

Glacial Landscapes



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Definition and Relevance...

- ... large, perennial accumulation of ice, snow, and sediment that originates on land and moves downslope (USGS, 2019)

- Almost 10 percent of the world's land mass is currently covered with glaciers

- $\frac{3}{4}$ of Earth's freshwater stored in glaciers

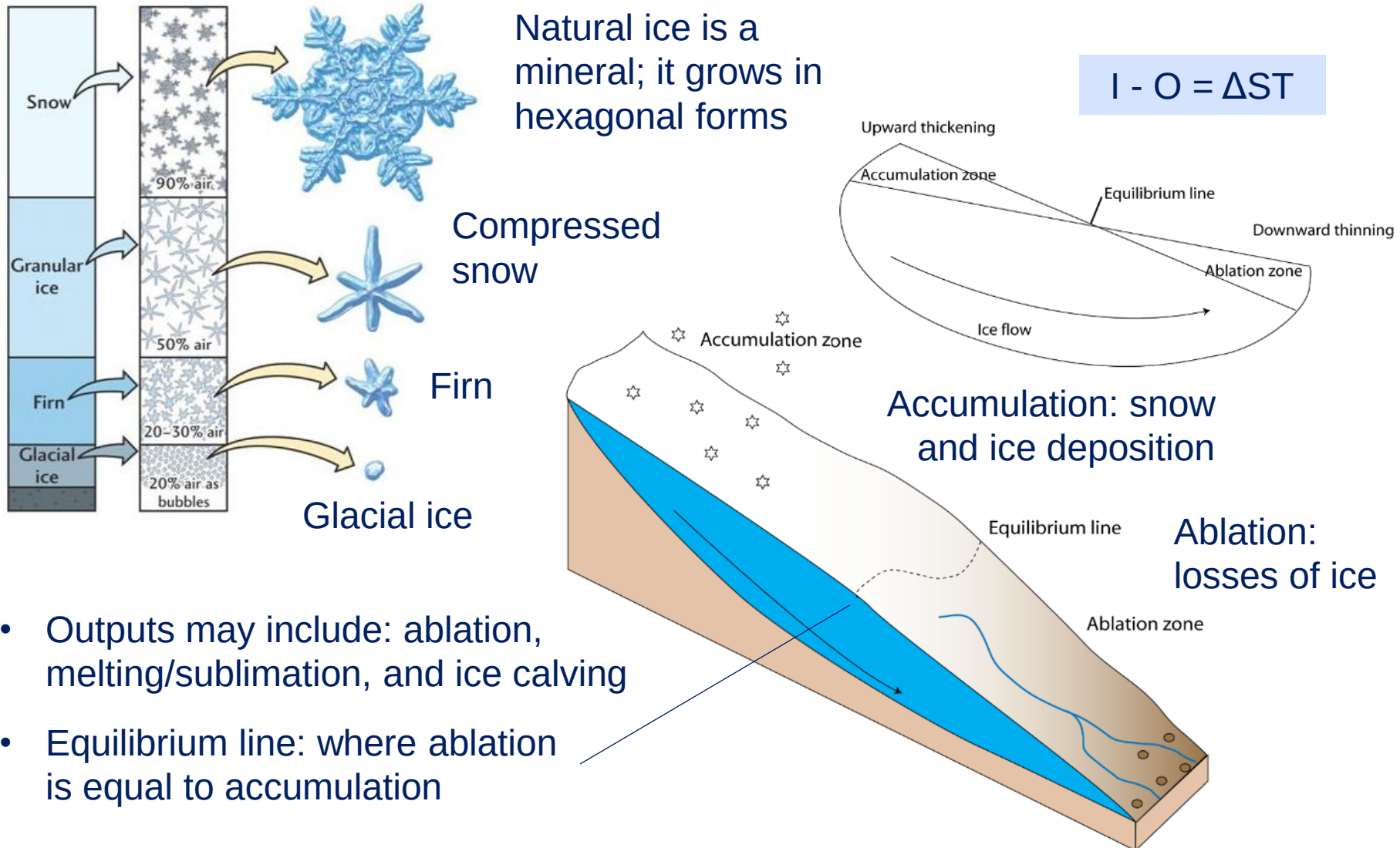
- In the (recent) past, glaciers have covered more than one third of Earth's surface...

... providing invaluable information about past climates

<https://www.youtube.com/watch?v=C3Jwnp-Z3yE>

A glacier...

- ... large, perennial accumulation of ice, snow, and sediment that originates on land and moves downslope (USGS, 2019)



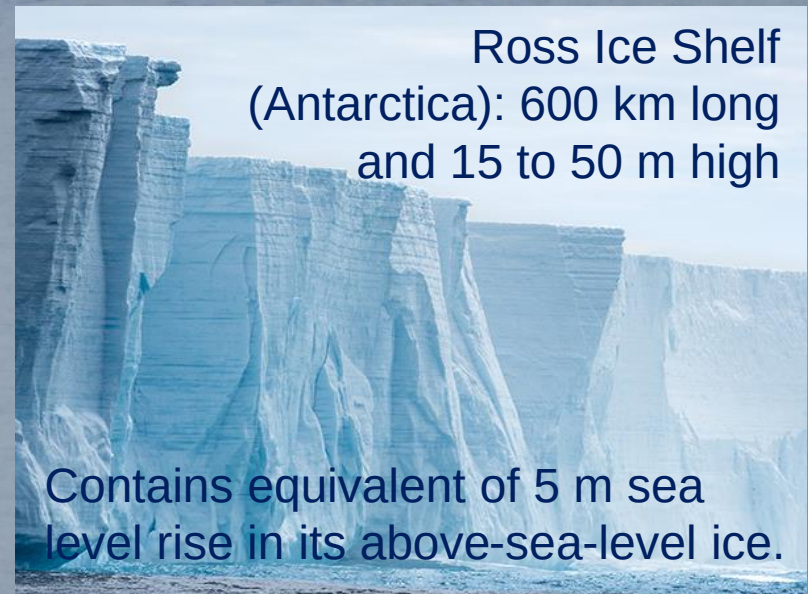
Types of glaciers

- **Ice sheets (continental glacier):** Largest glaciers: ice mass over land
- Greenland + Antarctica = 95 % of all glacial ice currently on Earth
- If melted, they would raise global mean sea level by about 66 m



- **Ice shelves:** Sheets of ice floating on water and attached to land:

- **Alpine (or mountain) glaciers:**
Relatively small glaciers
occurring at high elevations...



Ross Ice Shelf
(Antarctica): 600 km long
and 15 to 50 m high

Contains equivalent of 5 m sea
level rise in its above-sea-level ice.

Alpine glaciers

Ice caps cover mountain peaks

Cirque glacier: found up high; in a bowl-like depression

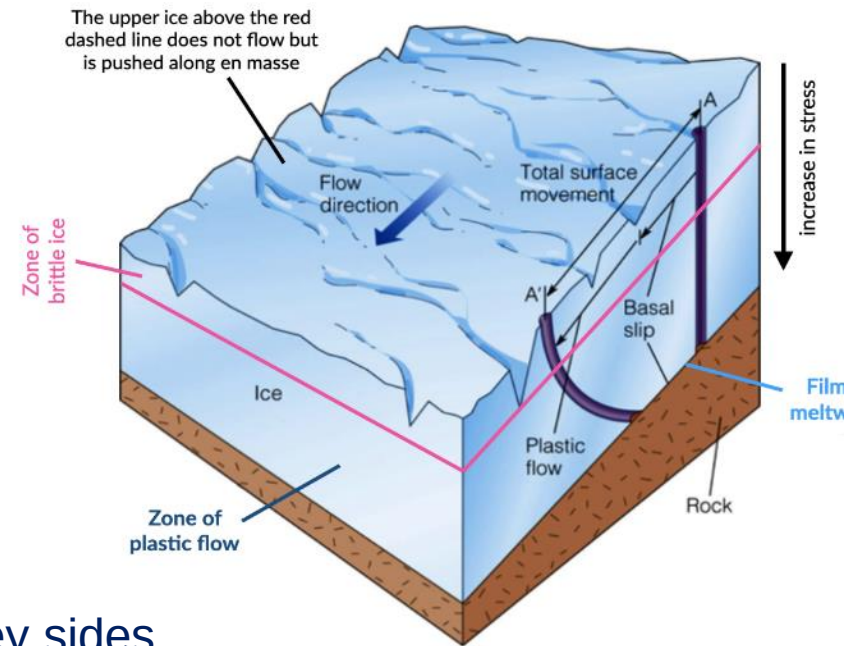


Piedmont glacier: extends into a flatter area.

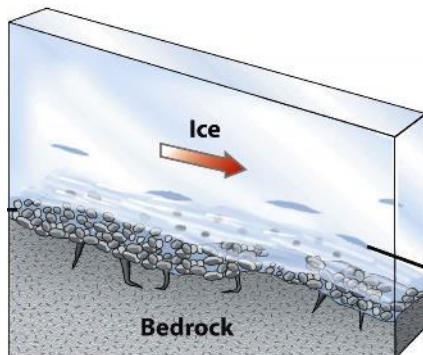
Valley glacier: extends down the mountains into the valley

Glacier movement

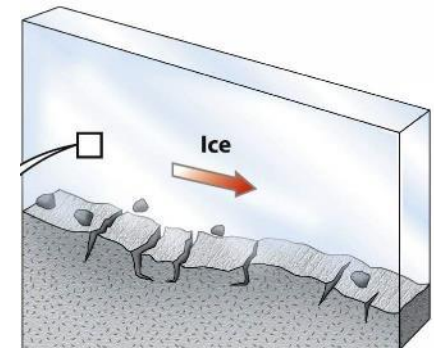
- Constrained by valley walls
- Glaciers slide over their bed, via:
 - (1) Basal slip: meltwater at base, warmer, slides over bedrock
 - (2) Internal flow: deformation of ice crystals - kind of like creep
- Similar to rivers - friction with bed and valley sides
- Fastest movement in the centre of cross section - less friction



<https://twitter.com/i/status/1388061216392761347>



- Wet-bottom glaciers: Water flows along base of glacier, basal sliding, ice slips over a meltwater/sediment slurry
- Dry-bottom glaciers – Cold base is frozen to substrate, movement is by internal plastic deformation of ice



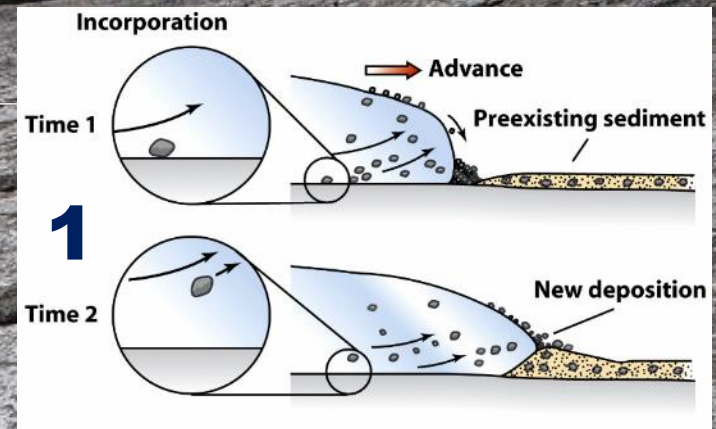
Glacial erosion

- Incorporation, abrasion, fracturing, and plucking (or joint block removal)

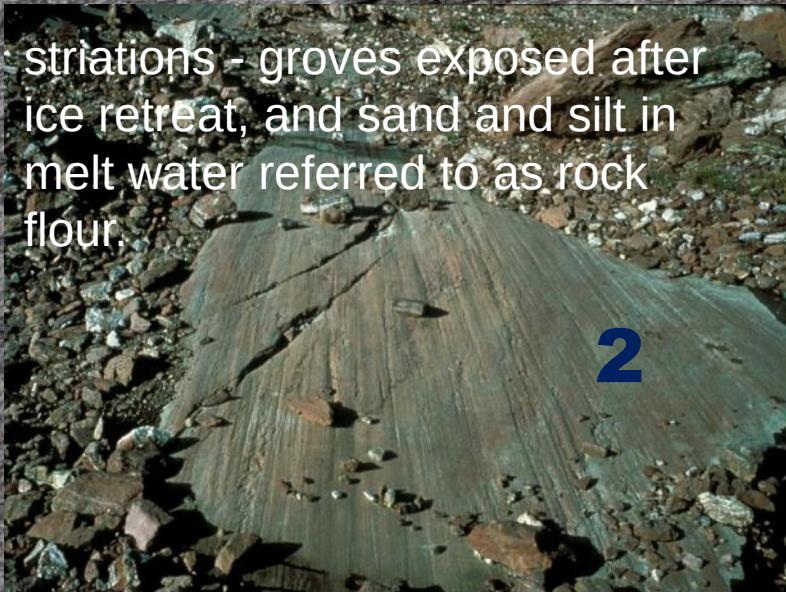
Plucking or quarrying of rock
4 along existing fractures
within the rock

Grinding and scratching of bedrock
by debris carried in ice

striations - groves exposed after
ice retreat, and sand and silt in
melt water referred to as rock
flour.

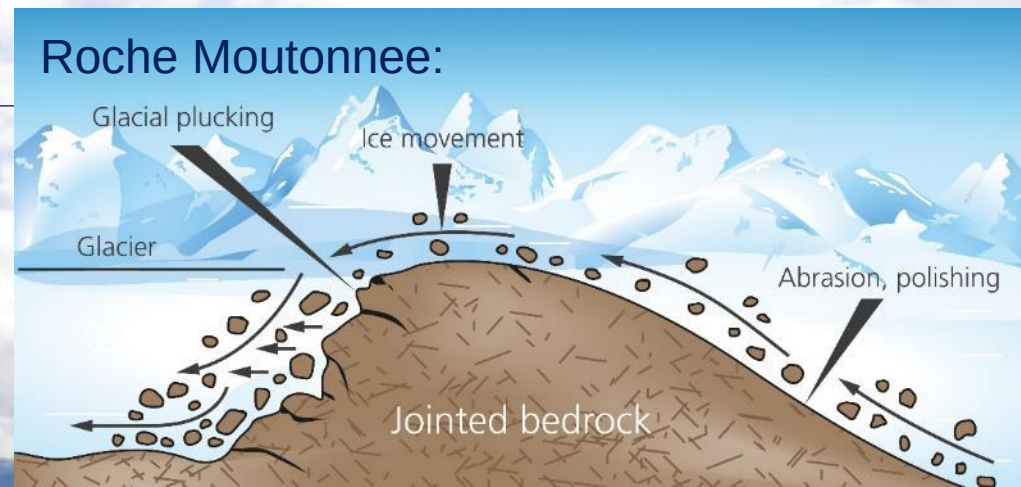


Pressure by basal ice and by debris
carried along in the ice exert high shear
stresses causing fractures



Glacial erosion

Queenstown NZ



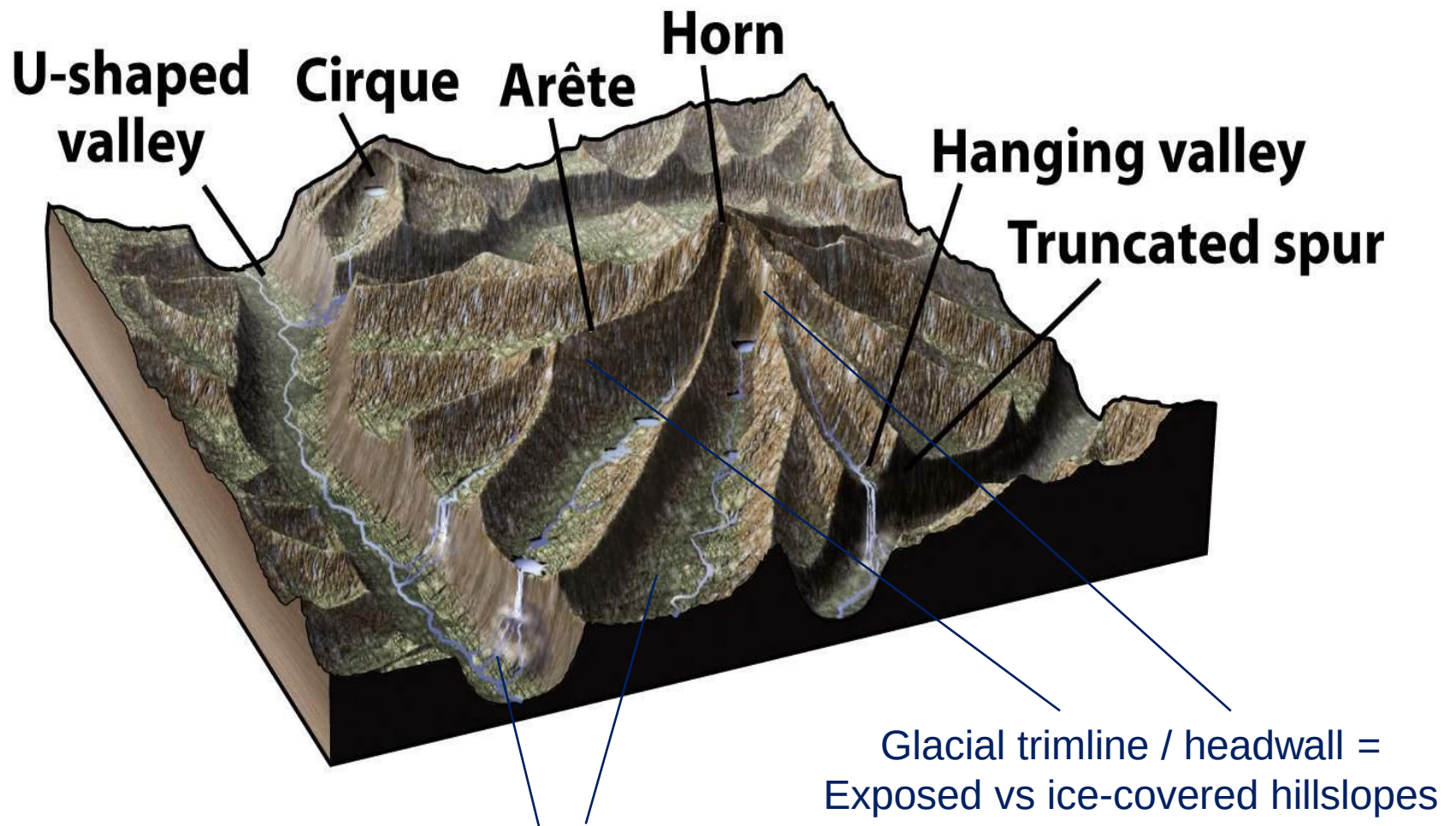
Abrasion and fracturing on stoss side and plucking on lee (downstream) side

Mt Erie,
Washington US



Glacial erosion

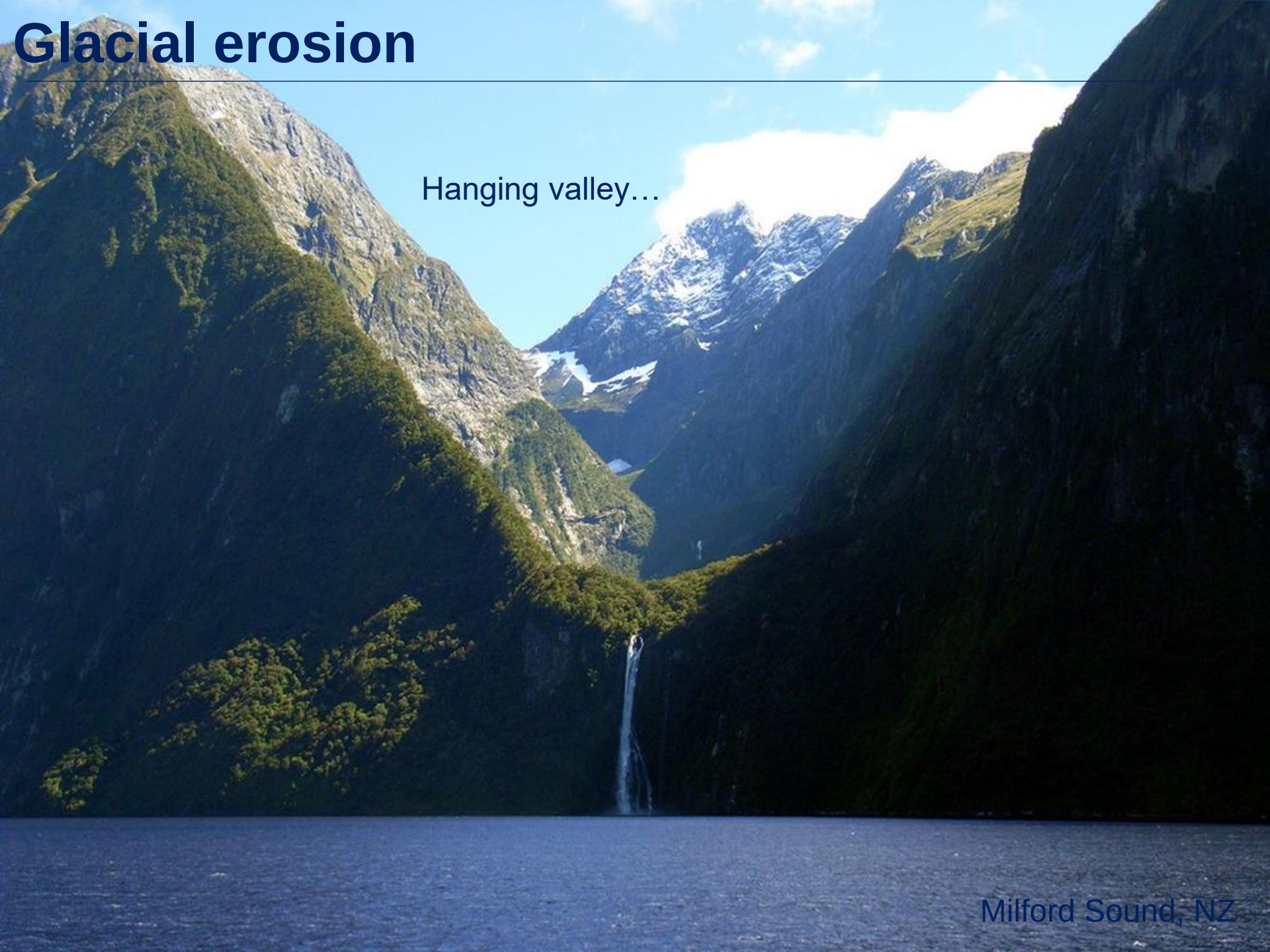
Alpine erosional features - function of local glaciation - cirques and valleys



Lower valley has a greater rate of erosion - creates a drop off

Glacial erosion

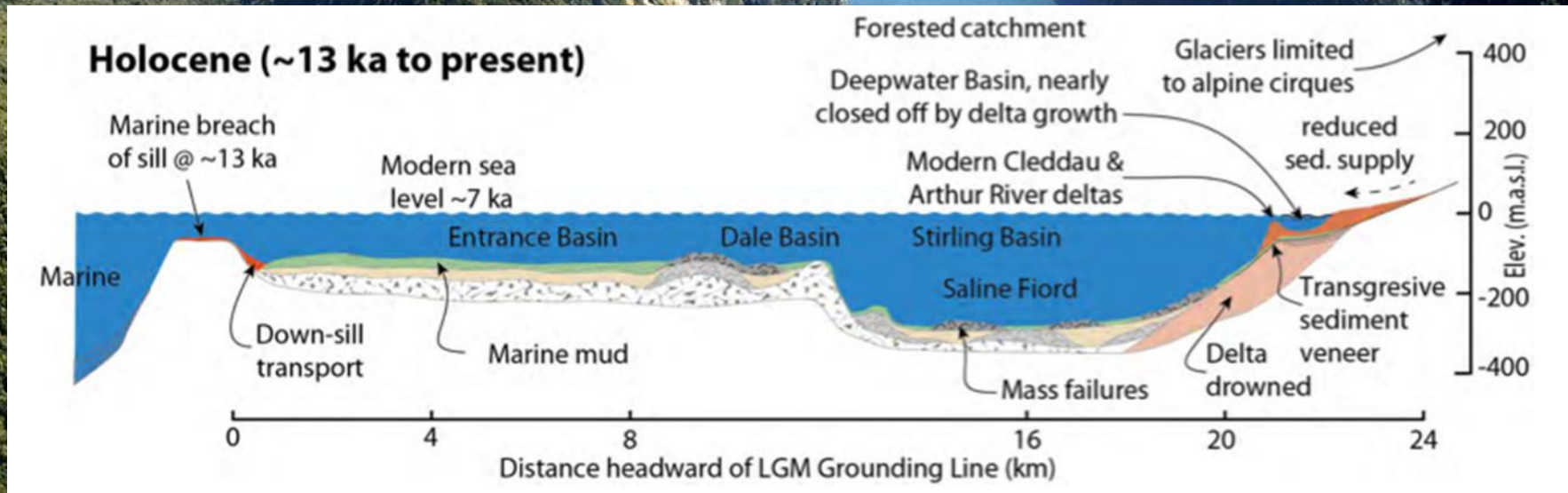
Hanging valley...



Milford Sound, NZ

Glacial erosion

Fjords - deeply eroded coastal glacial valleys, sea level rises to flood the valley

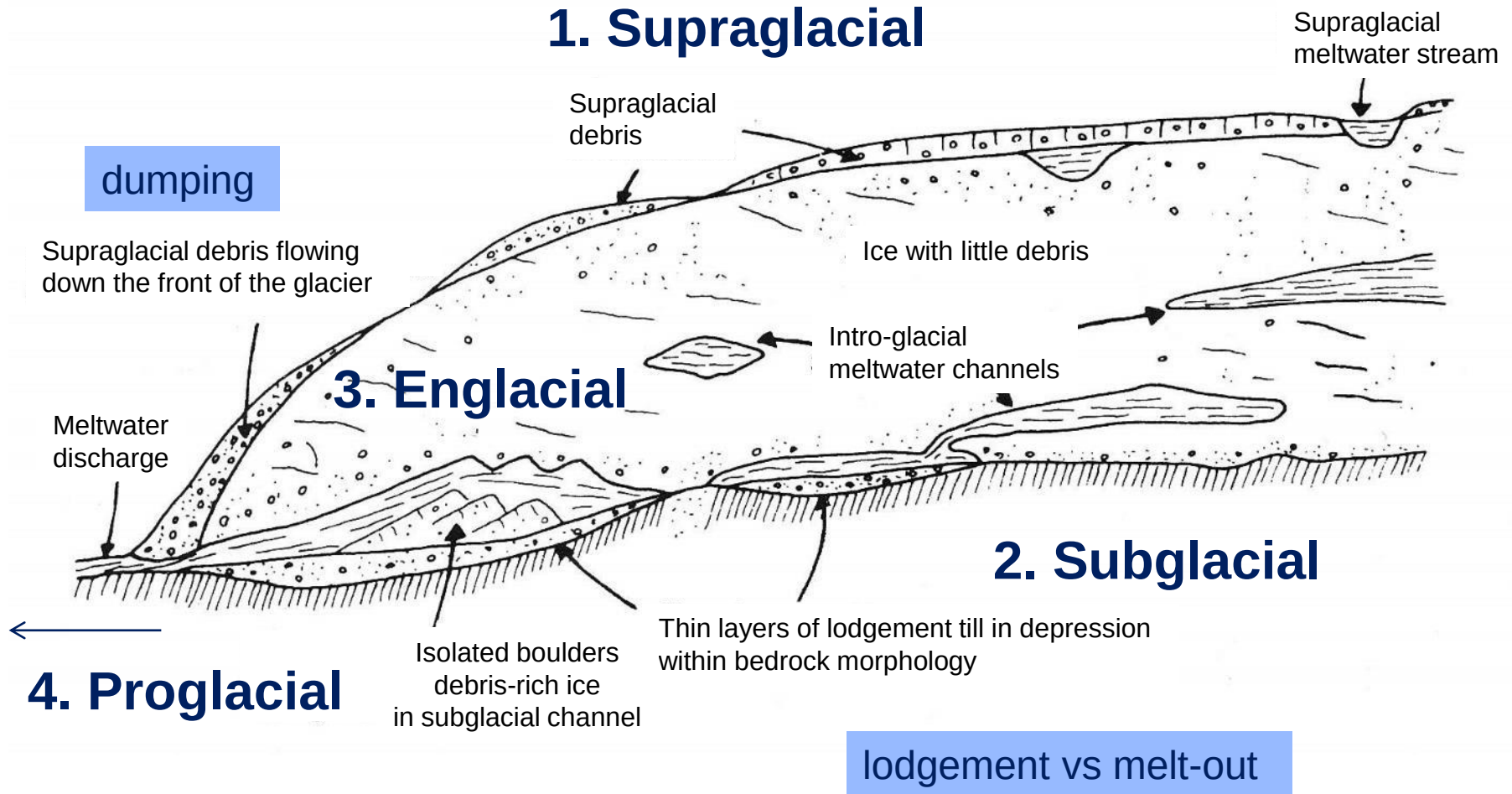


- Fjords have a sill at the front - **glacial sediments** left behind - restrict tidal exchange and cause salinity stratification

3 minutes...



Glacial Sediment Transport



- Sediment deposited as a result of glacial erosion / transport is “glacial drift”
- Position of sediment release: subglacial, along margins, at terminus...

Glacial sediment...

- From glacier bed and valley walls

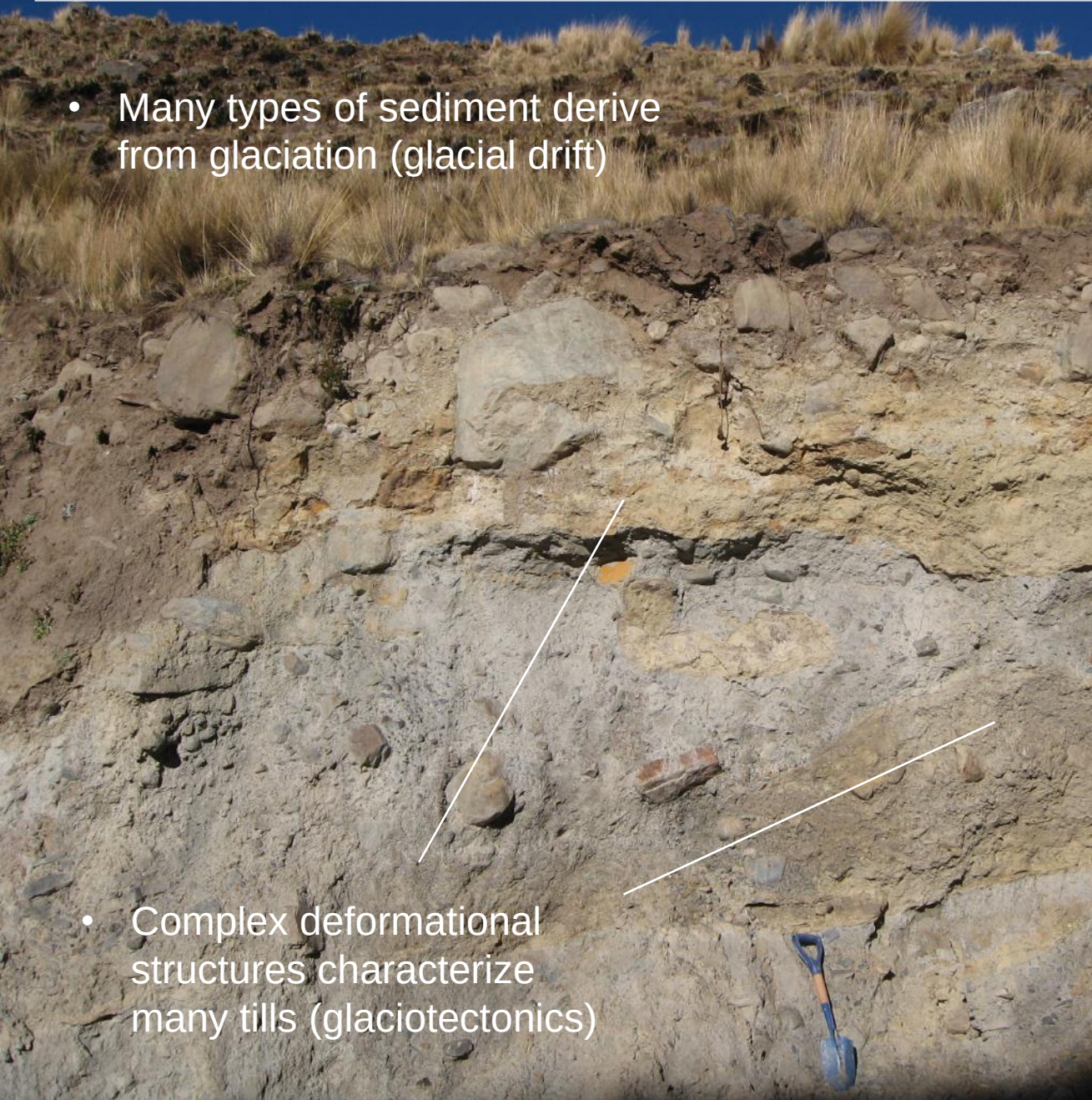


Glacial sediment...

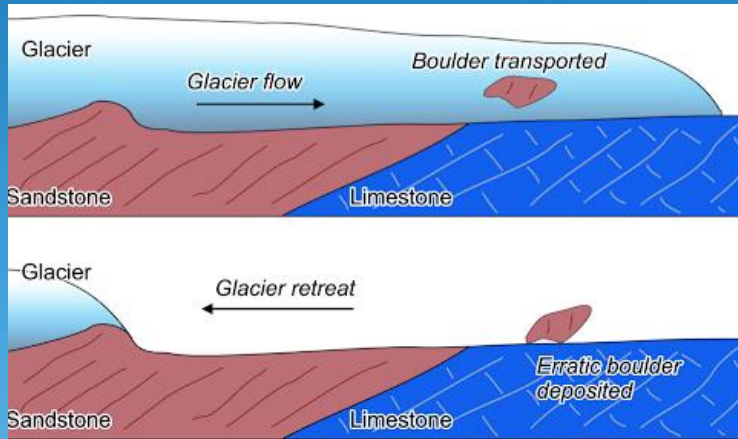
- Many types of sediment derive from glaciation (glacial drift)



- Complex deformational structures characterize many tills (glaciotectonics)



Glacial sediment...



- **Erratics** - rocks that were transported by the glacier and left behind after glacier melted

- Dropstones - ice rafted or glacier transported, sub-aqueous



Glacial depositional landforms

- Moraine: landform from accumulation of till...

Lateral moraine

Meltwater accumulation at the front of a glacier – glacial lake

Terminal moraine



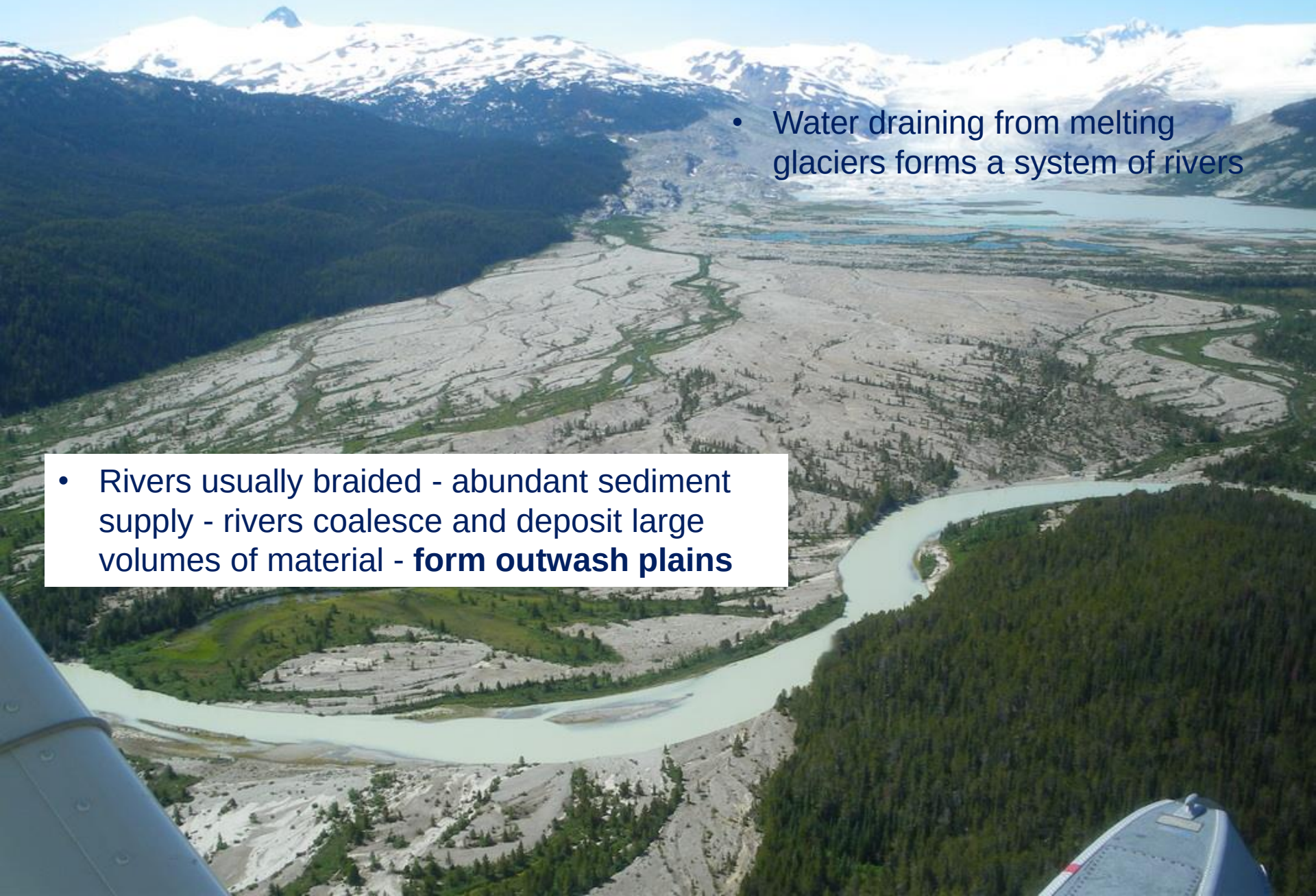
Glacial depositional landforms



Proglacial environments

- Water draining from melting glaciers forms a system of rivers

- Rivers usually braided - abundant sediment supply - rivers coalesce and deposit large volumes of material - **form outwash plains**



Proglacial environments

- Transition to fluvial processes (e.g. sorting, bedload, and imbrication)



- ... and aeolian deflation !!



3 minutes...



Proglacial environments

Retreating glacier = Degradation (?)

- Term "**paraglacial**" to refer to changes in sediment yield (and discharge) as a result of the presence, and then retreat, of glaciers in a landscape...

- Paraglacial landscape response: long relaxation times...

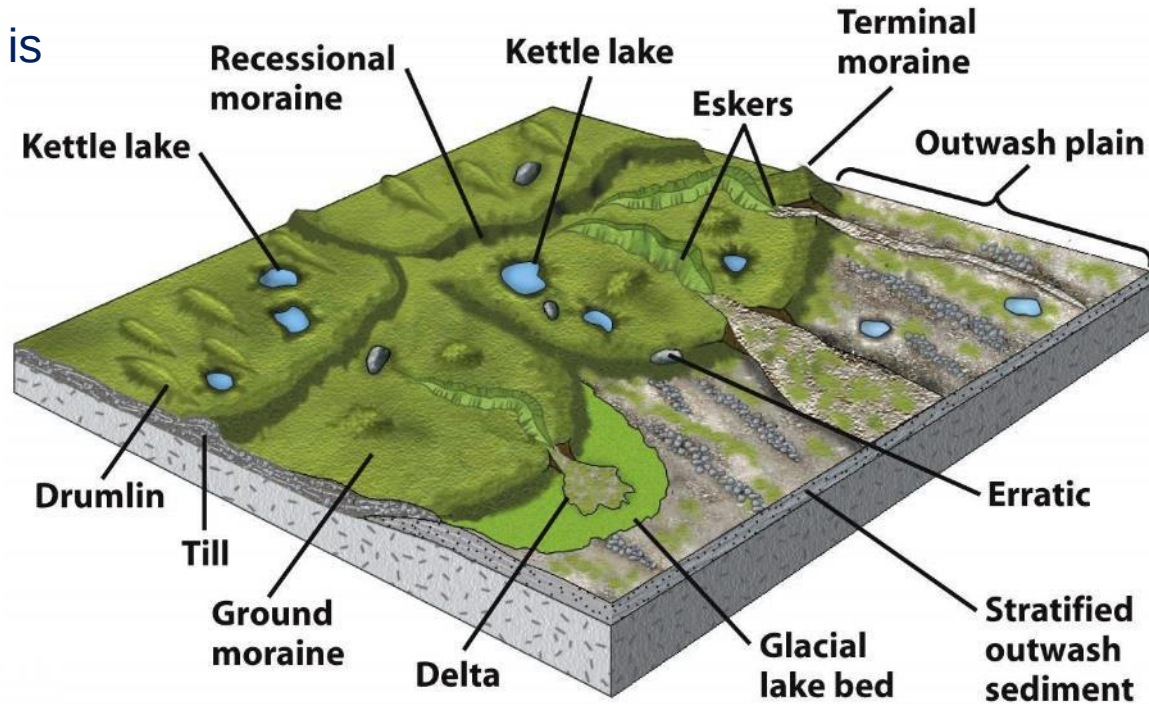
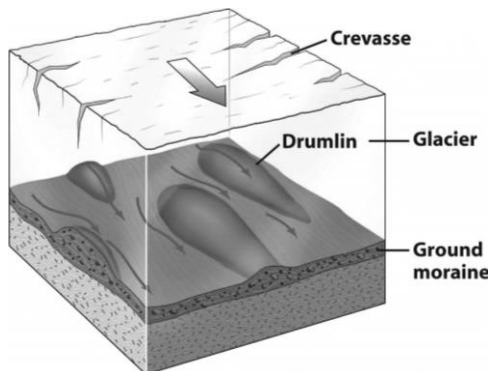
Advancing glacier = Aggradation...

Paraglacial environments

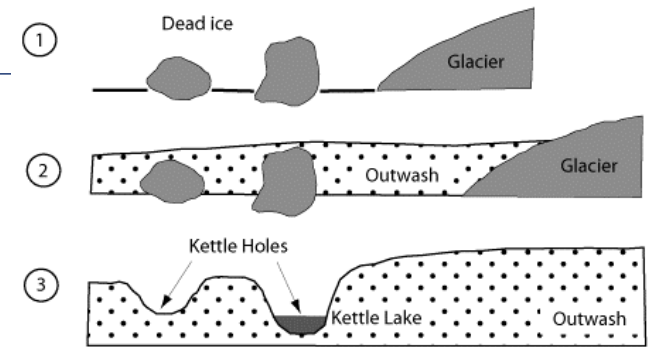
- End moraines form at the stable toe of a glacier
- Terminal moraines form at the farthest edge of flow
- Recessional moraines form as retreating ice stalls

- Ground moraine is till left behind by rapid ice retreat (hummocky, flat land surface)

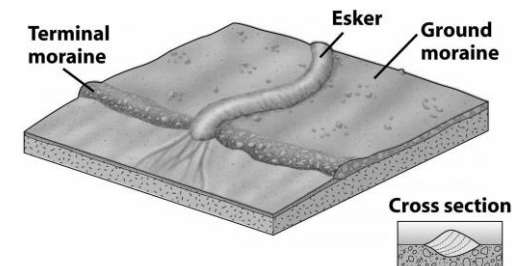
- Drumlins: molded lodgment till



- Eskers are long, sinuous ridges of sand and gravel - form as meltwater channels within or below ice

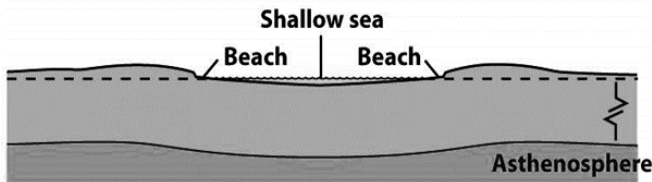
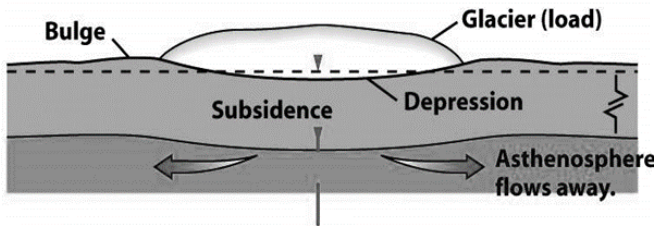


- Kettle holes and lakes from dead ice

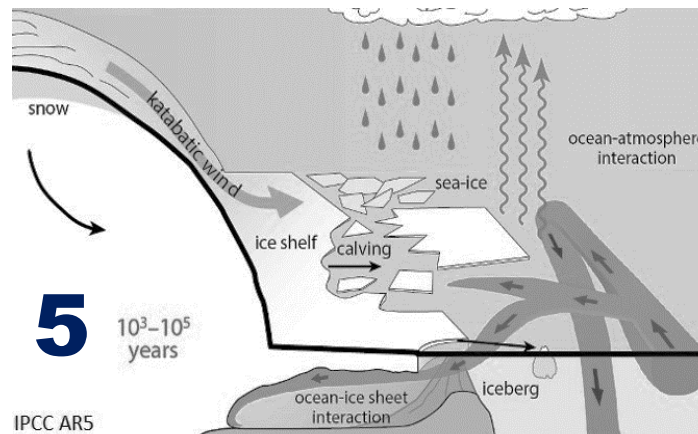
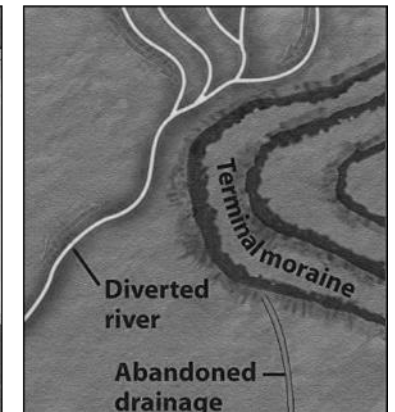
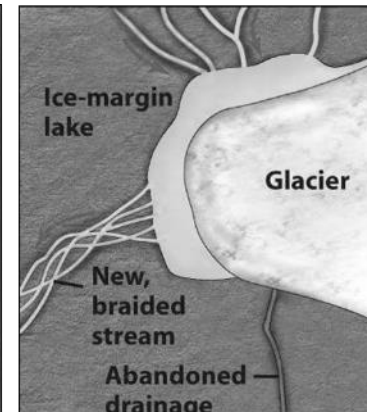
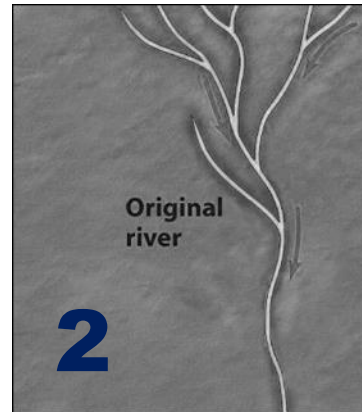
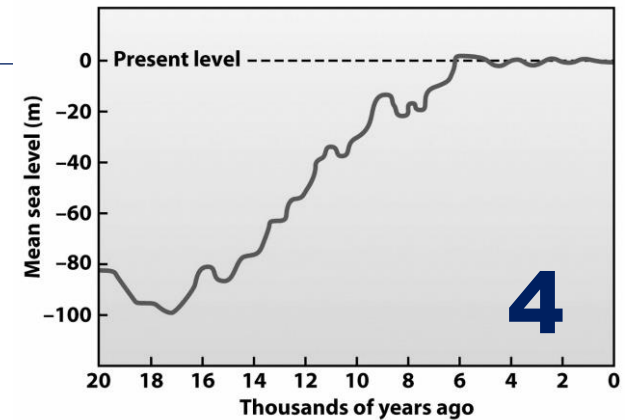


Consequences of glaciations

- 1** • Re-shaping of landscapes... (see above!!)



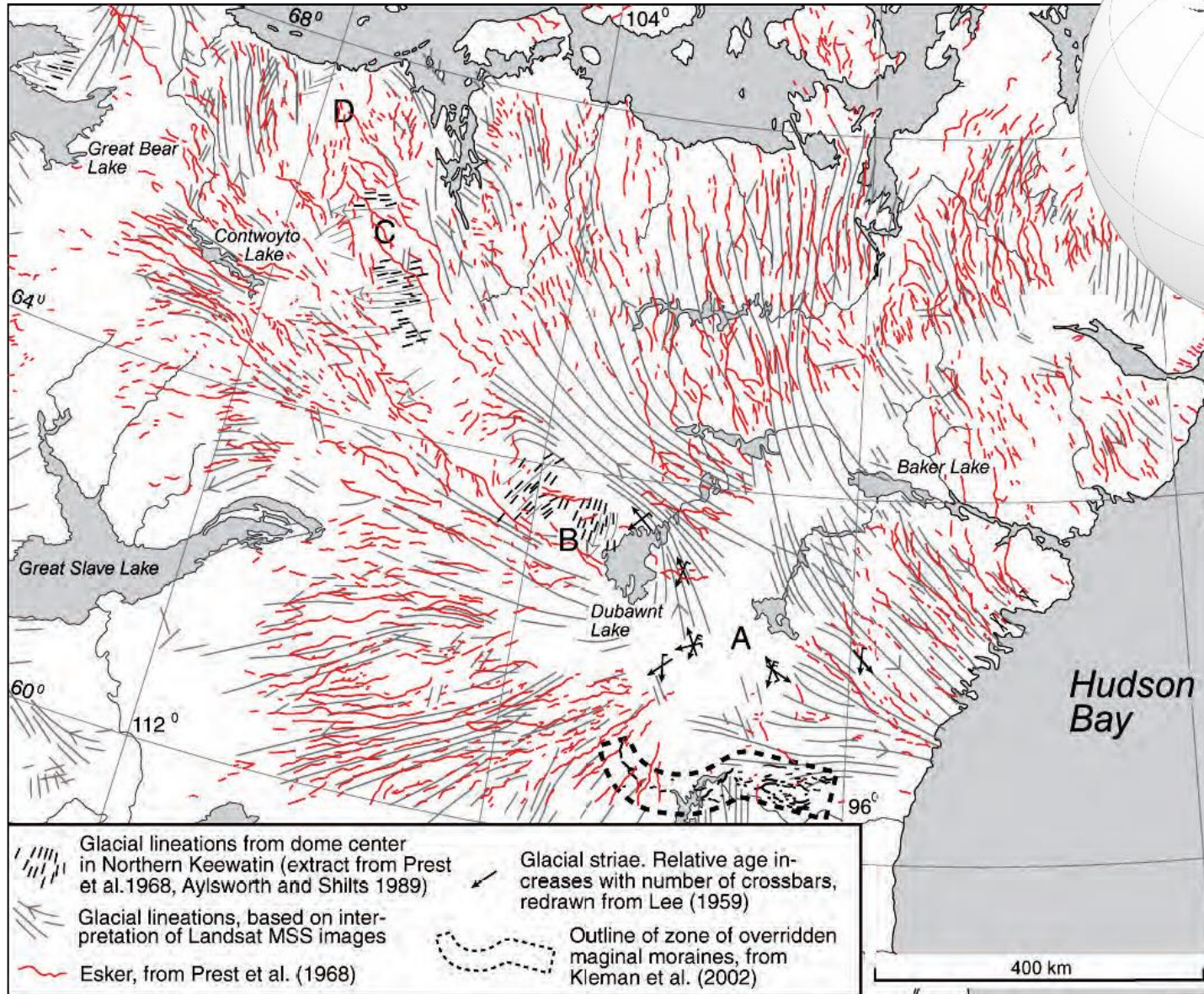
- Sea level – Ice ages cause sea level to rise and fall



- 3**
- Subsidence and isostatic rebound (until today = 10s of ka)
 - Interaction of ice sheets and atmosphere-ocean system, weather patterns change

- Drainage:
 - (i) re-plumbing river systems
 - (ii) large glacial lakes
 - (iii) mega-flooding

Past and Present

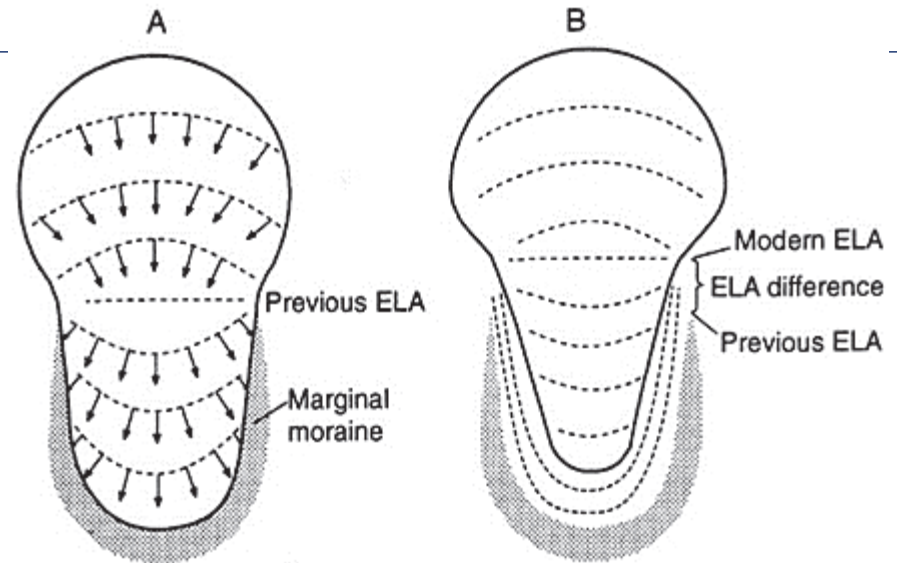
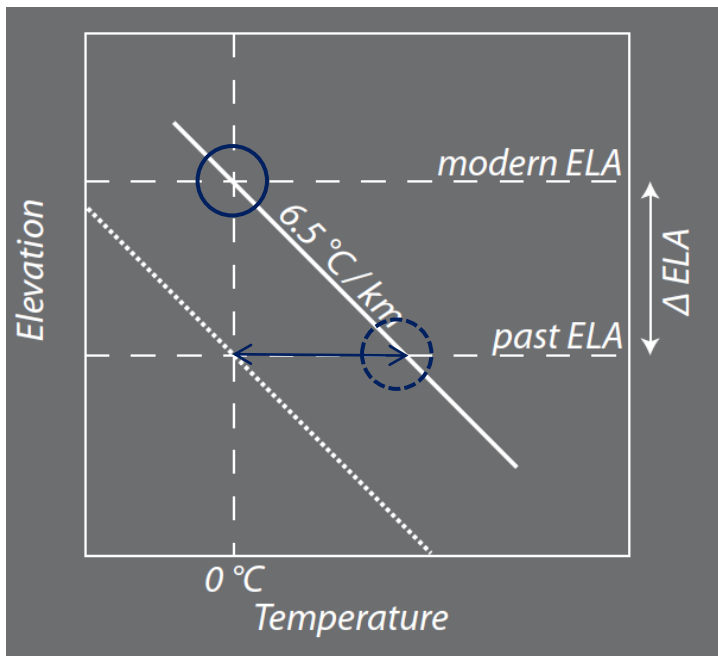


- Reconstruction of ice sheet extent and dynamics through mapping and analysis of glacial landforms and landform assemblages

Past and Present

Interpretation of climate from past valley glaciers:

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



1. AAR (Accumulation-area ratio)
2. MELM (Max. Elevation of lateral moraine)
3. THAR (Toe-to-headwall ratio)
4. Others...

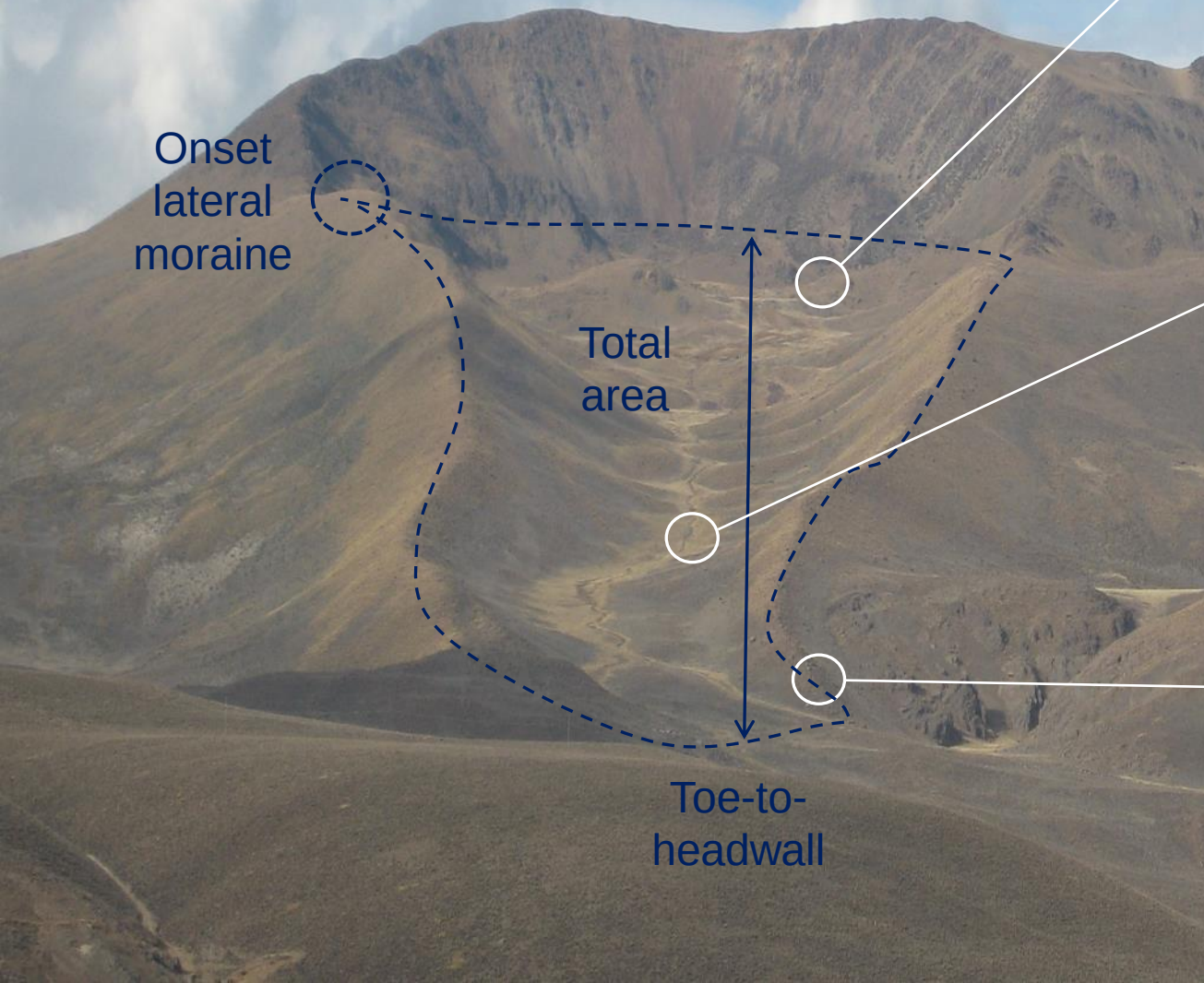
... Assumptions:

- Past lapse rate is same as modern
- Snowfall has been constant...
- ... physical models can help

!

Past and Present

- Determining ELA
- Dating glacier extent



Past and Present and Future

- Glaciers in the Alps from the last ice age to 2100 (state-of-the-art simulation)



<https://www.youtube.com/watch?v=9h-bQKiX7nQ>

Glaciers of the Future

- With global anthropogenic warming, now all monitored glaciers in all regions show a decrease in area, length and ice mass, with some disappeared completely already
- These ones will be gone in 2100

Natural + anthropogenic warming

now

1870

Rhone glacier,
Switzerland

Bernese Alps,
Switzerland



Take home...

- Glaciers form if ice mass balance is positive
- Snowline or equilibrium line altitude (ELA) separates zone of ice accumulation and ablation
- Glacier formation depends on temperature AND moisture (snowfall)
- Glaciers are important agents for erosion, transport and deposition of sediment
- Variety of glaciers produce a variety of forms

Steinglacier,
Switzerland

Paraglacial
landscapes on
the rise...

Position mid-
19th century

