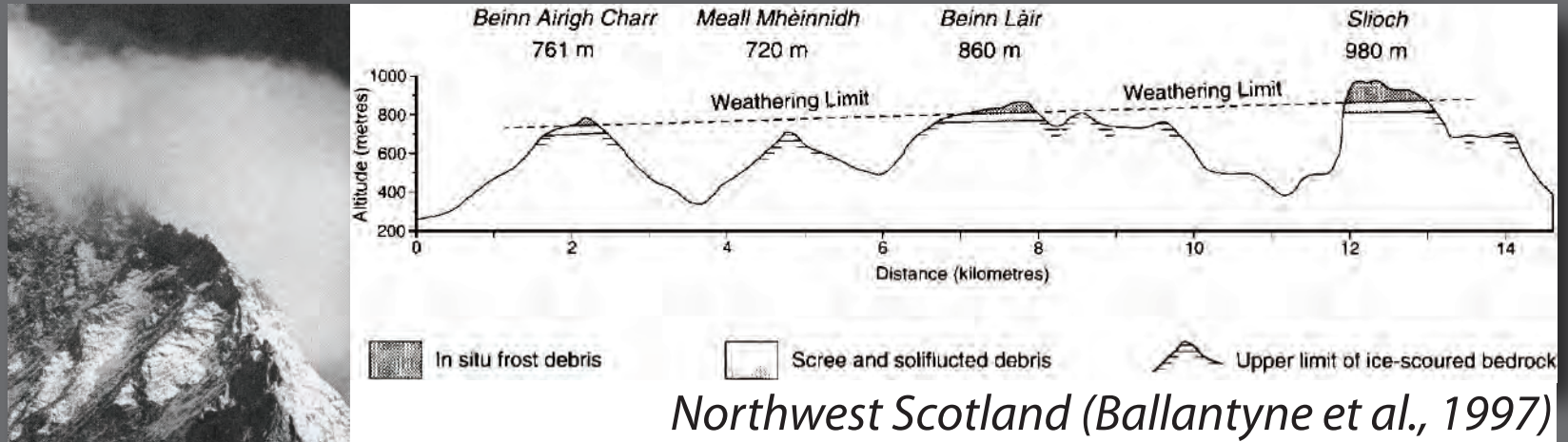


Becker, R. A. et al. incl. Iverson, N. R. (2014). Preexisting fractures & the formation of an iconic American landscape: Tuolumne Meadows, Yosemite National Park, USA. *GSA Today*, 24(11).

Glacial erosion - cirques and tarns



Glacial erosion - trimlines

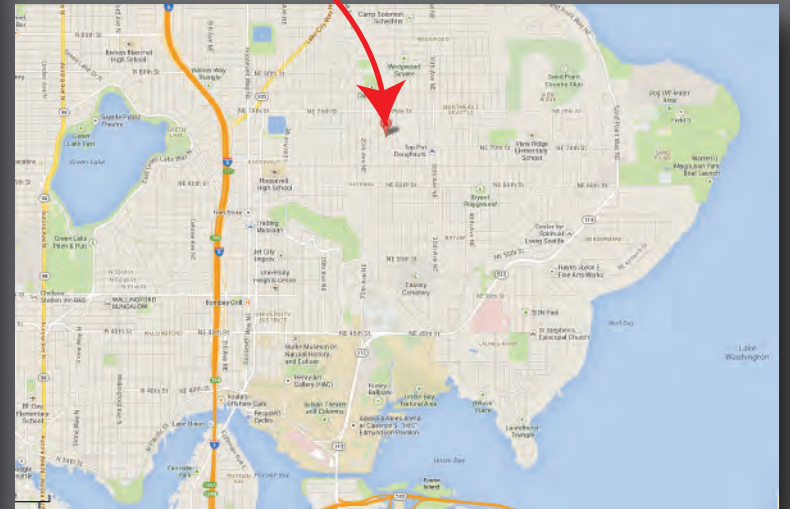


Ellsworth Mtns, Antarctica (Denton et al., 1992)

Glacial deposition - glacial erratics



Glacial deposition - glacial erratics





SEATTLE

Everett

Tacoma

Olympia

Seattle

Glacier Dyke

Sultan River

North Fork Skykomish

South Fork Skykomish

North Fork Snoqualmie

Middle Fork Snoqualmie

Snoqualmie Pass

South Fork Snoqualmie

Cedar River - Cedar Lake

Green River

White River

Chinook Pass
MT. RAINIER

OLYMPIA

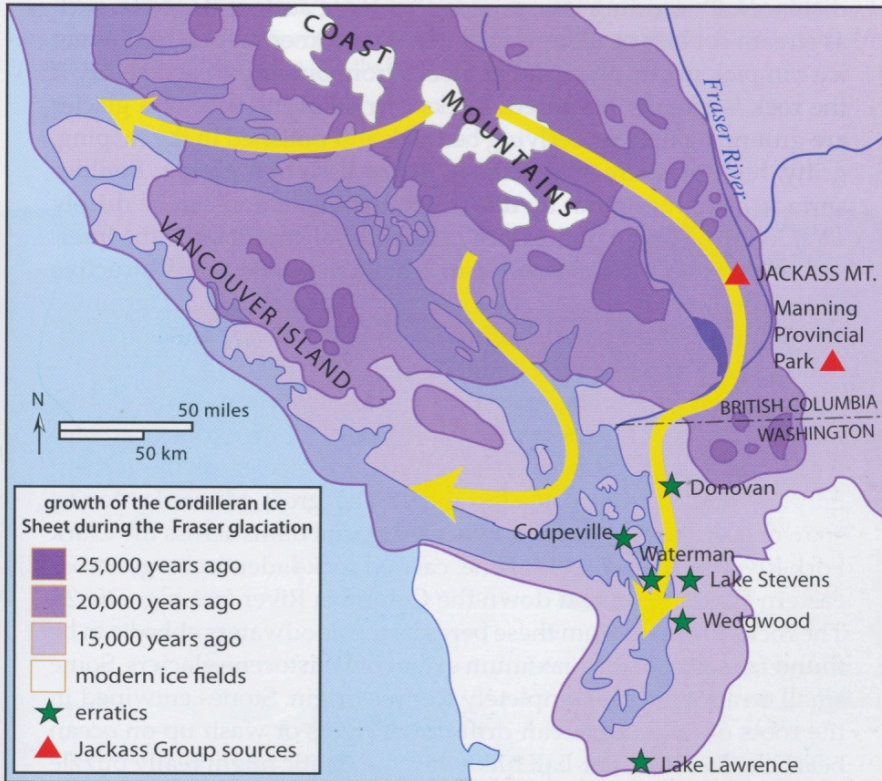
ACQUITY

MASSA

48°

47°

Erratics with distinctive lithology, Puget Sound



During the Fraser glaciation the Cordilleran Ice Sheet expanded radially from small ice caps covering mountains, such as those found today in British Columbia's Coast Mountains. The Puget Lobe flowed south into the Puget Lowland less than 20,000 years ago and reached its maximum southern extent around 15,000 years ago. (From Booth et al. 2003.)



Whatcom Community College geology instructor Doug McKeever spins the 3000 pound "Levitating Sphere" of from Donovan erratic of Jackass Mountain conglomerate.

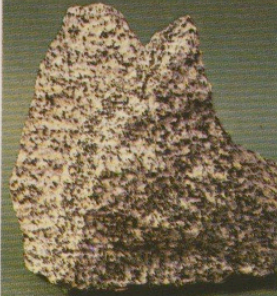




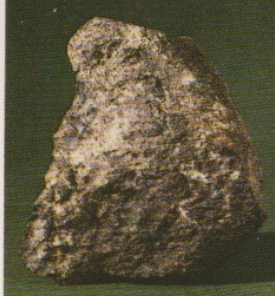
9/1



9/2



9/3



9/4

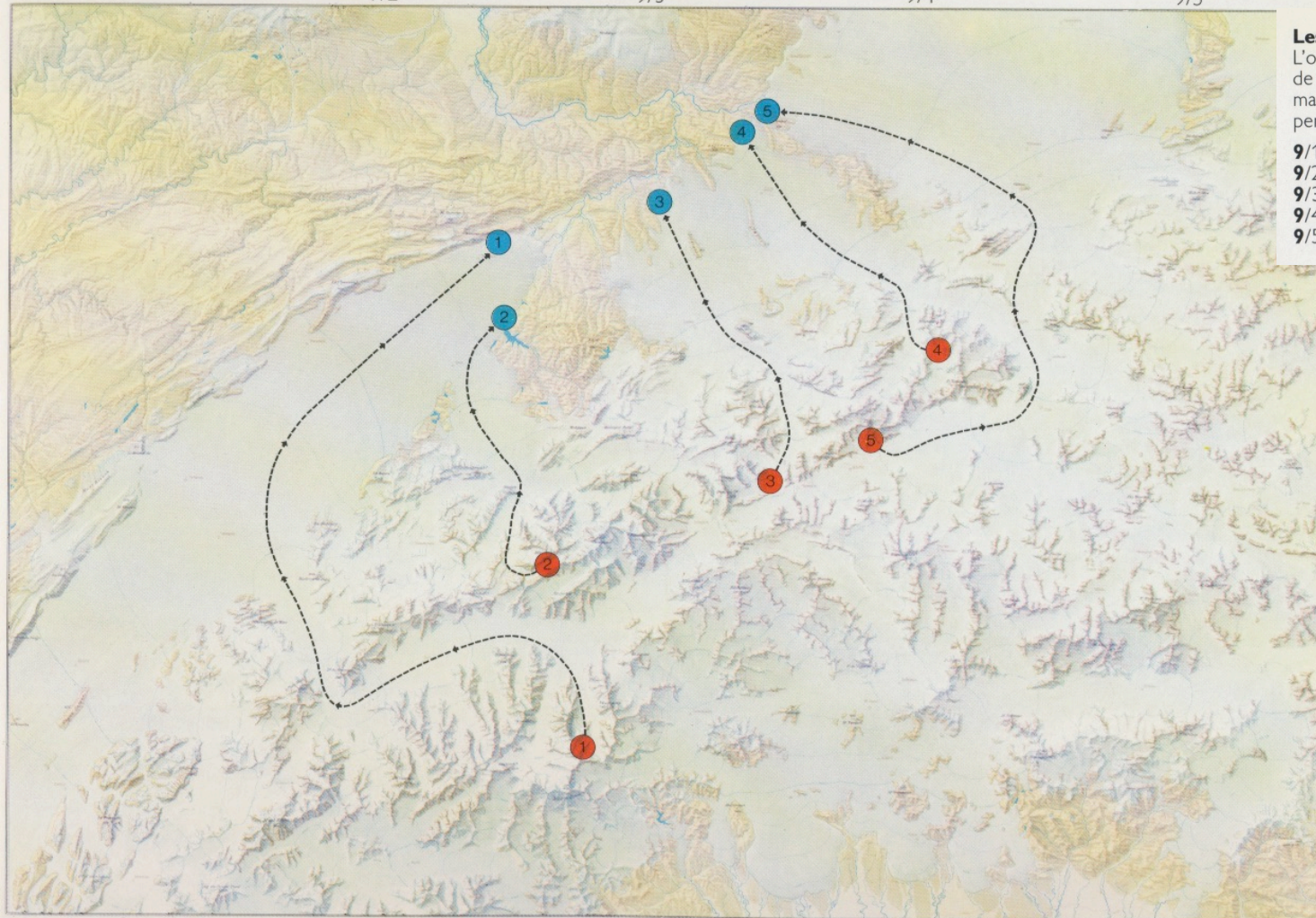


9/5

Les itinéraires des blocs erratiques

L'origine (rouge) et le lieu de découverte (bleu) de quelques blocs erratiques caractéristiques sont marqués sur la carte (10) représentant la Suisse pendant le dernier âge glaciaire.

- 9/1 Gabbro de la vallée de Saas Glacier du Rhône
- 9/2 Granite de Gastern Glacier de l'Aar
- 9/3 Granite des Schöllenen Glacier de la Reuss
- 9/4 Sernifite (Verrucano) Glacier de la Linth
- 9/5 Granite de Punteglias Glacier du Rhin



Glaciers et névés durant la dernière période glaciaire (Würmien), stade maximum

Territoires libres de glaces
Graviers fluvio-glaciaires des basses

Ancien lac

From La Suisse
et ses Glaciers,
1980

Glacial deposition - moraines



*Little Ice Age moraines on
Easton Glacier, Mt Baker*

Photo: John Scurlock

Glacial advance & landform dating - dendrochronology

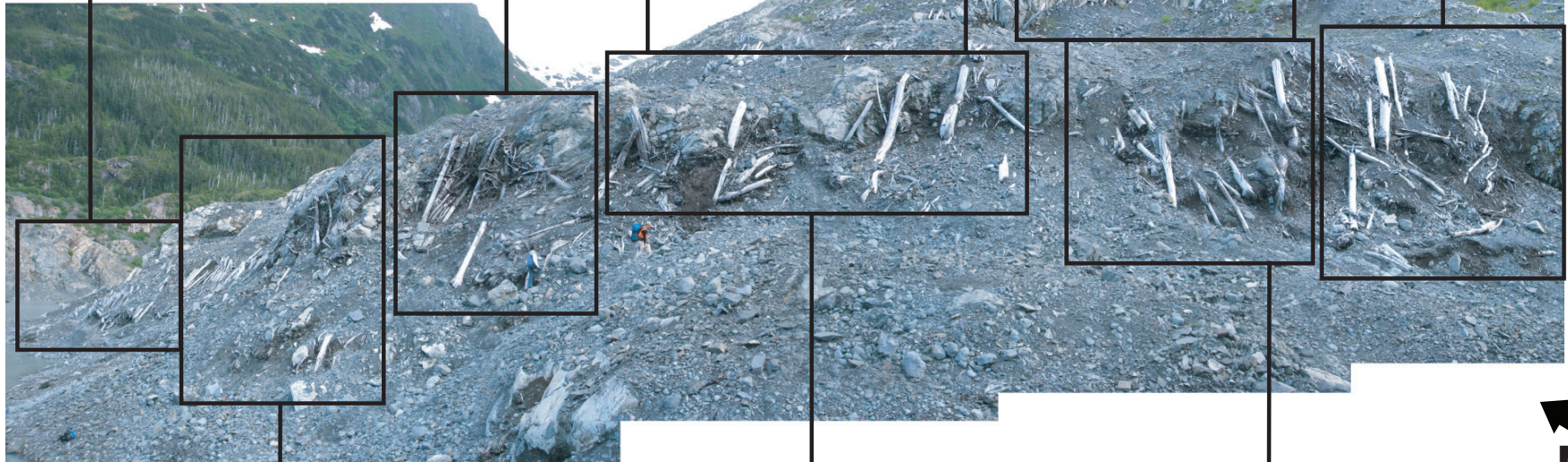
Site 3: CG05-09 (1786AD)
(61.08469N, 146.96613W, 18.5m - 21m)

Site 8: CG05-14 (1809AD)
(61.08381N, 146.96681W, 68.5m - 70m)

Site 1: CG05-07 (1777AD)
(61.08491N, 146.96585W, 7m - 10.5m)

Site 7: CG05-13 (1807AD)
(61.08398N, 146.96706W, 50m - 53m)

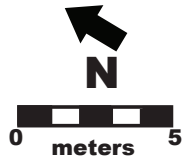
Site 6: CG05-12 (1799AD)
(61.08412N, 146.96684W, 41.5m - 49.5m)



Site 2: CG05-08 (1783 AD)
(61.08479N, 146.96588W, 11.5m - 18.5m)

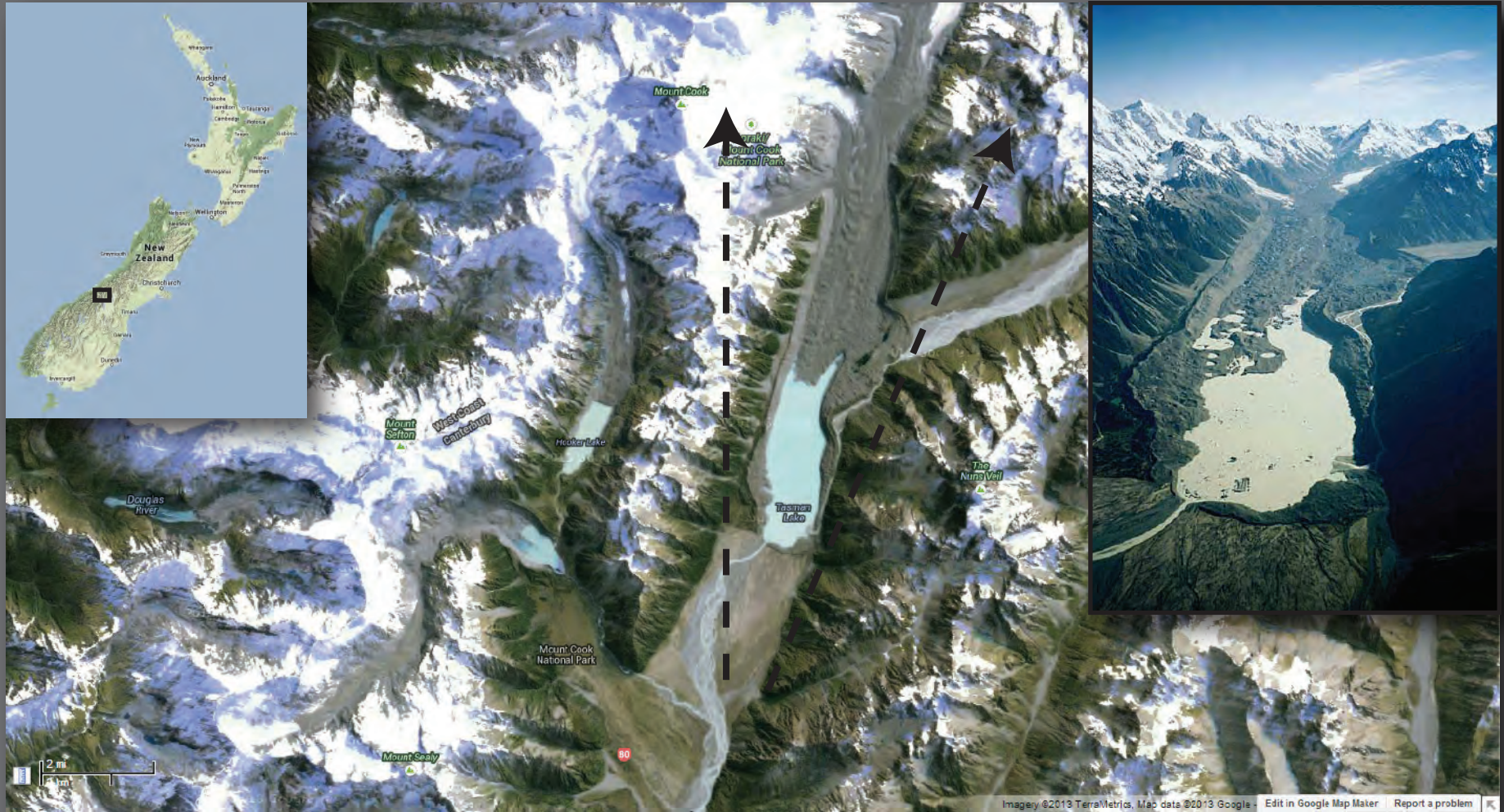
Site 4: CG05-10 (1792 AD)
(61.08436N, 146.96635W, 27m - 31.5m)

Site 5: CG05-11 (1798 AD)
(61.08421N, 146.96643W, 33m - 35.5m)

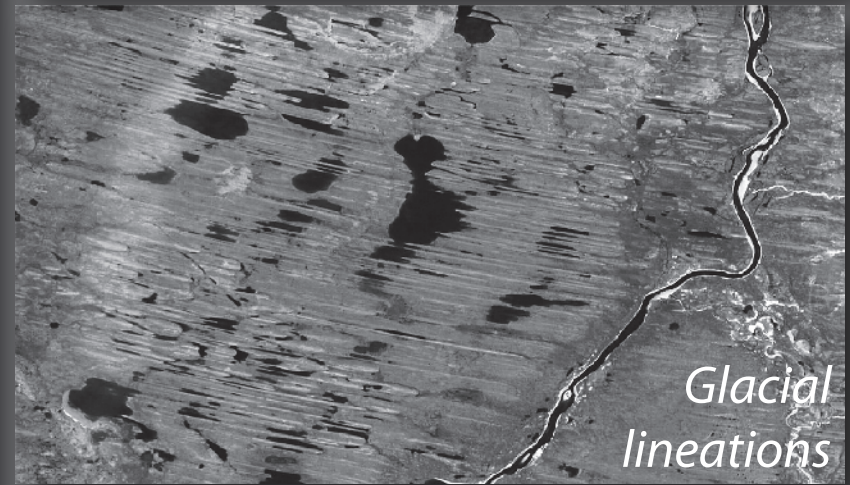
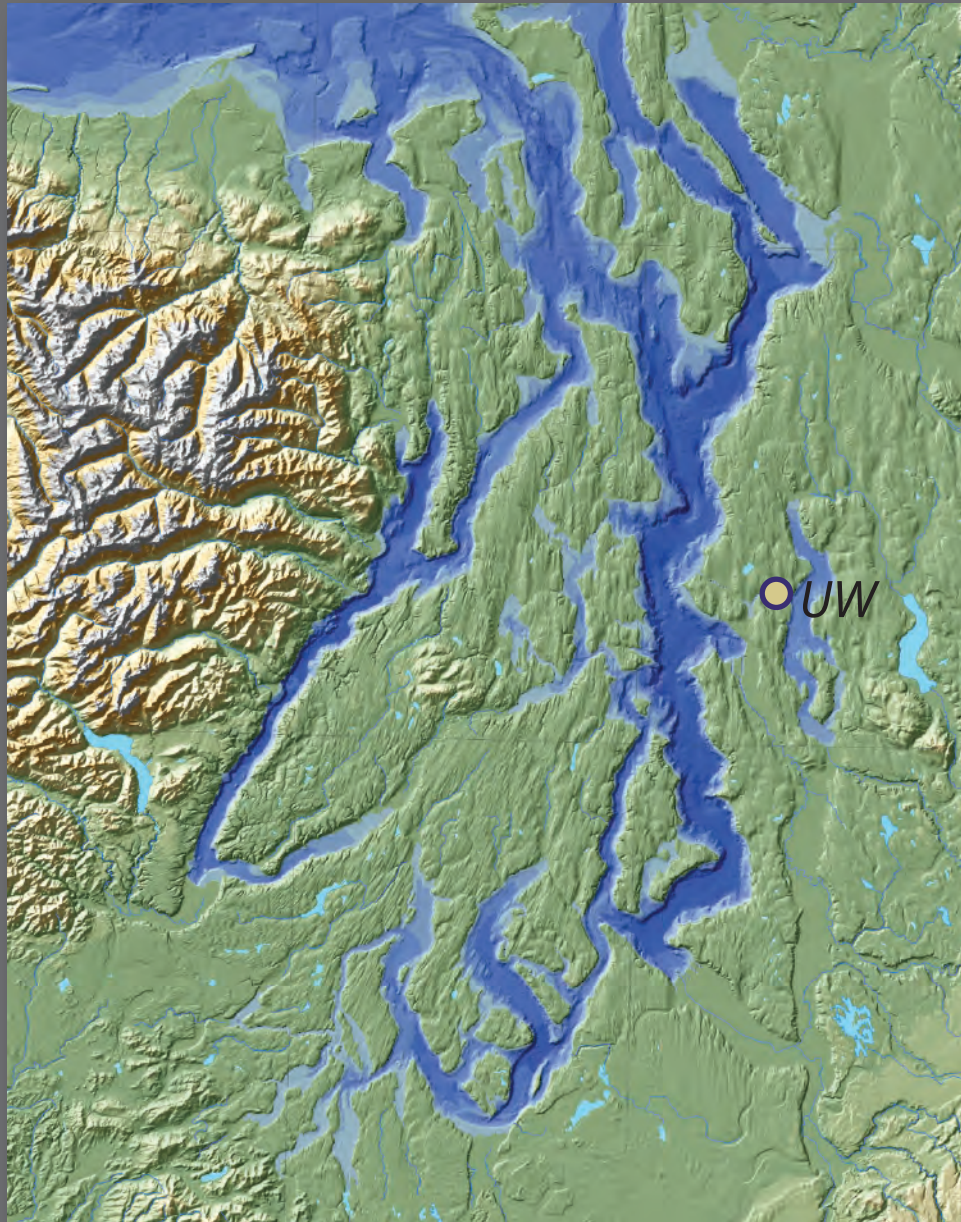


Land-Lobe Glacier, next to Columbia Glacier, Alaska
Courtesy of Greg Wiles

Glacial deposition - moraine limits

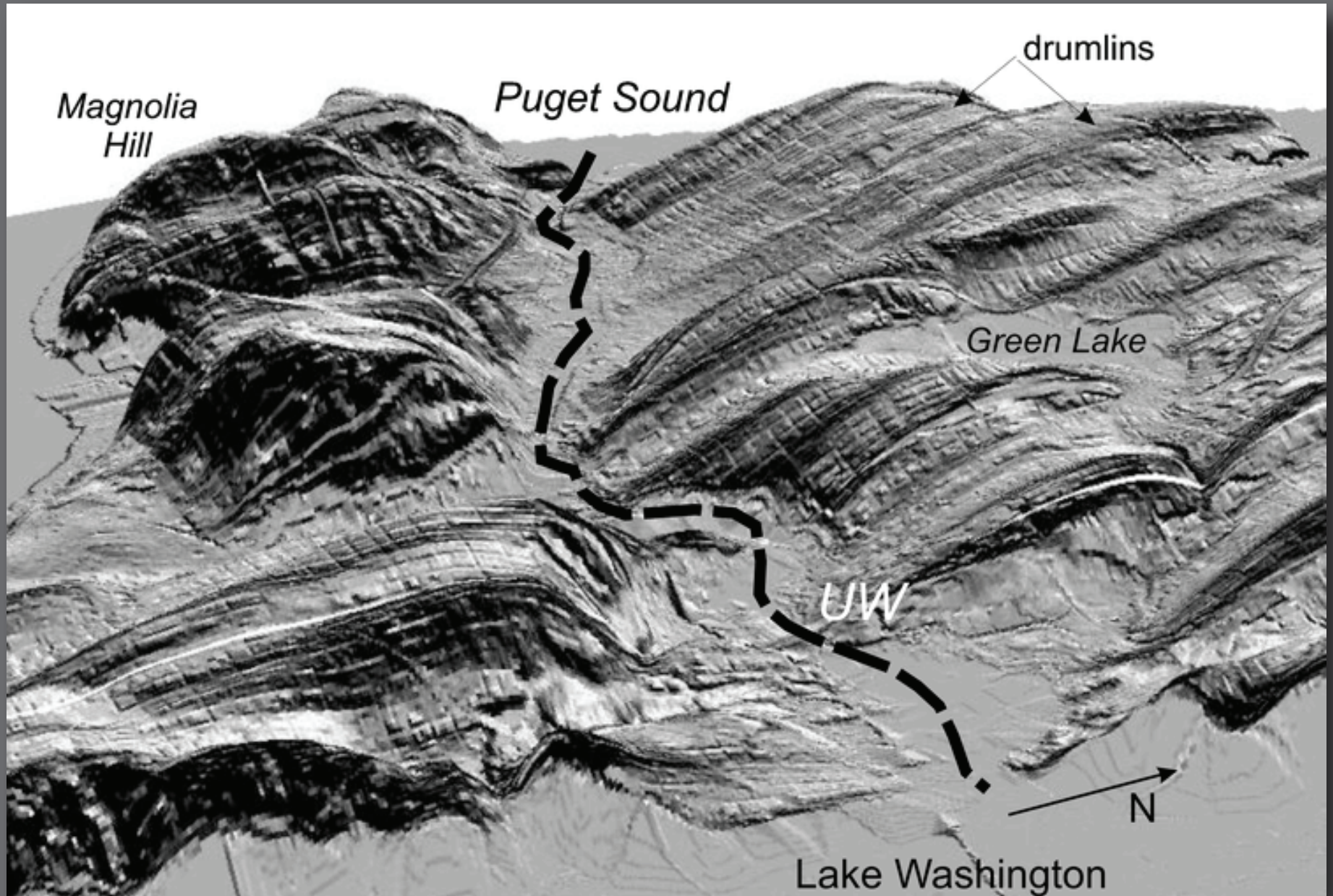


Streamlined subglacial bedforms



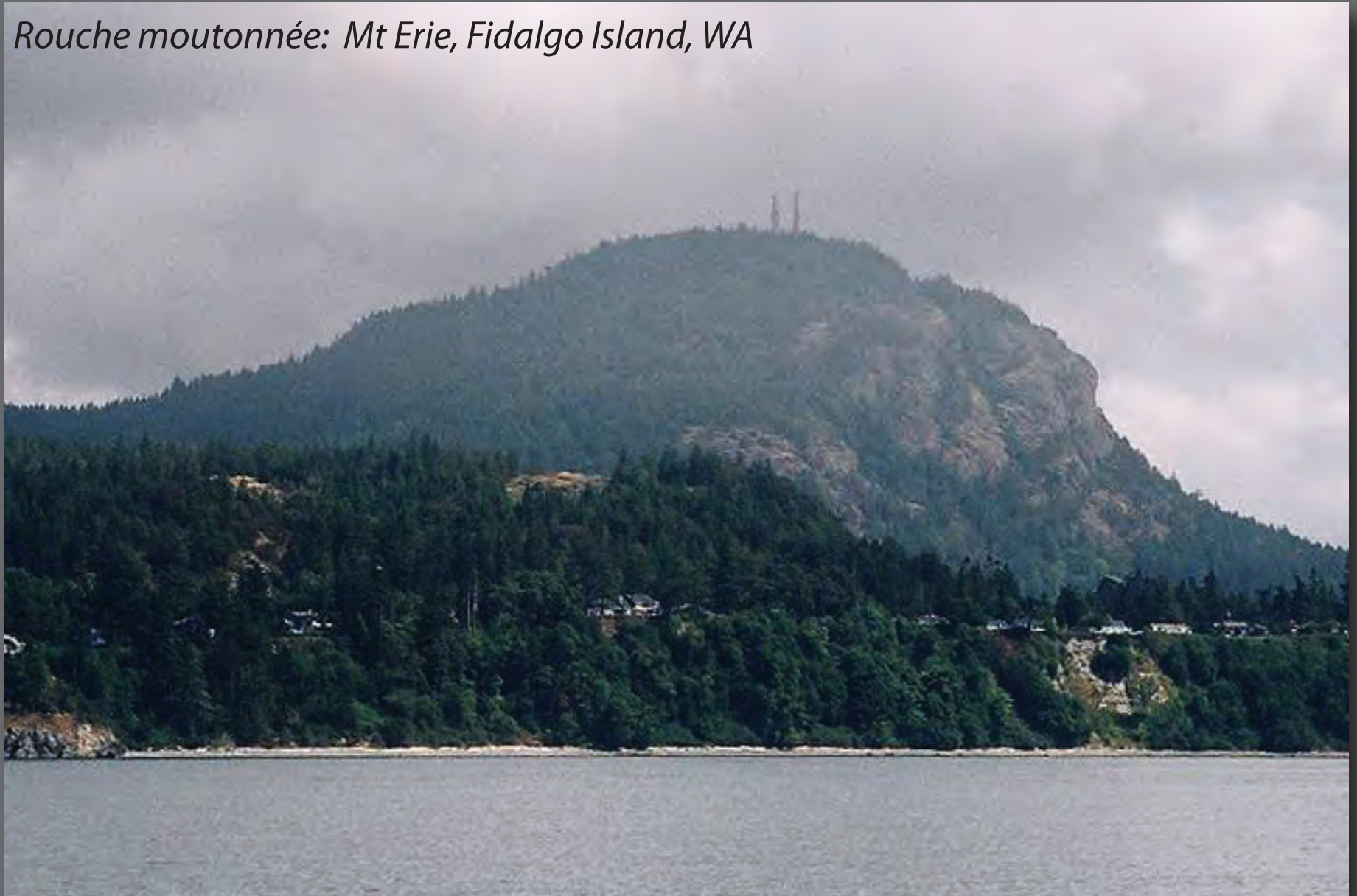
- Poorly understood (hard to observe subglacial formation)
- Erosion? Accretion? Both?

Streamlined subglacial bedforms



Streamlined subglacial bedforms

Rouche moutonnée: Mt Erie, Fidalgo Island, WA



Glacial deposition - eskers



Subglacial tunnel, somewhere in Iceland



*Esker melting out of Brúarjökull, Iceland
Photo: L.R. Bjarnadóttir*

Glacial deposition - eskers

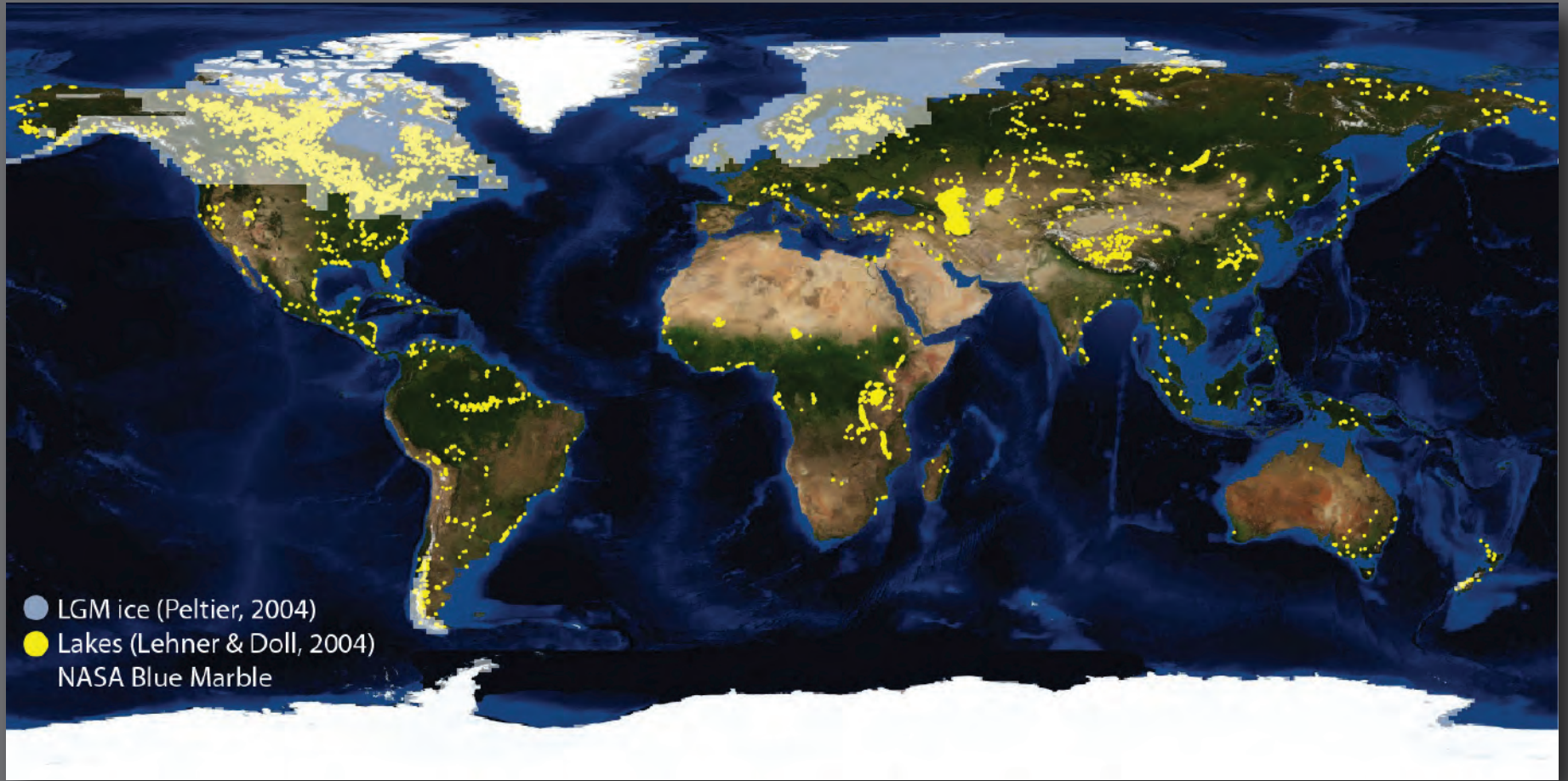
Rörströmssjön, Sweden



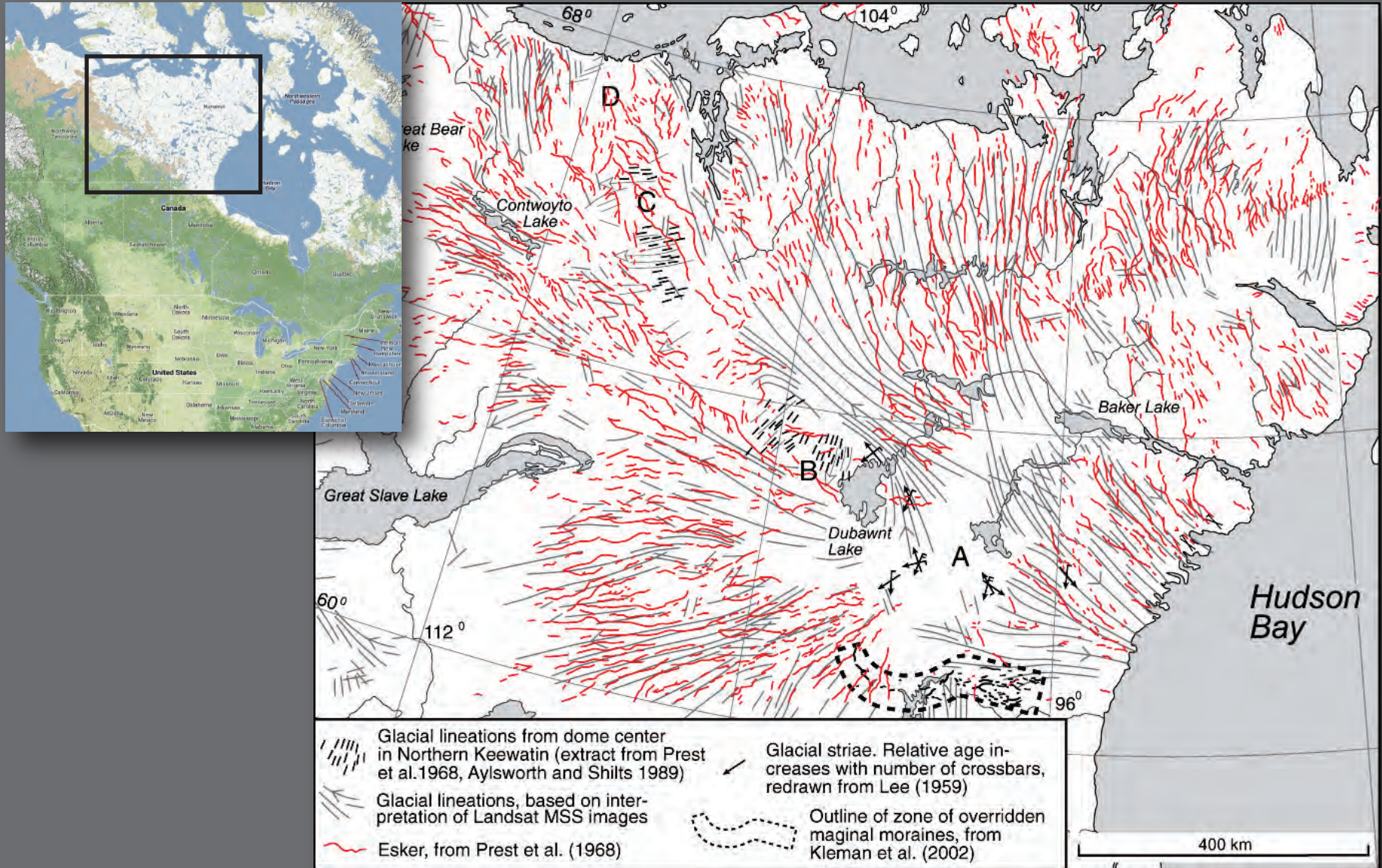
Image © 2013 Lantmäteriet/Metria
Image Landsat
Image IBCAO

Google earth

Glacial erosion -lakes



Glacial landform assemblages - Keewatin



Kleman et al., 2006

Survival and superimposition of landforms



Image Landsat

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data LDEO-Columbia, NSF, NOAA

Google earth

Convict Lake moraines, Sierra Nevada

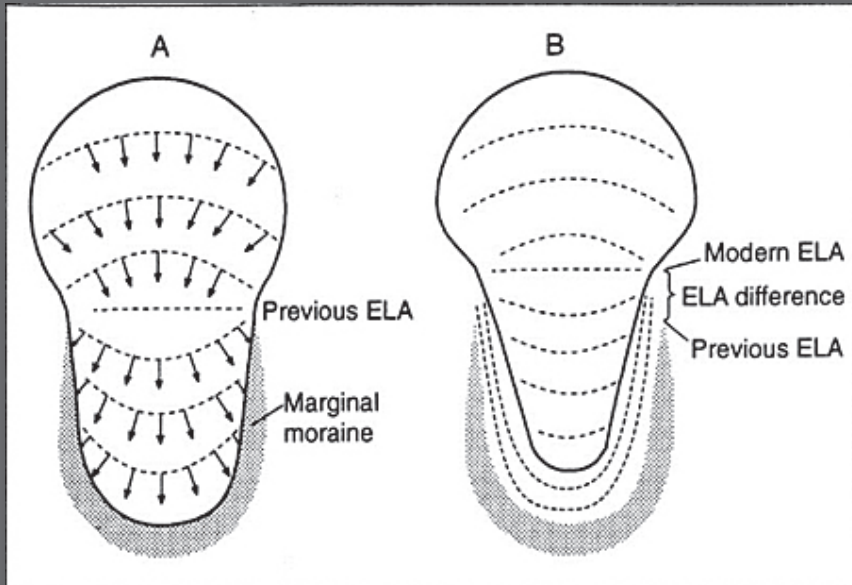
Equilibrium-line reconstruction

Equilibrium-line altitude (ELA):

- Long-term snowline
- Fairly consistent among neighboring valleys (in a given climate)
- Approximates the 0°C isotherm

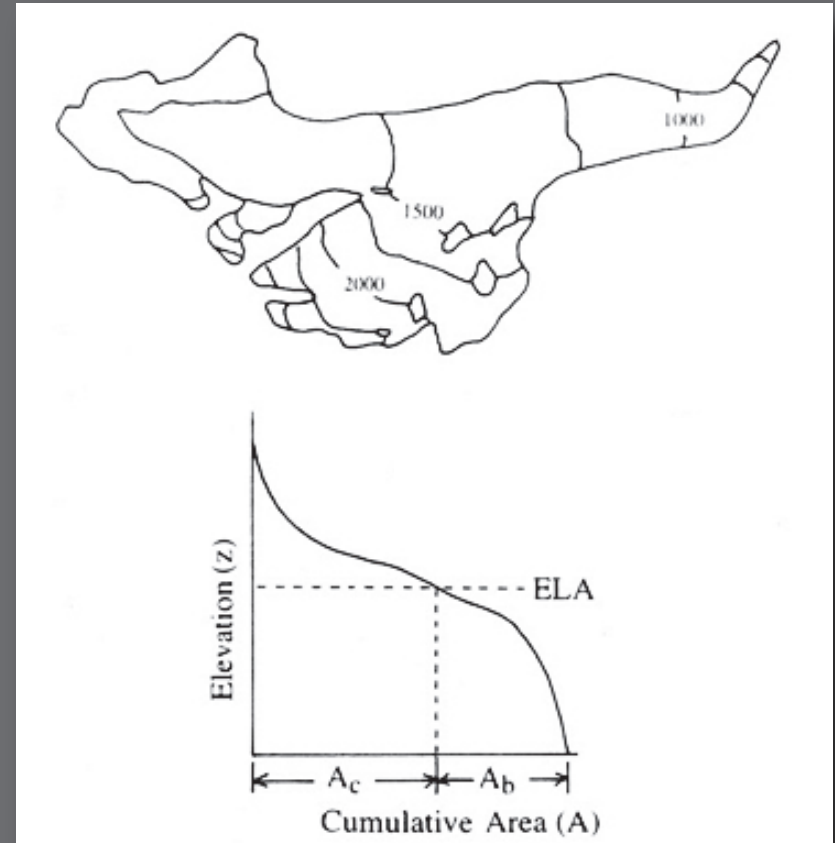
Elevation of lateral moraines:

- Accumulation area: flow is down and inward
- Ablation area: flow is up and outward
- Lateral moraines begin roughly at ELA

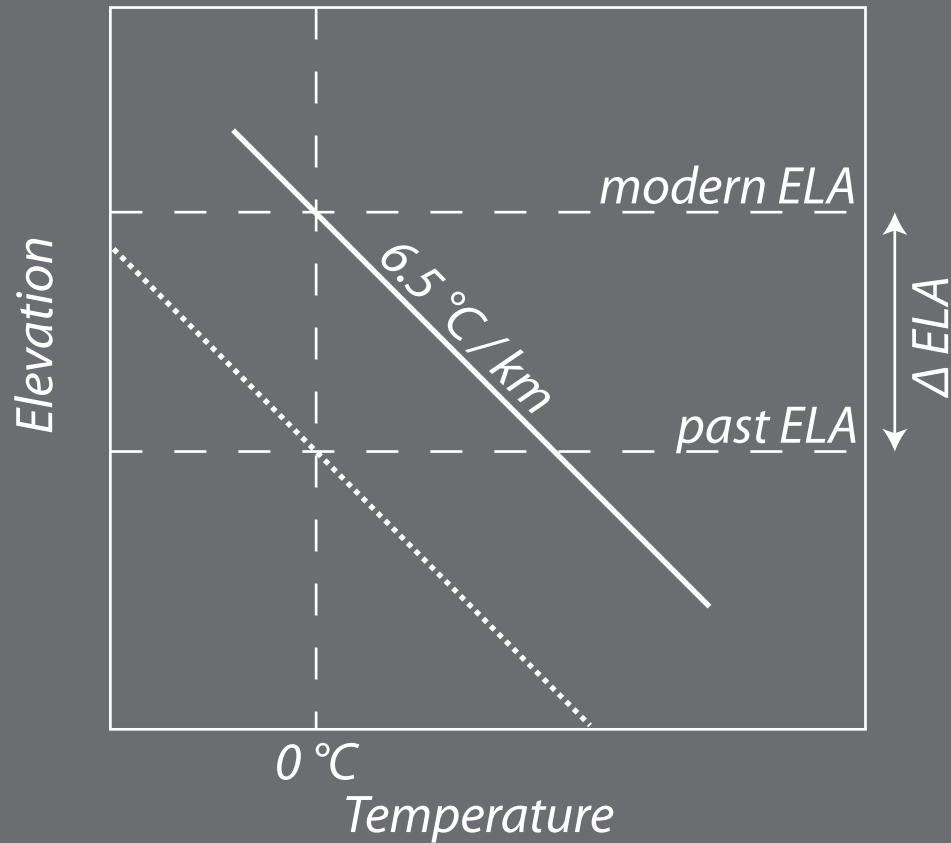


Accumulation-area ratio (AAR):

- $\text{AAR} = \text{accumulation area} / \text{total area}$
- $\text{AAR} \sim 0.65$ for many modern glaciers
- Calculate prior ELA from reconstructed glacier length and hypsometry



Paleo-climate estimates



Assumptions:

- Past lapse rate is same as modern
- Snowfall has been constant

Glacial landform dating



Glacial landform dating - dendrochronology



From Porter & Swanson, QUATERNARY RESEARCH 50, 205–213 (1998)

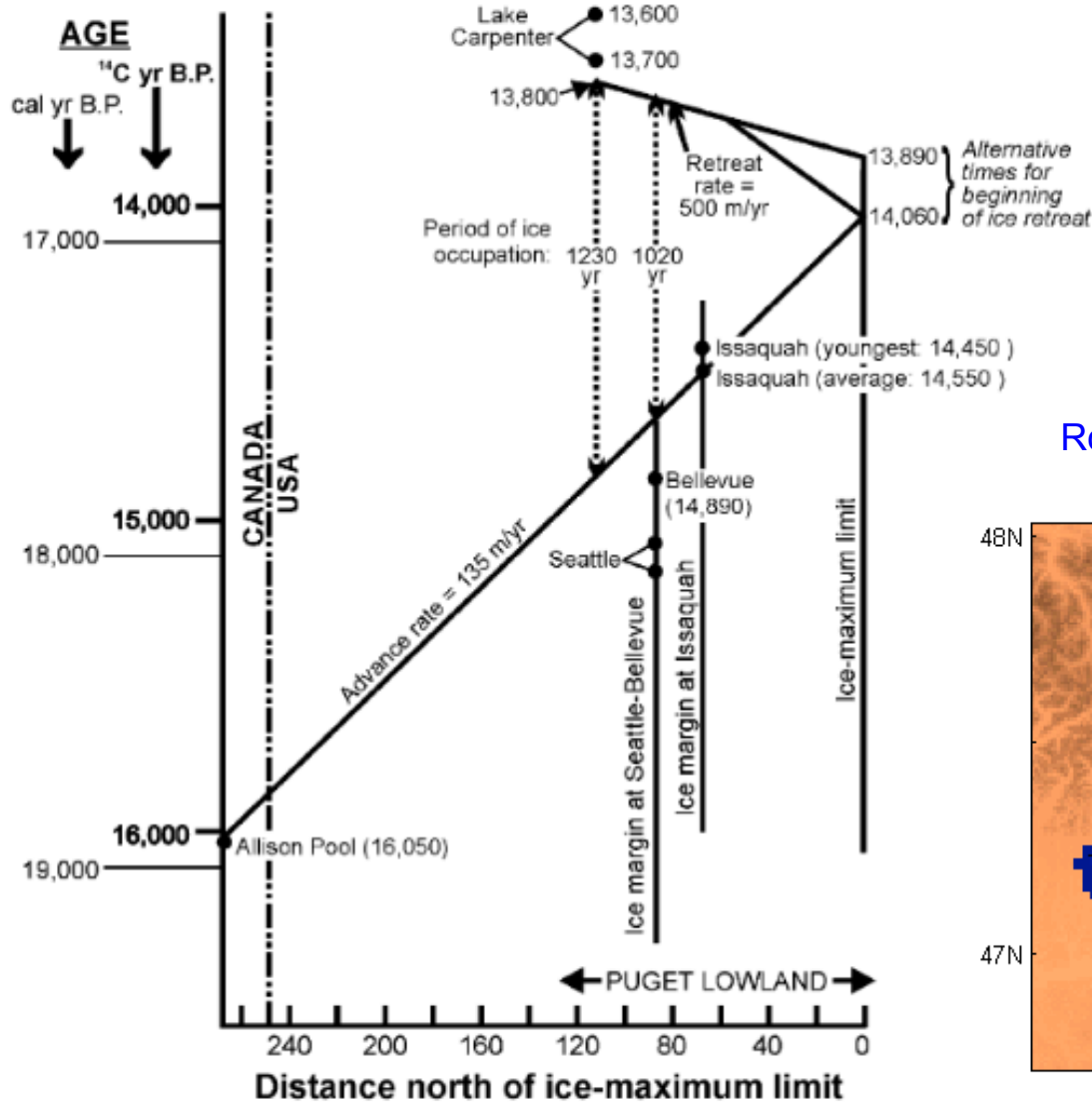
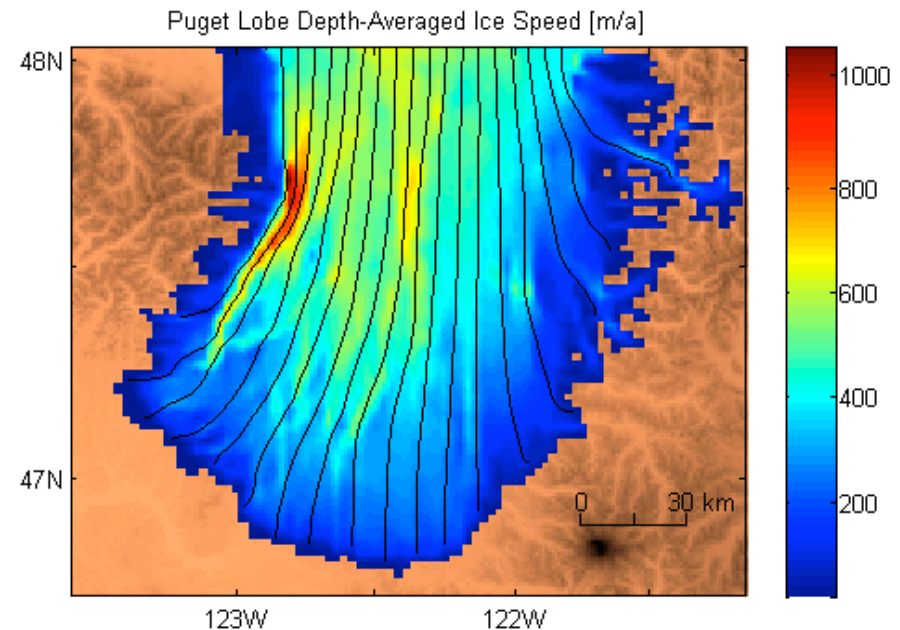


Fig. 9. Rates of Puget lobe advance and retreat in the Puget Lowland during the Vashon Stage (modified from Porter & Swanson, 1998). Rapid advance and retreat are required to honor the limiting radiocarbon dates from Lake Carpenter, Seattle, Bellevue, and Issaquah. Maximum ice-sheet extent could have persisted at most a few hundred years.

Robert Sheerer's 2-D model at 2.1 km-resolution



Glacial landform dating - lichen growth



Rhizocarpon Geographicum

Porter, 1981

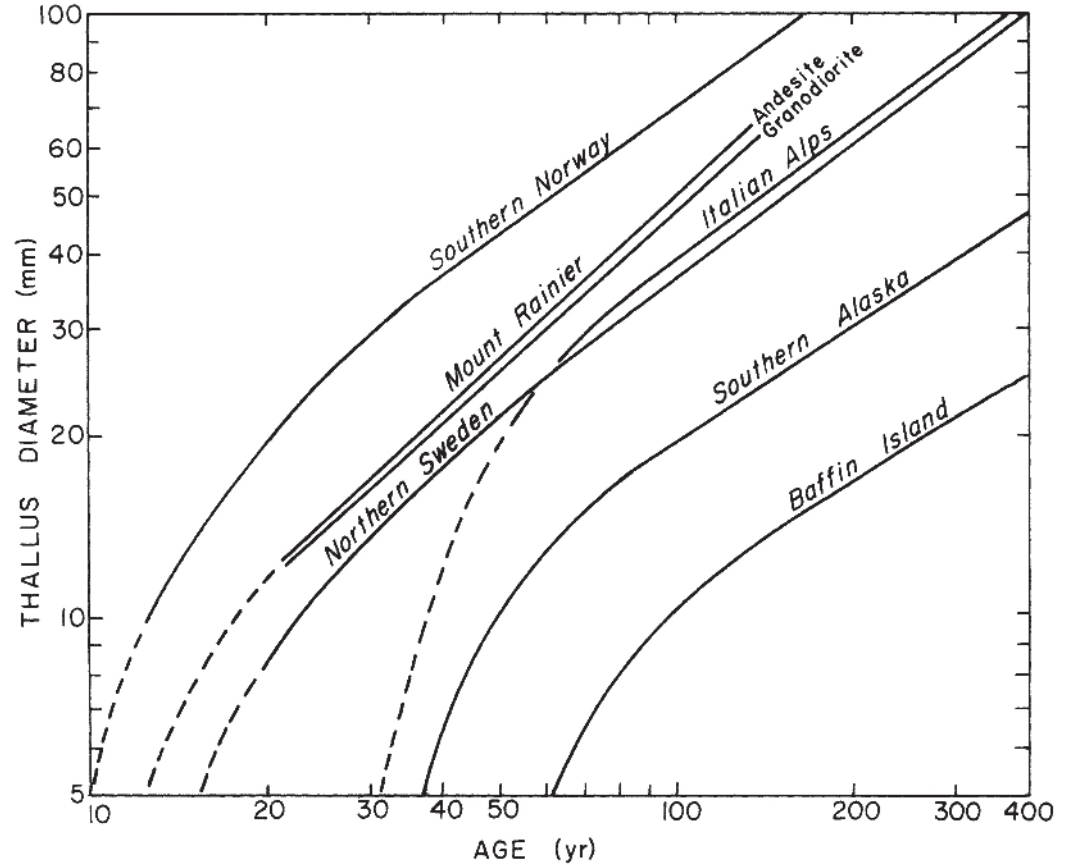
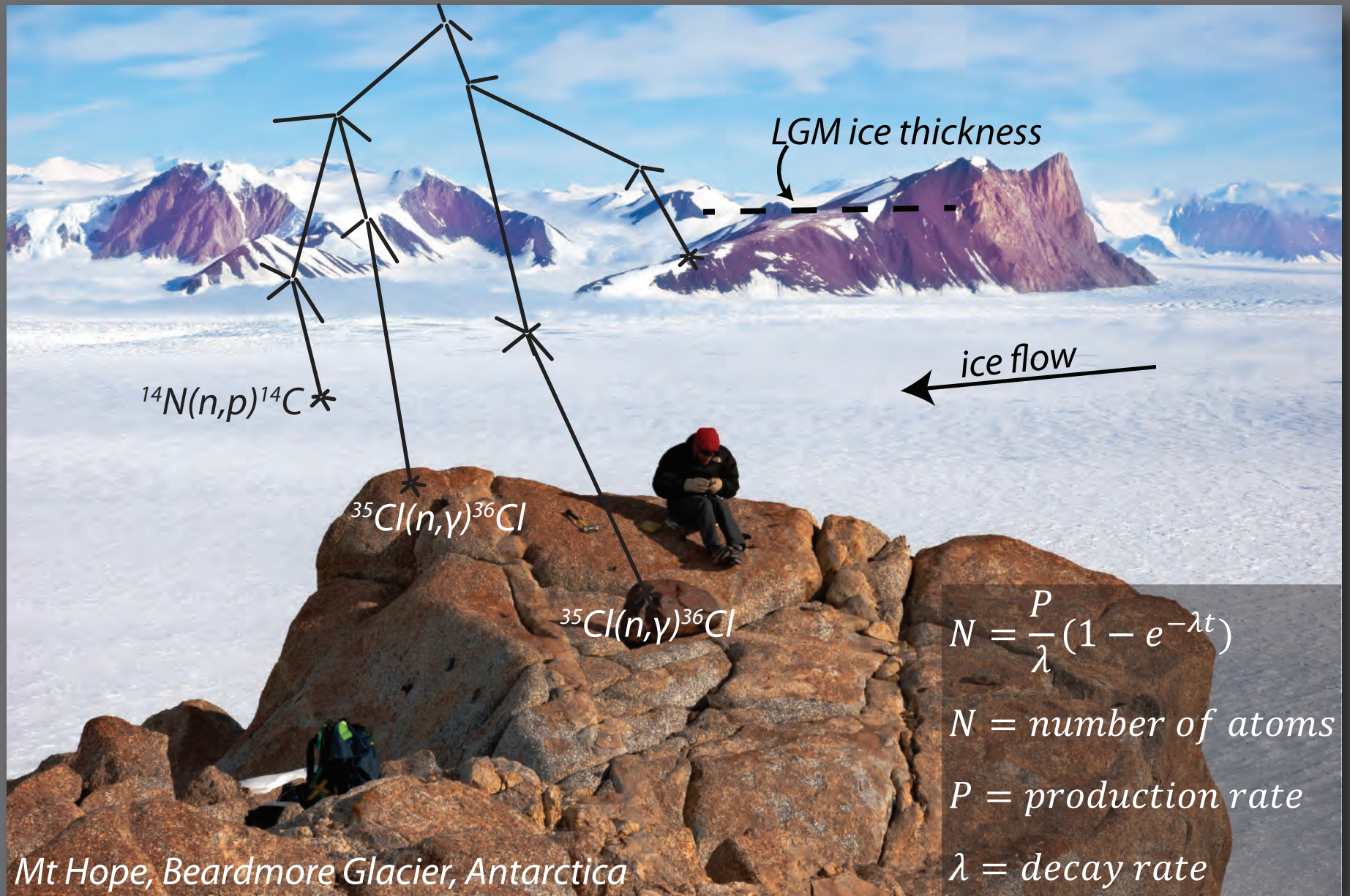


FIGURE 4. Growth curves of *Rhizocarpon geographicum* for selected Northern Hemisphere sites. See Table 4 for sources of data. Dashed portion of curves indicate segments where control data are lacking or of minimal quality.

Glacial landform dating - volcanic ash



Glacial landform dating - exposure dating



$^{14}\text{N}(n,p)^{14}\text{C}^*$

$^{35}\text{Cl}(n,\gamma)^{36}\text{Cl}$

$^{35}\text{Cl}(n,\gamma)^{36}\text{Cl}$

LGM ice thickness

ice flow

$$N = \frac{P}{\lambda} (1 - e^{-\lambda t})$$

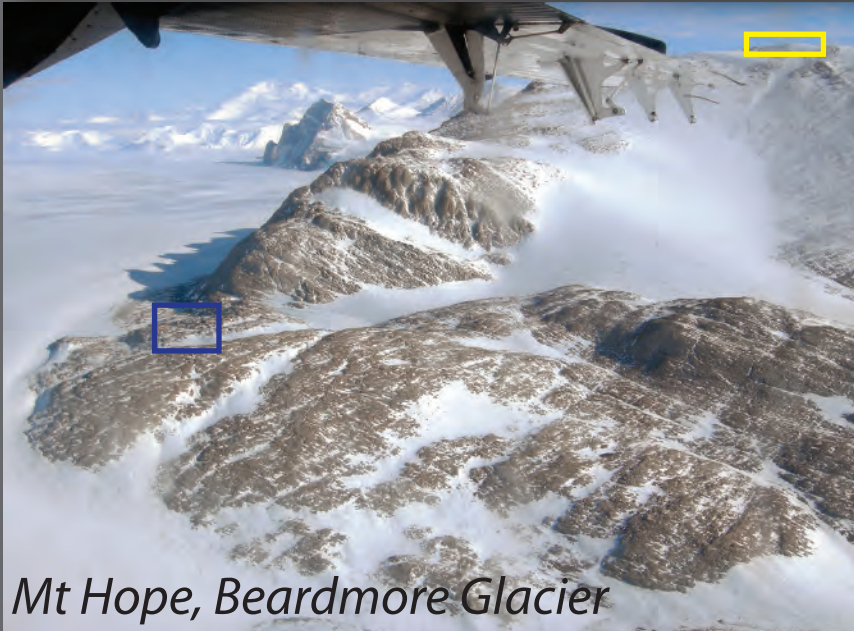
$N = \text{number of atoms}$
 $P = \text{production rate}$
 $\lambda = \text{decay rate}$

Mt Hope, Beardmore Glacier, Antarctica

Beardmore Glacier - polythermal LGM ice

Summit:

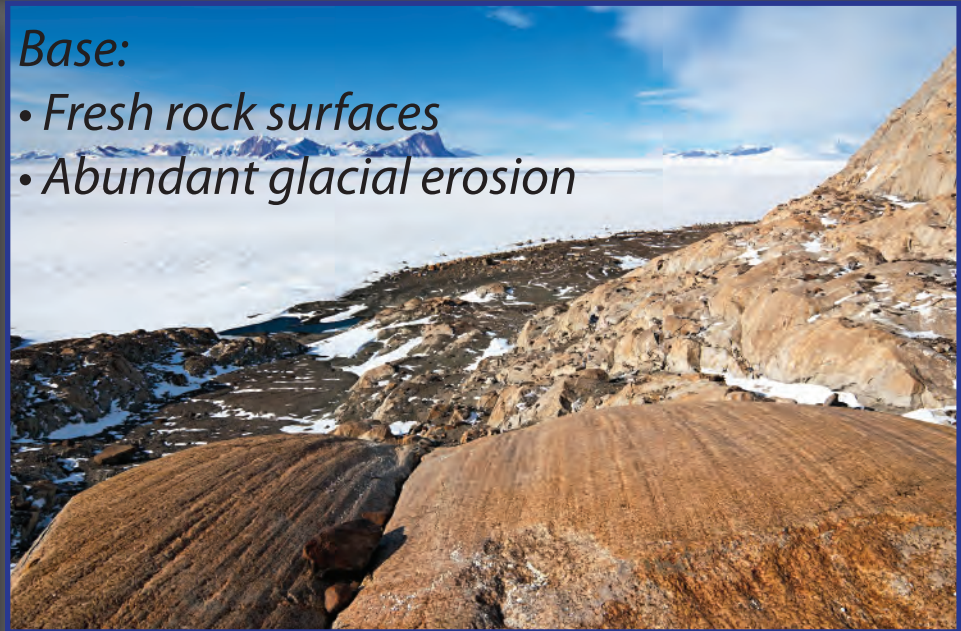
- Old, weathered rock
- No glacial erosion



Mt Hope, Beardmore Glacier

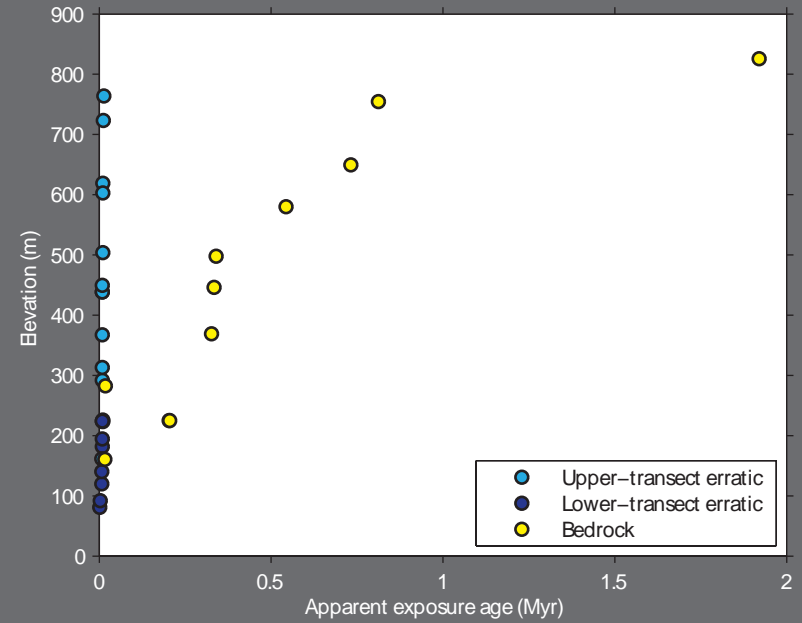
Base:

- Fresh rock surfaces
- Abundant glacial erosion

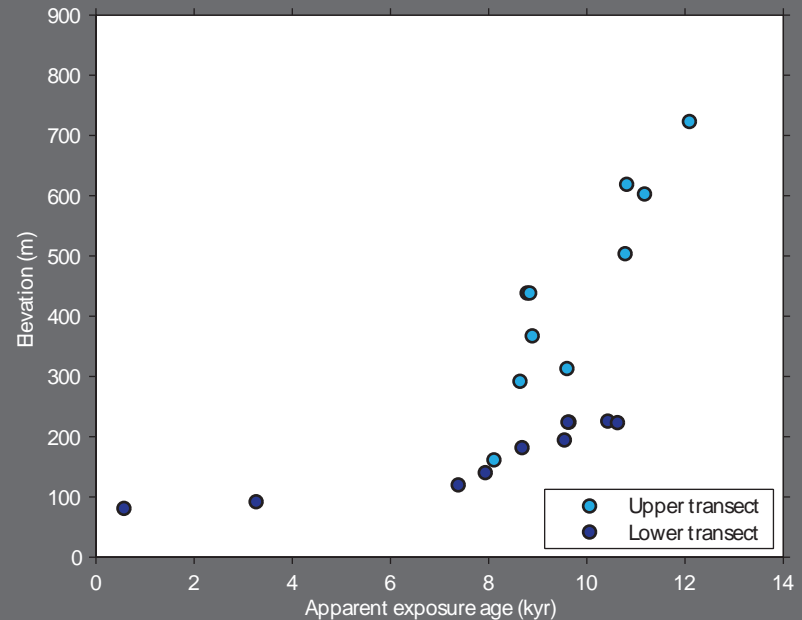


Beardmore Glacier - exposure ages

Glacial erratic on bedrock

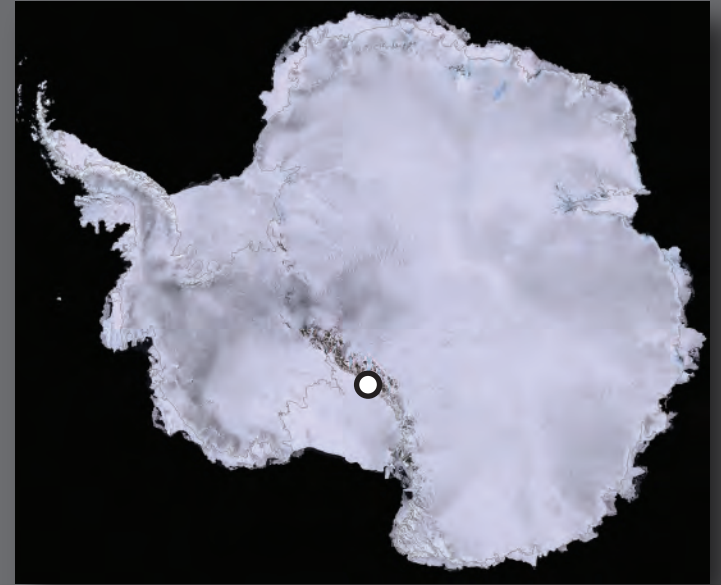


Mt Hope, Beardmore Glacier

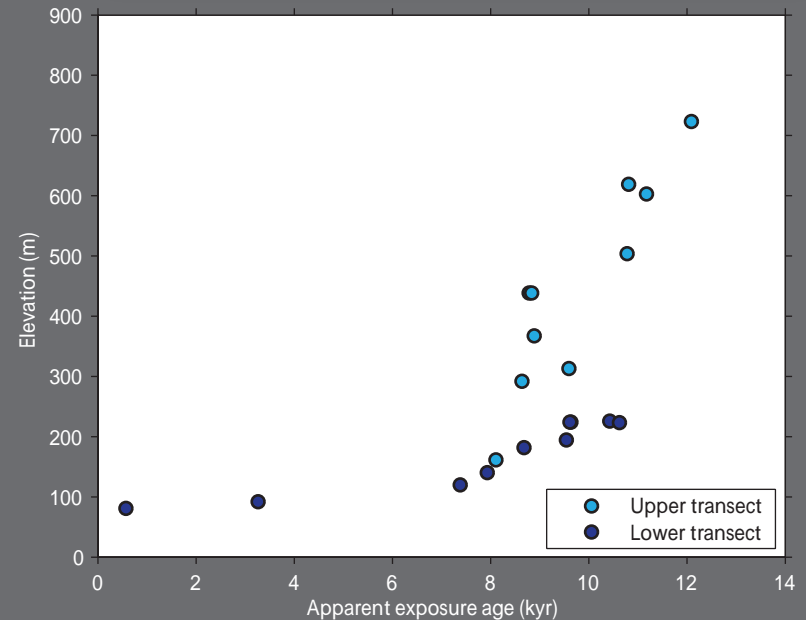


Beardmore Glacier - post-LGM deglaciation

Glacial erratic on bedrock



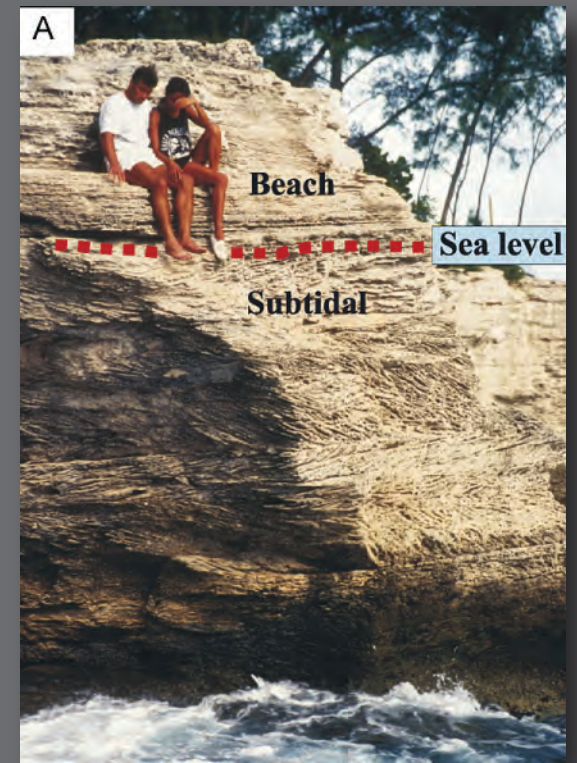
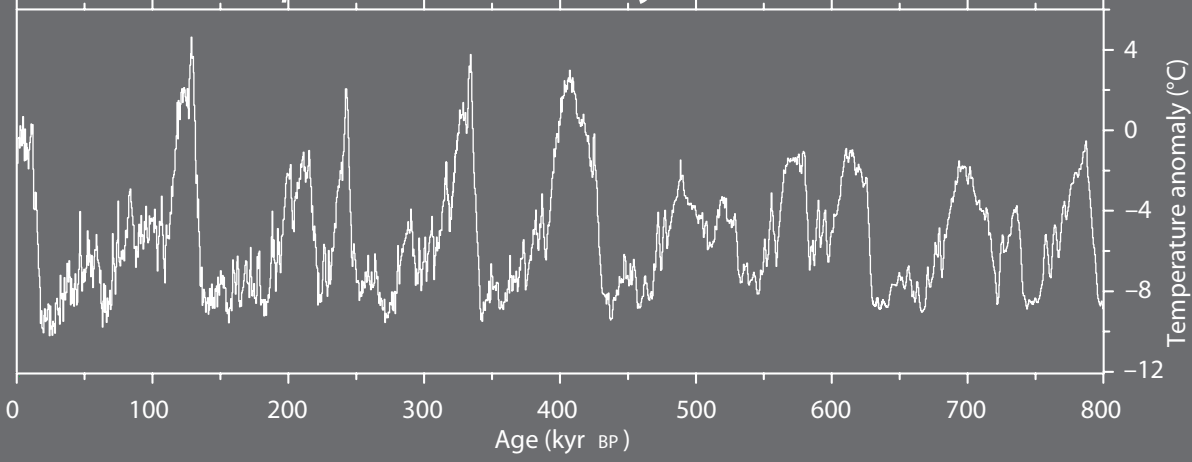
Mt Hope, Beardmore Glacier



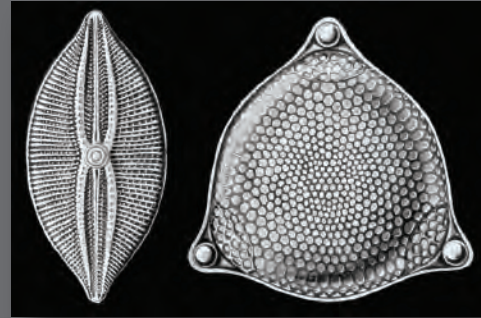
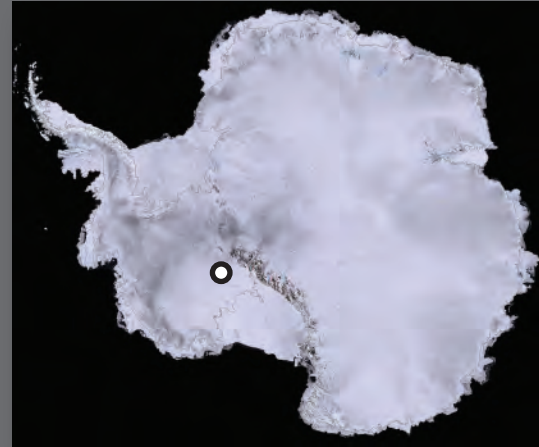
What about smaller-than-present ice sheets?

- Most glacier reconstruction focuses on glacial periods
- Ice sheets were reduced during past warm climates
- Future climate likely similar to past warm interglacials

Dome C temperature anomaly (Jouzel et al., 2007)

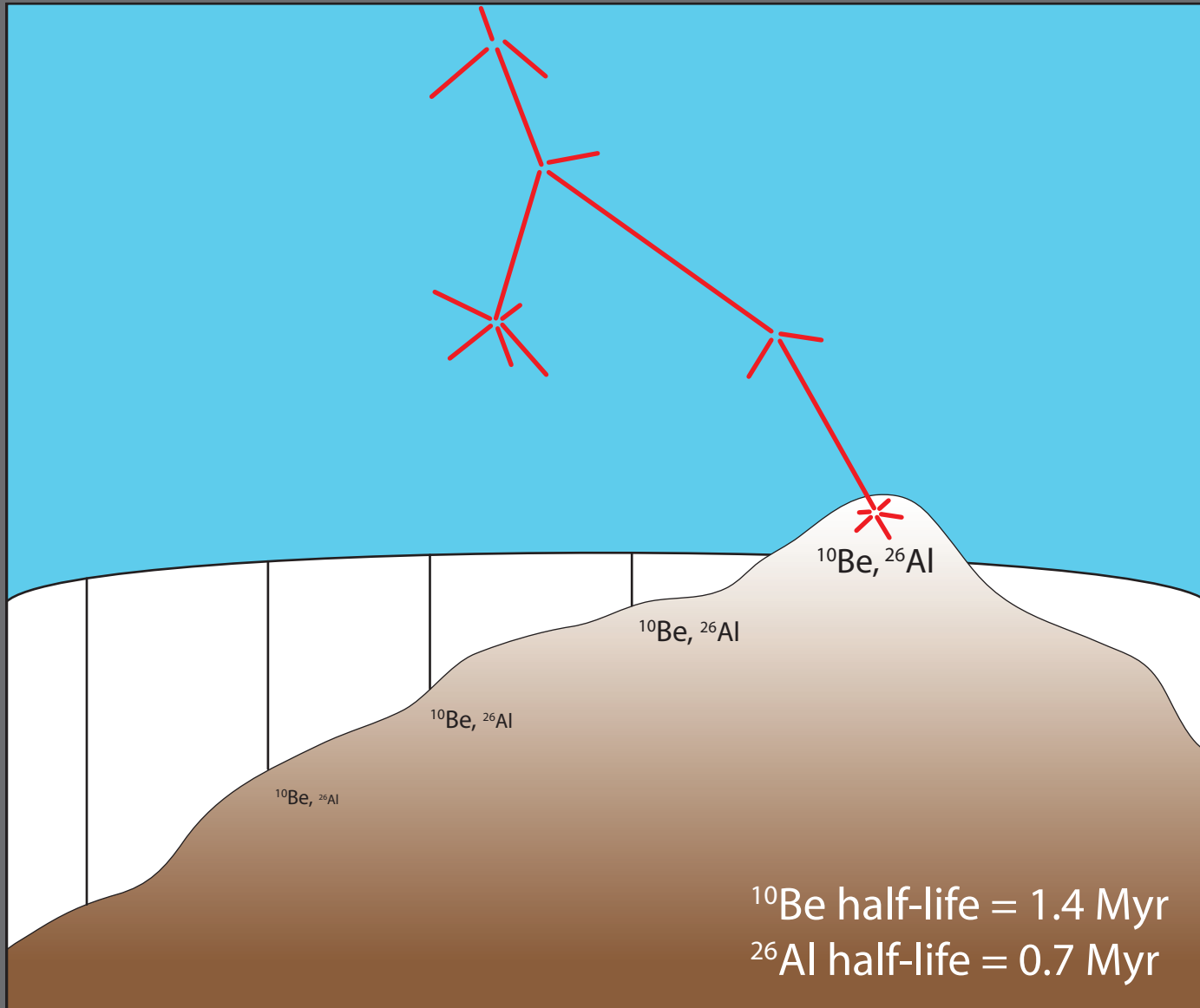


Hearty et al., 2007



Scherer et al., 1998

Subglacial cosmogenic nuclides



“The strange beauty of ice extruded from the earth on a cold morning contains hidden secrets of nature for those who look beneath their feet.”

by David Cavagnaro
This Living Earth



Needle Ice, Sierra Nevada