

Glacial Processes



Feel the Strain of Stress

Goals

- ❑ Have an basic understanding glacial climates;
- ❑ Learn how glaciers form and move;
- ❑ Learn how glaciers shape landforms through erosion and construction processes;
- ❑ And much more! We may get into glacial history soon or wait to we discuss climate change.

The formation of ice, ice, baby

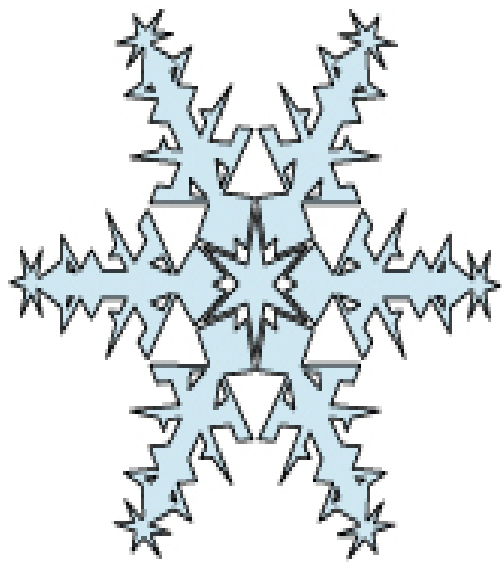


Seriously

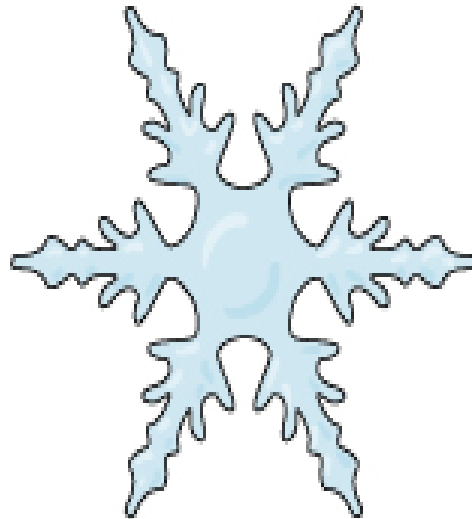
1. **Snow**, a chemical sediment composed of ice crystals (Density 0.01 to 0.03 g/cm³)
2. **Firn**, deepening to basal granular ice as a consequence of compaction and melting/refreezing (Density 0.55 g/cm³)
3. **Ice**, when the granular ice crystals are frozen together so that air can no longer penetrate the structure firn becomes ice (Density 0.97 g/cm³)

Ice

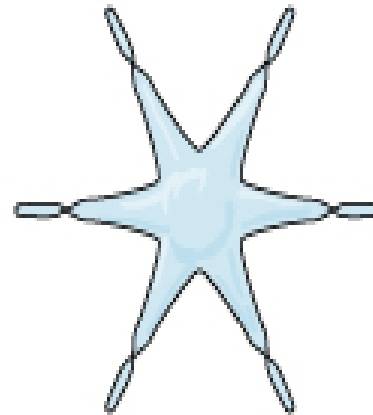
- ❑ Ice is a special kind of metamorphic rock.



First day



2 days



12 days

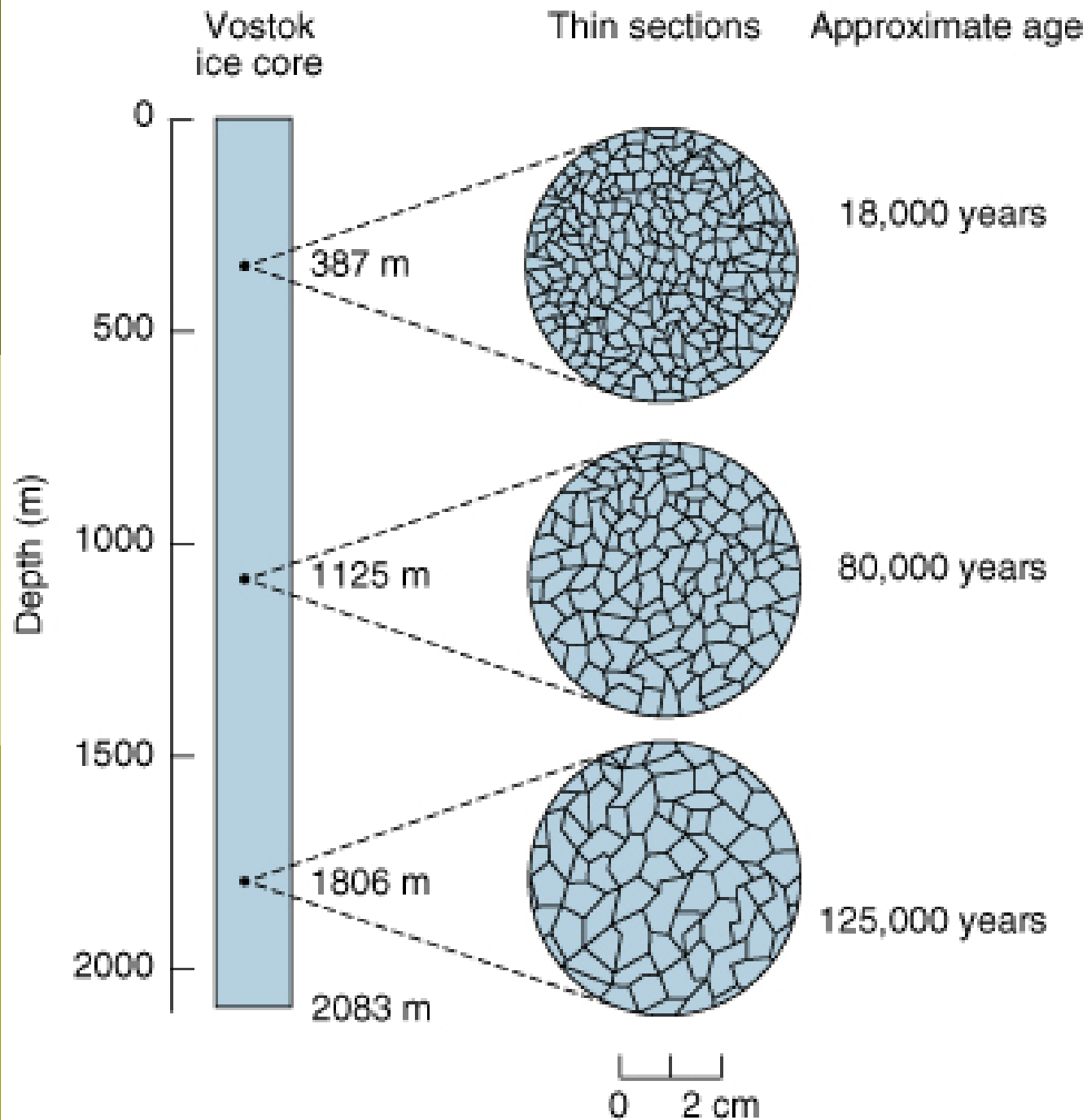


49 days



57 days

The process of snow to glacial ice can take anywhere from 12 to over 200 days.



Ice
Depth
Vs.
Time

Glaciers

- ❑ A body of ice and firn composed of recrystallized snow and frozen melt water lying wholly or mostly on land and shows evidence of present or former motion.
- ❑ Glaciers originate in areas where snow accumulation exceed loss
- ❑ Glaciers then flow downward and outward toward areas where the losses exceed any gain.

Glaciers are NOT

- ❑ Sea ice, is not considered a glacier because it does not lie on land and does not move by its self.
- ❑ Permanent snow fields are NOT glaciers because they lack motion.



Glacial Regime: Behavior of a glacier through time.

□ Terms

- Accumulation zone
- Equilibrium line
- Ablation zone

Zone of accumulation

- ❑ Area of positive gain, (building snow/ice mass)
- ❑ Vectors of particle motions are downward into the ice mass as each year's snowfall adds to the glacier.

Zone of Ablation

- ❑ Area of loss
- ❑ The down glacier area ice is lost to melting, sublimation, erosion, and caving into water.

Equilibrium line

- ▣ The downglacier edge of net annual accumulation.

Important concepts

- ❑ When Accumulation $>$ Abalation a glacier will advance.
- ❑ When Accumulation $<$ Abalation a glacier will retreat.
- ❑ When Accumulation $=$ Abalation a glacier is in a steady-state.

Punch line concept



Active glaciers

- ❑ Moving glaciers
- ❑ A Retreating (shrinking) glacial margin does not mean a glacier is moving backwards
- ❑ It means that within an active setting the processes of Abalation > Accumulation.
 - The glacier is still moving **forward**;
 - ❑ Rapid (melting, calving, erosion) exceeds
 - >
 - ❑ Inputs into the zone of accumulation

Glacial Classifications

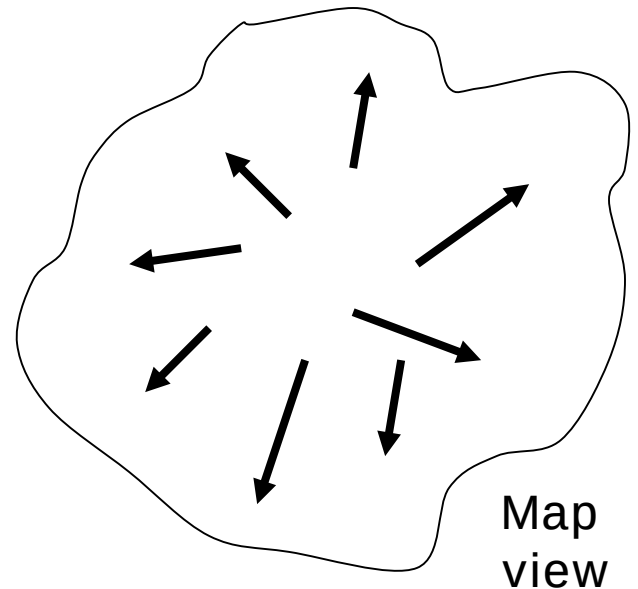
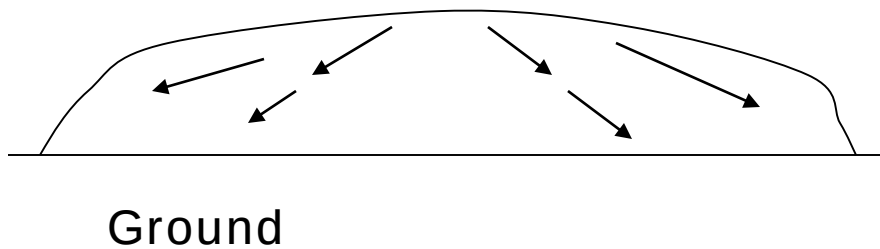
1. Dynamic
2. Morphologic
3. Thermal

Dynamic classification of glaciers

1. Active, the glacier is in motion (advancing or retreating).
2. Stagnant, the glacier is not in motion, it is dead.

Morphologic classification of glaciers

1. Continuous sheets; Ice sheets (i.e. continental glaciers) that flow from a central topographic high.



Ice caps are much smaller!!
($\sim < 50,000 \text{ km}^2$)

Ice sheets and caps

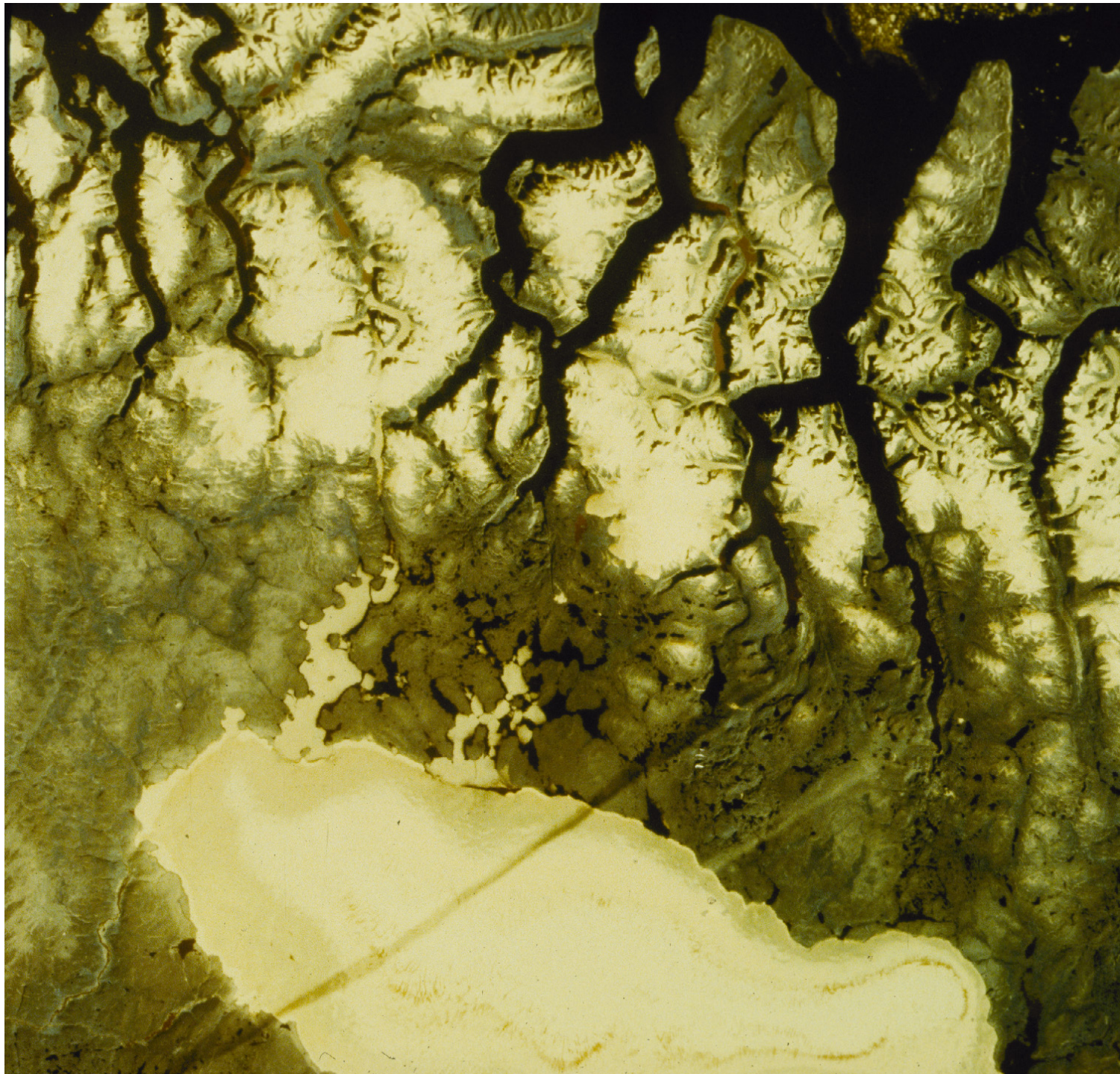
- ❑ Are unconfined systems
- ❑ Large ice sheet develop there own orographic precipitation patterns
- ❑ The zone of accumulation resides in the center of the sheet/cap
- ❑ The zone of ablation lies on the periphery of the ice mass.
- ❑ Are extremely sensitive to climatic change.

Ice sheet cont.

- ❑ They are large enough not to be confined by topography.
- ❑ Modern Ice sheets E.g. Greenland and Antarctic glaciers
- ❑ Modern Ice caps E.g. Barnes Ice cap, Baffin Island

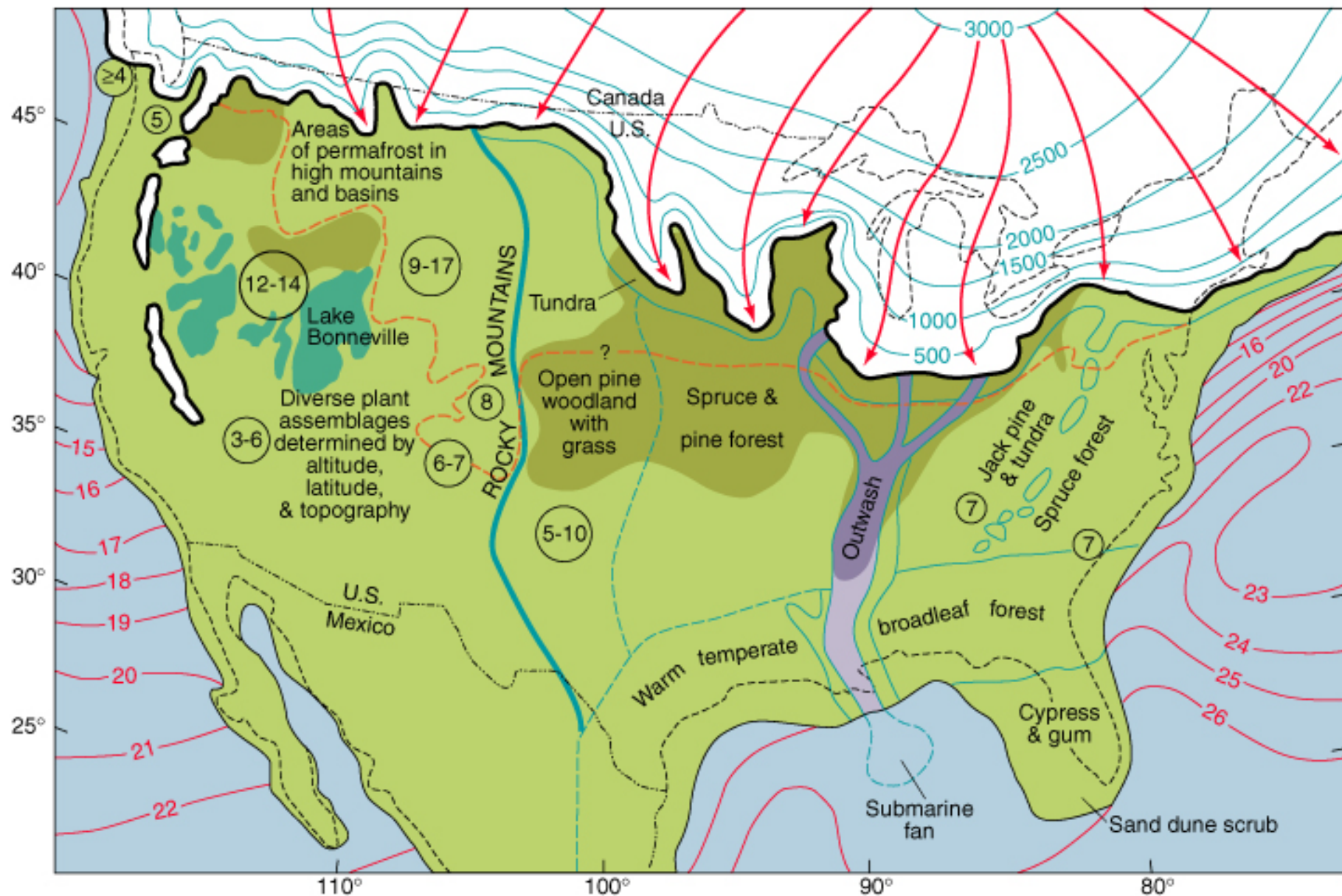
The Greenland Ice Sheet







J. Stravers



----- Present coastline

—17— August sea-surface temperatures (°C)

----- Approximate southern limit of permafrost

— Glacier limit

—1500— Glacier surface contours (m)

Principal areas of dune sand and loess

Laurentide Ice Sheet

Ice sheets are a of system of positive feedbacks

- ❑ A system that supports change!
 1. An increase in accumulation leads to
 2. An increase in height of the ice mass;
 3. Which increases the area for the zone of accumulation relative to the ablation zone
 4. Resulting in accelerated growth!

What will happen if accumulation declines?

- ❑ The opposite! But still supporting change.
- ❑ Ice caps of Iceland, Scandinavia, and Canada
- ❑ Lower summits = a lower Equilibrium line
- ❑ Makes growing icecaps more difficult

Morphologic classification of glaciers

2. Alpine (mountain) glaciers; Glaciers that are bound by topographic features such as mountains or valleys.
 - a. Valley glaciers
 - b. Cirque glaciers

Cirque glaciers

- ❑ Occupy amphitheater-like hollow in alpine areas near the firn line.
- ❑ They are more frequent on northward or eastward facing slope in the Northern Hemisphere, where solar energy is least.
- ❑ In areas of high precipitation cirque glaciers may flow downvalley and join valley glaciers.



The Dinwoody Glacier in late summer (Wind River Range, WY)

Cirque glaciers



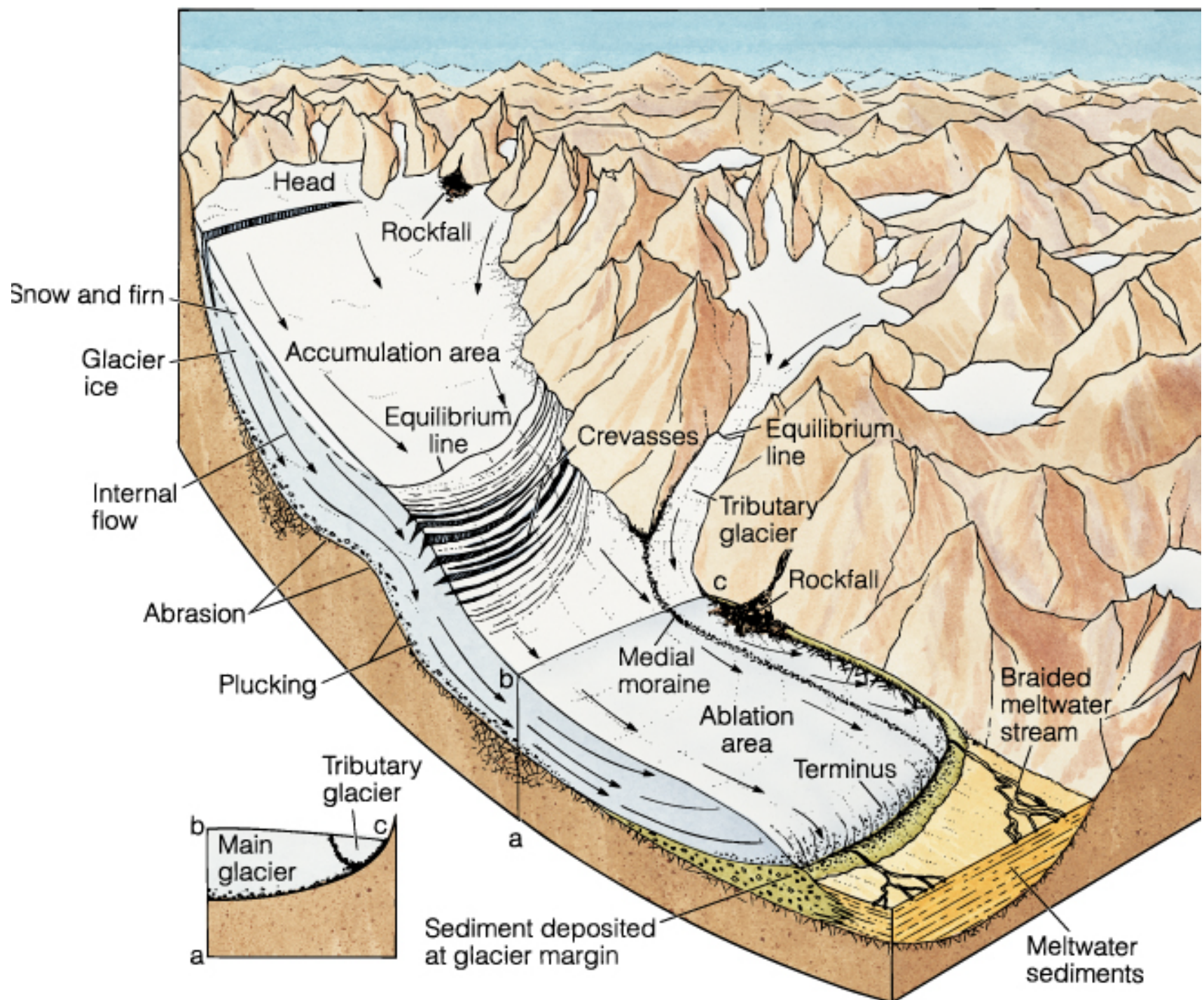


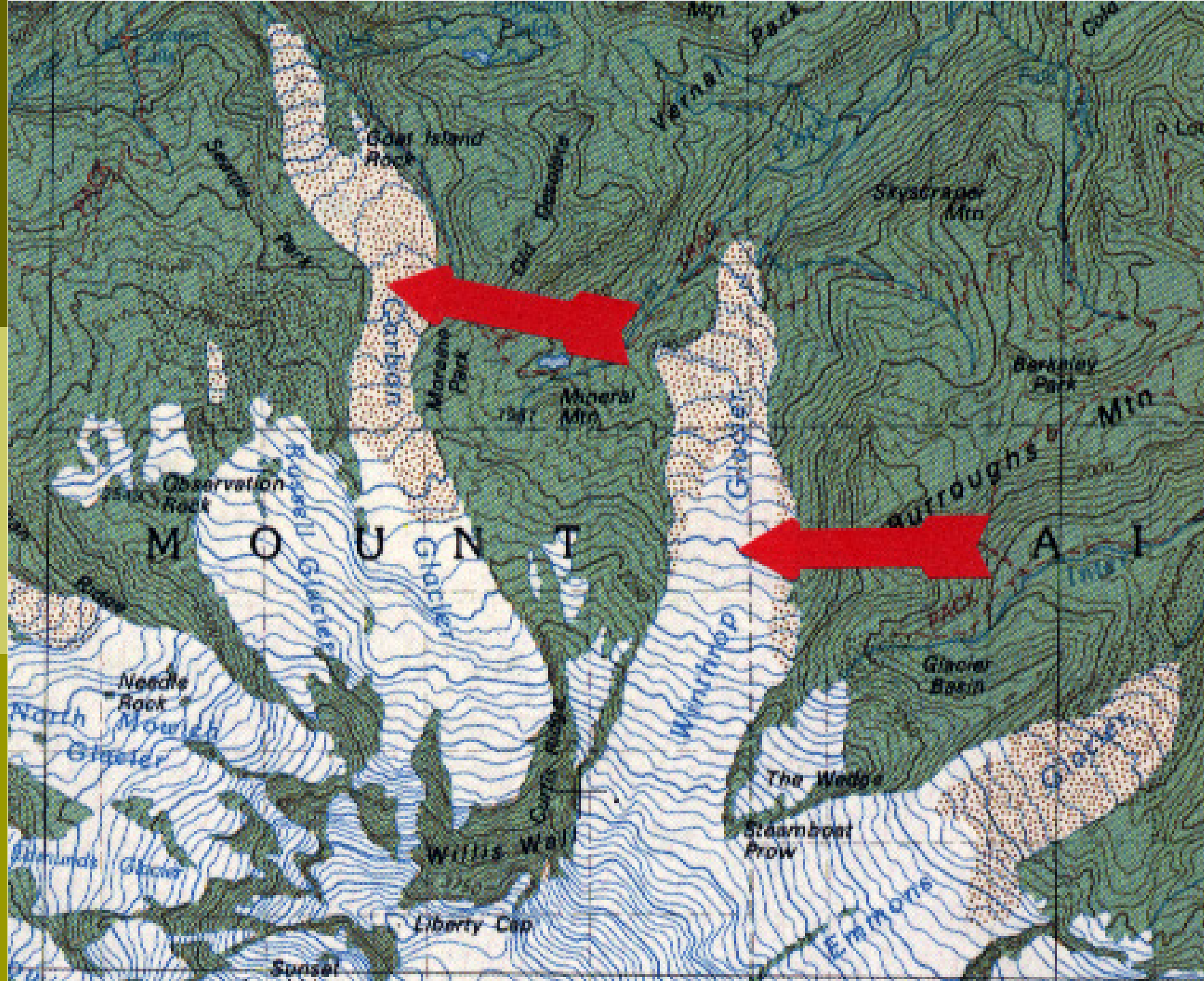
Valley glaciers

- ❑ Flow well beyond their cirques in long, winding valleys
- ❑ Velocity generally increase down glacier in the zone of accumulation, *extending flow*
 - Common in areas where ice flows over a rapid drop in the bedrock
- ❑ Within the zone of ablation, longitudinal velocity generally decreases to near zero at the toe, *compressing flow*

Characteristics

- ❑ Mountain elevations
 - Cold
 - Typically receive increase precipitation
 - Good ingredients for building glaciers
- ❑ Valley glaciers are often feed by tributary glaciers
- ❑ Have a high surface gradient (Avg. 10 percent)





Tributary glaciers, (Yentna Glacier Alaska)



Morphologic classification of glaciers

3. Piedmont glaciers, form when glaciers discharge ice as a broad, radially flowing lobe onto plains at the foot of mountains
 - ▣ Piedmont glaciers may also extend into standing bodies of water.



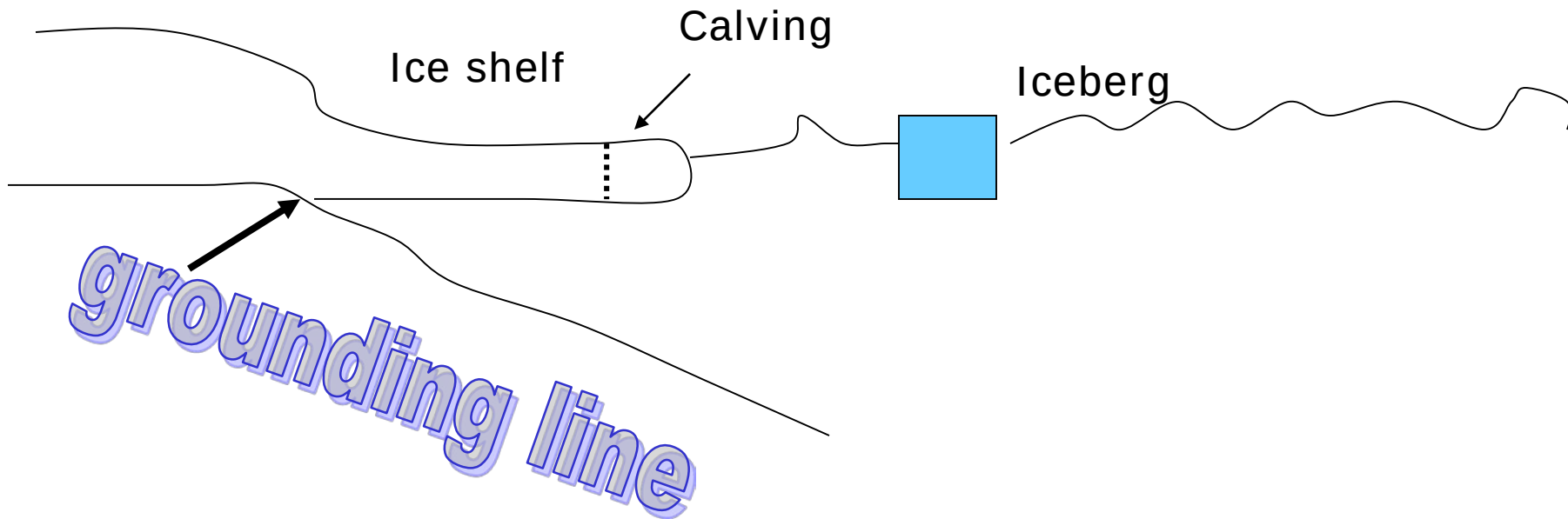
C.E.
Heinzel

Piedmont Glacier, Baffin Island



Glacial calving

Calving is when glacial ice from an ice shelf breaks off into the water forming an iceberg.





Thermal classification of glaciers

- ❑ Temperate glaciers
- ❑ Polar (cold-based) glaciers
- ❑ Sub-polar glaciers

Temperate glaciers

- ❑ Where ice is at, or near, pressure-melting temperature (PMP = pressure melting point)
- ❑ The transition from Firn to Ice is relatively fast.
- ❑ Ice temperatures decrease downward due to the effect of increasing pressure on the melting temperature.
 - This glacial pressure is capable of producing a strange brew in the basal environments of glaciers.



Zero degrees Celsius and below

- ❑ Ice may coexist with water at the base of a glacier!!!!
 - Due to the high-pressure environment.
- ❑ Temperate glaciers are also called Wet-based glaciers.
- ❑ This effect produces interesting results,
 - Ice deformation
 - Glacial movement

Polar (cold-based) Glaciers

- ❑ Ice is entirely below the pressure melting point, the glacier are frozen to the base.
- ❑ Melting does not occur and the conversion of firn takes much longer than in temperate glaciers
- ❑ Abalation, only by calving, wind erosion, or sublimation.
- ❑ Movement?

Sub-polar glaciers

- ❑ Frozen to base, as in Polar
- ❑ But, melting occurs in the summer months.
- ❑ Intermediate (Seasonally temperate/polar)

Glacial Movement



More than you ever wanted to know about ICE?

- ❑ The melting point of ice decreases with increasing pressure.
 - So with increased pressure ice may melt at temperatures lower than ZERO Celsius
 - The pressure-melting point applies to melting temperatures at a specific pressure.
 - Pressure melting facilitates ice motion and the transfer of mass by melting and refreezing at points of lower stress (Regulation)

Ice Flow



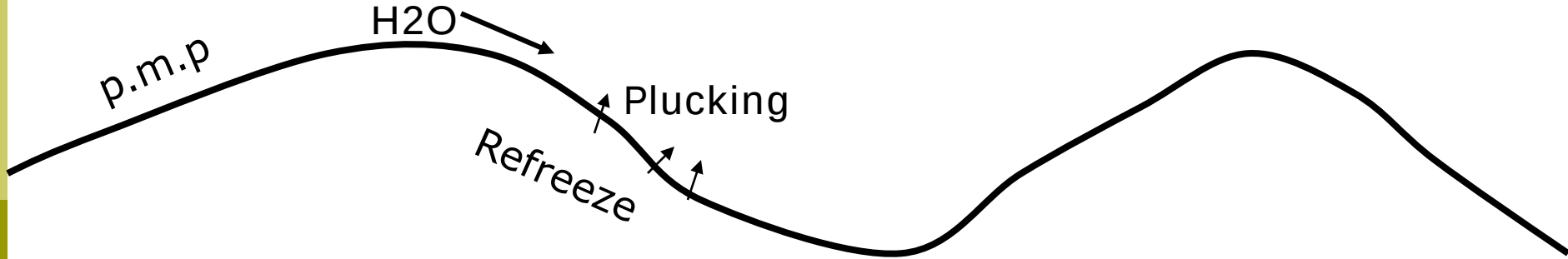
Enhanced
Creep

H₂O

p.m.p

Plucking

Refreeze



Ice Behavior

□ Applied stress vs. Ice response

- Elastic
- Plastic
- Brittle

□ Factors

- Type of stress applied (tensional, compressional, shear, or hydrostatic)
- The amount of applied stress
- The rate at which the stress is applied
- The temperature

Elastic

- The amount of strain (deformation) is proportional to the stress applied.
 - Once the stress decreases the material (ice) is capable of returning to its original size/shape.

Plastic

- ❑ When Stress exceeds a 'critical point' the strain is no longer proportional to stress,
 - Additional stress may then lead to substantial deformation (strain).
 - The material (ice) will no longer be able to return to its original shape, even after the stress subsides.

Brittle

- ❑ If the enough stress is applied rapidly, the ultimate strength of the ice will be surpassed and the ice will fracture/break.

Cool concept

- ❑ The average crushing strength of ice is 30 kg/cm².
- ❑ Prolonged application of stress as low as 1 kg/cm² is capable of producing large amounts of deformation.
 - Ice will behave plastically even under low stress conditions.

The Glen-Nye Equation

□ $\dot{\epsilon} = A \tau^n$

- $\dot{\epsilon}$ = Strain rate
- A = Temperature dependent coefficient
- τ = shear stress
- n = related to crystal orientations

Bigger, faster, stronger?

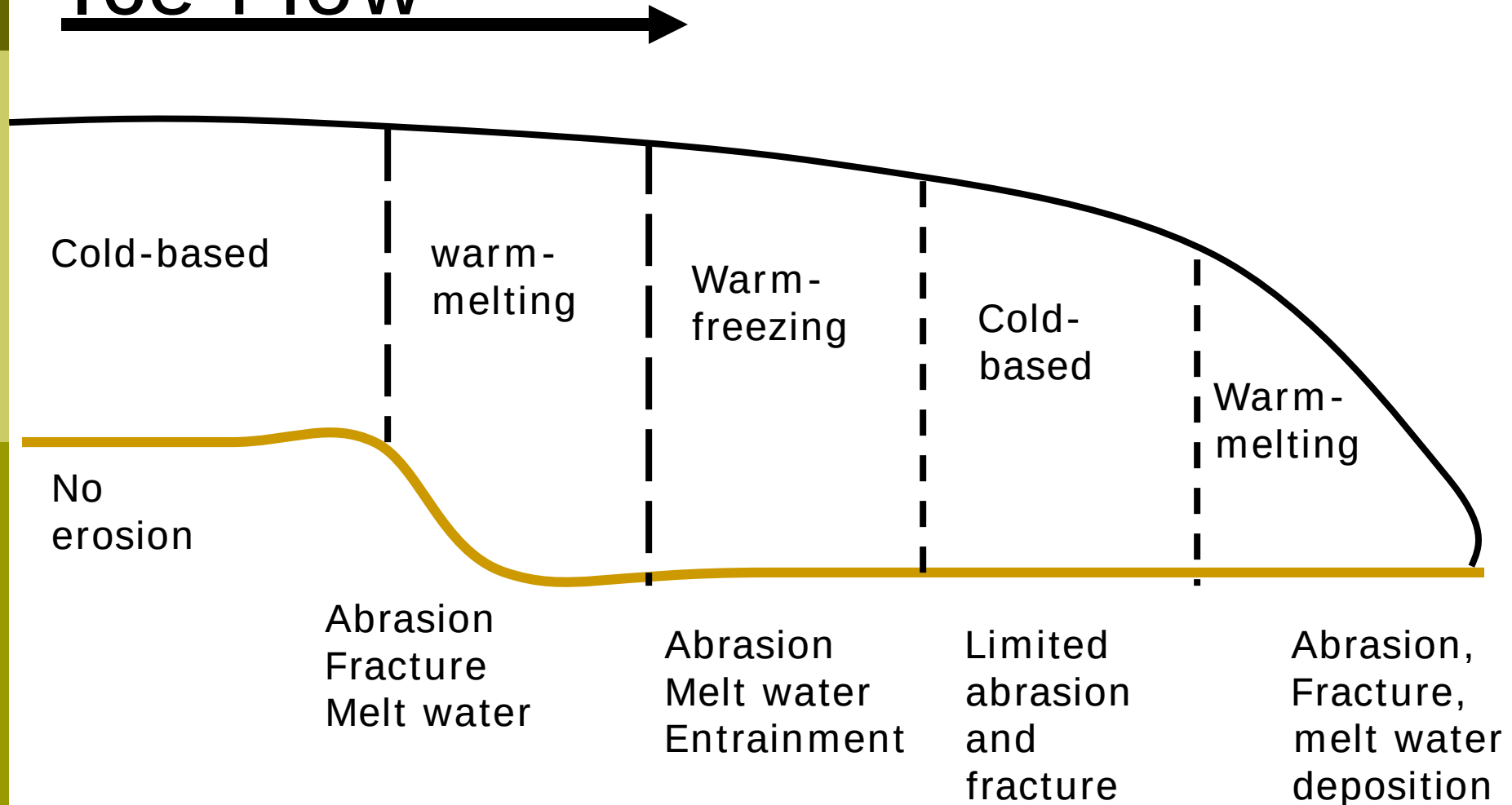
- The thicker the glacier
 - The steeper the slope
 - The faster the flow
 - The more plastic deformation

Temperature's role

- ❑ Warmer ice deforms with more ease compared to cold ice.
- ❑ Temperate glaciers at or near their pressure-melting point, generally exhibit higher rates of plastic flow than do polar glaciers whose ice is well below the freezing point.

Summary of Basal Thermal Regimes

Ice Flow

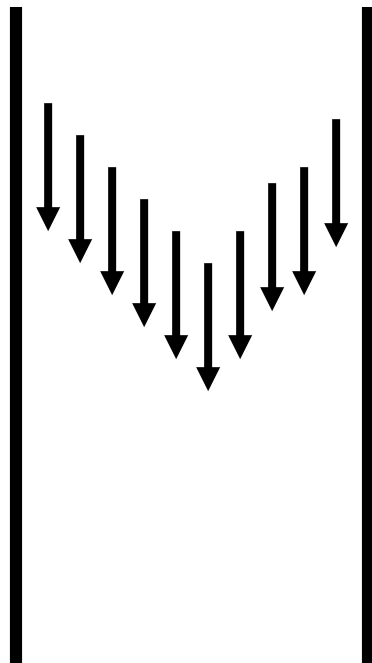


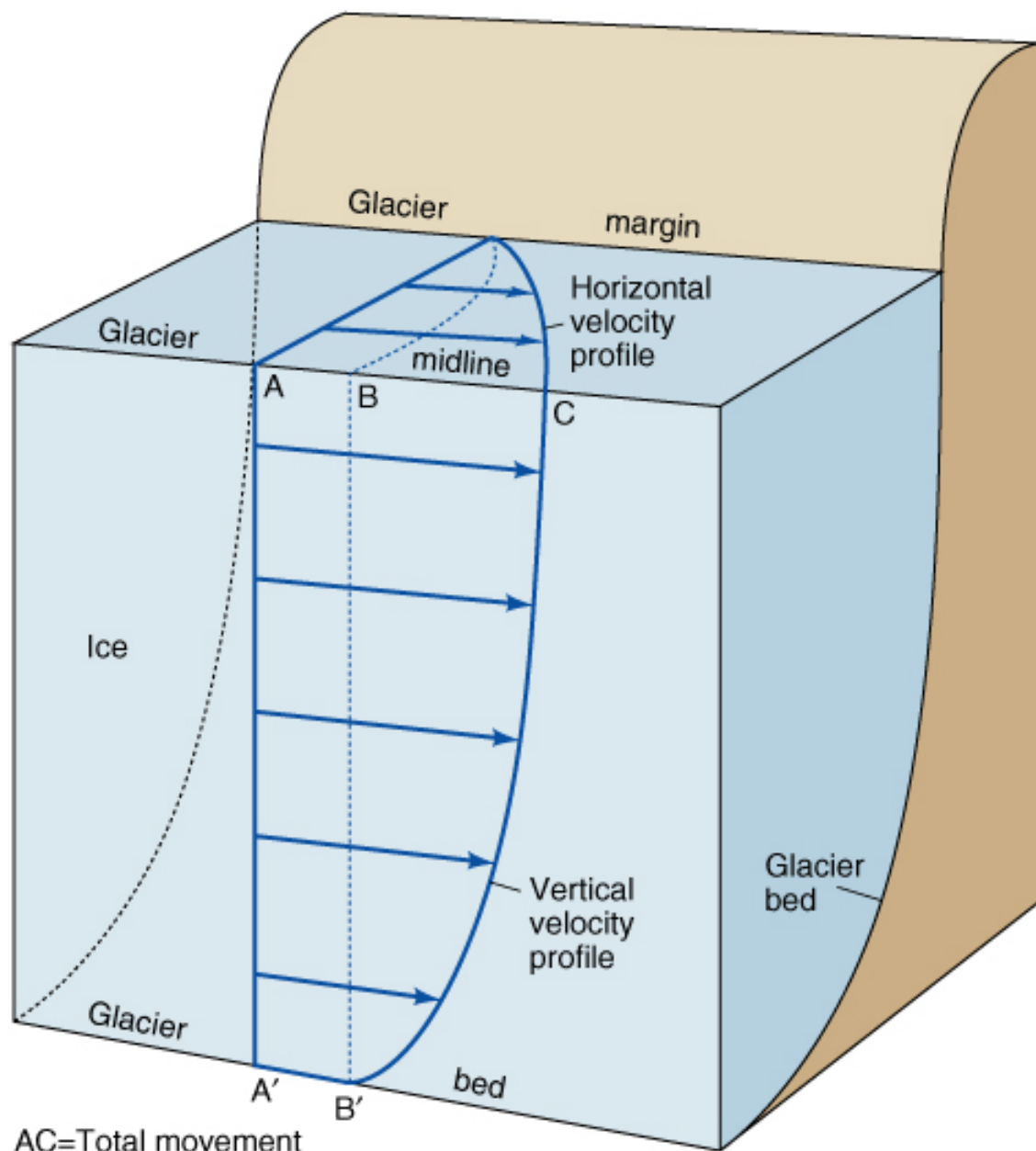
Glacial Velocities

- ❑ Variable (between glaciers, within glaciers, and seasonal variations)
- ❑ Alpine, Avg. 1 meter or less per day
- ❑ The Antarctic Ice sheet, few meters per year
- ❑ Highest velocities,
 - Steep gradients
 - Large accumulation areas
 - Outflow glaciers from some areas of Greenland are known to flow at 20 to 30 m/day!!

Velocity Profile

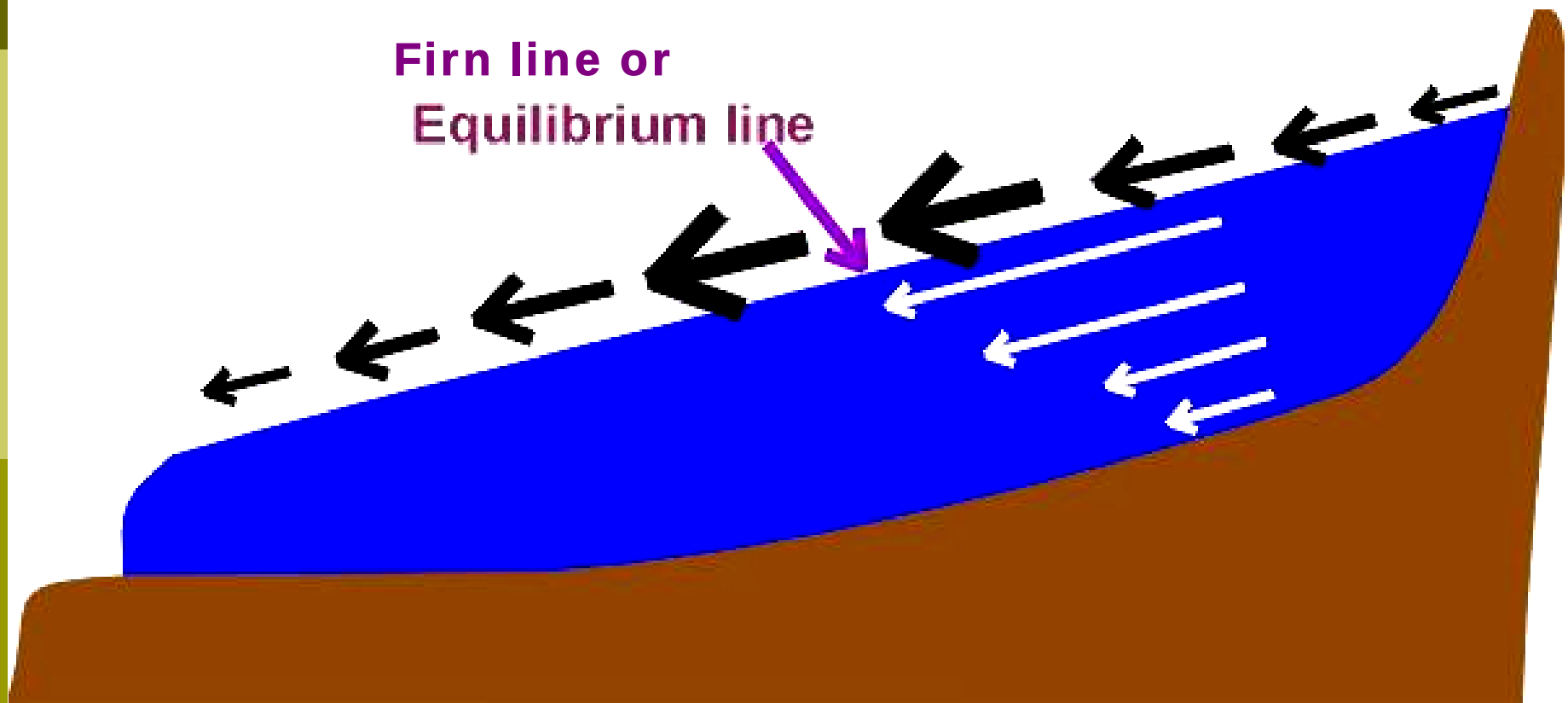
- ❑ Greatest near glaciers mid-line
- ❑ Lowest near the glaciers base and sides





AC=Total movement
 AB=A'B'=Sliding on bed
 BC=Internal flow

Velocities, Accumulation Vs. Abalation Zones



Movement types

- ❑ Basal Sliding
- ❑ Plastic Flow
- ❑ Internal Shearing

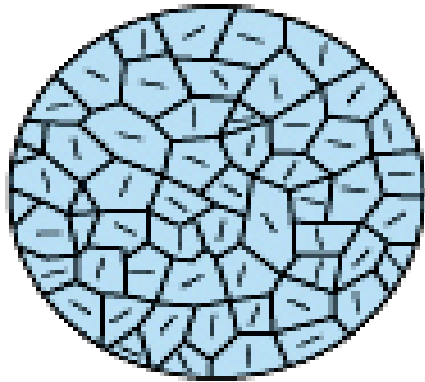
Basal Sliding

- ❑ Temperate glacial systems
- ❑ Greatest in thin glaciers on steep slopes
- ❑ Occurs in 'jerky' movements
 - Produces percussion marks, deep parallel grooves, striations, glacial polish
- ❑ Sub-glacial water under hydrostatic pressure
 - Appears to reduce the normal force (effective weight) of the overlying ice, which decreases friction and increase velocity/sliding

Plastic Flow

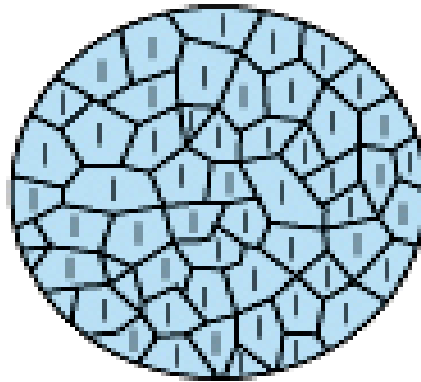
- ❑ Ice under low-pressure (stress) for long periods of time will flow plastically while in a solid state.
- ❑ Piedmont glaciers flowing out of confined valley onto a plain, exhibit plastic ice deformation.
- ❑ Ice flows plastically (flow continuously under its own weight) due to
 - Intergranular and Intragranular shifting
 - Recrystallization

Unstressed ice

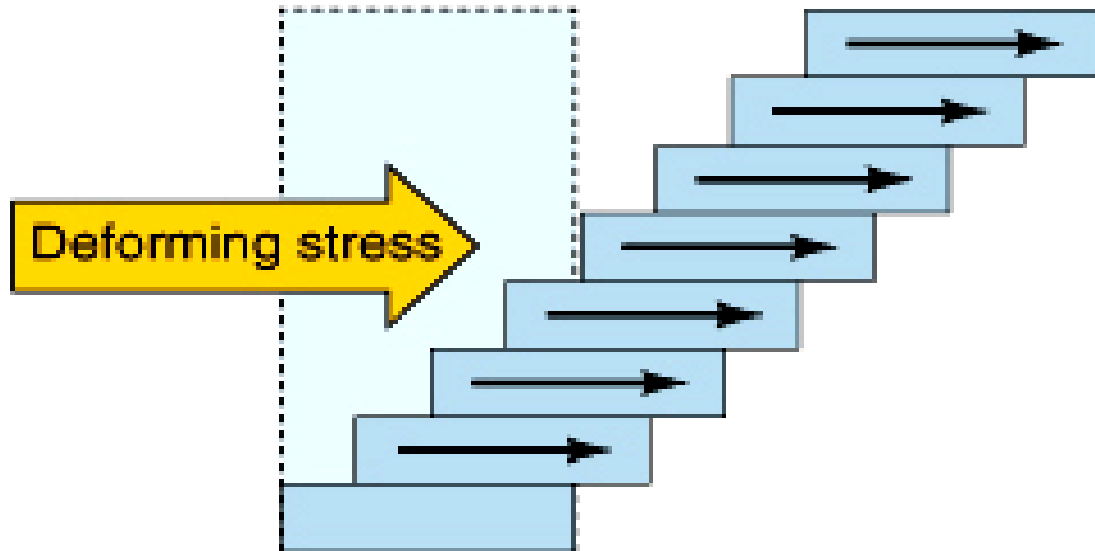
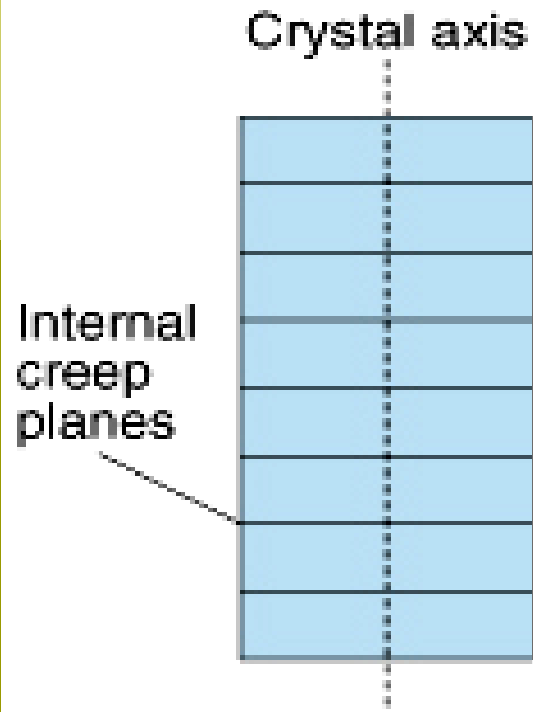


Randomly oriented
crystal axes

Stressed ice



Crystal axes
aligned



Plastic flow cont.

- ❑ Recrystallization of ice facilitates downglacier transfer of material.
- ❑ Compressive Vs. Extending plastic flow

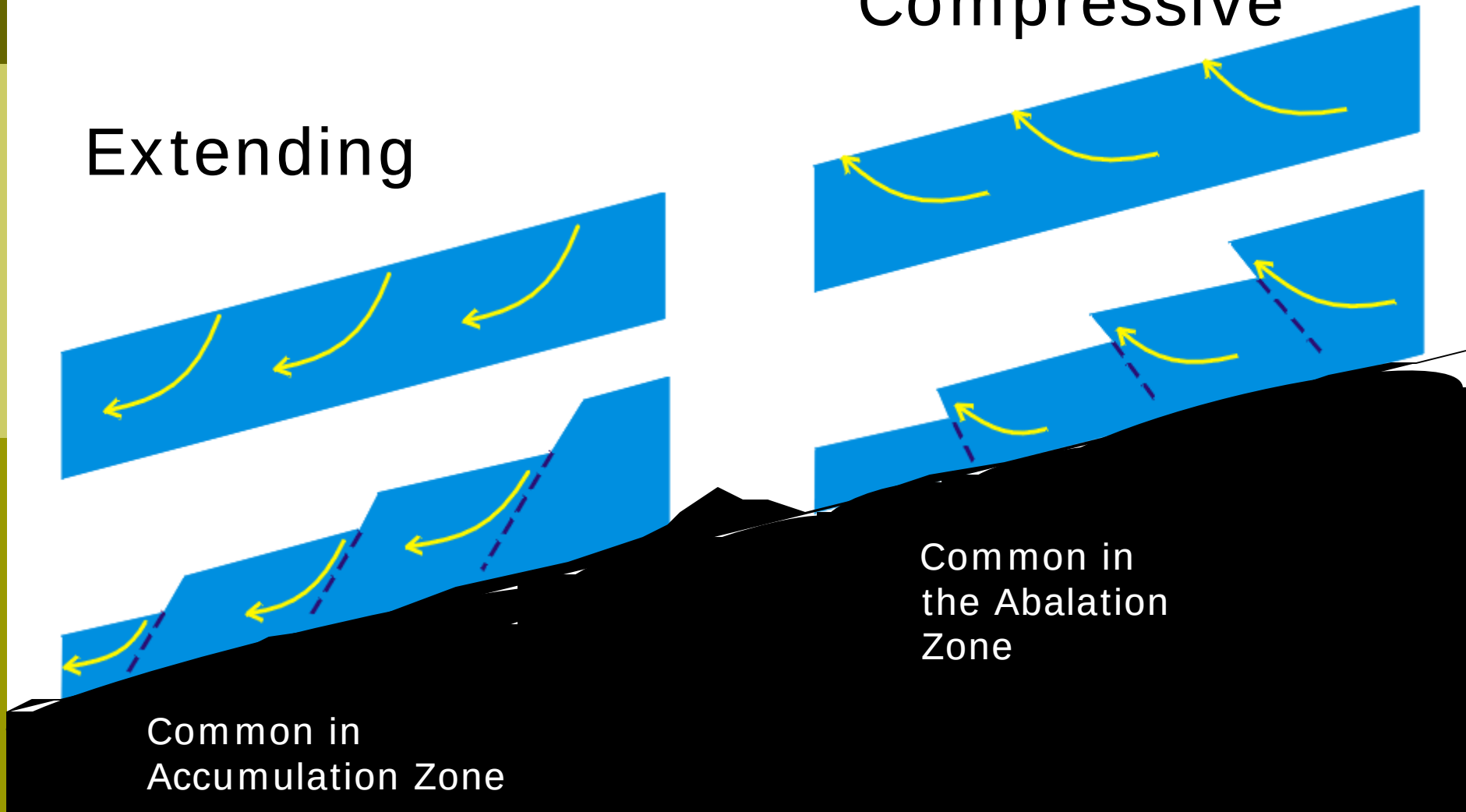
Compressive and Extending Plastic Flow

Extending

Compressive

Common in
Accumulation Zone

Common in
the Ablation Zone



Internal shearing

- ❑ Ice may respond as a brittle substance
- ❑ Upper 30m (100ft), near the terminus, typical area of brittle failure
- ❑ Important to the activity in at the terminus, but not a significant factor in over all glacial motion.

