# Glacial Processes and Products

# Goals

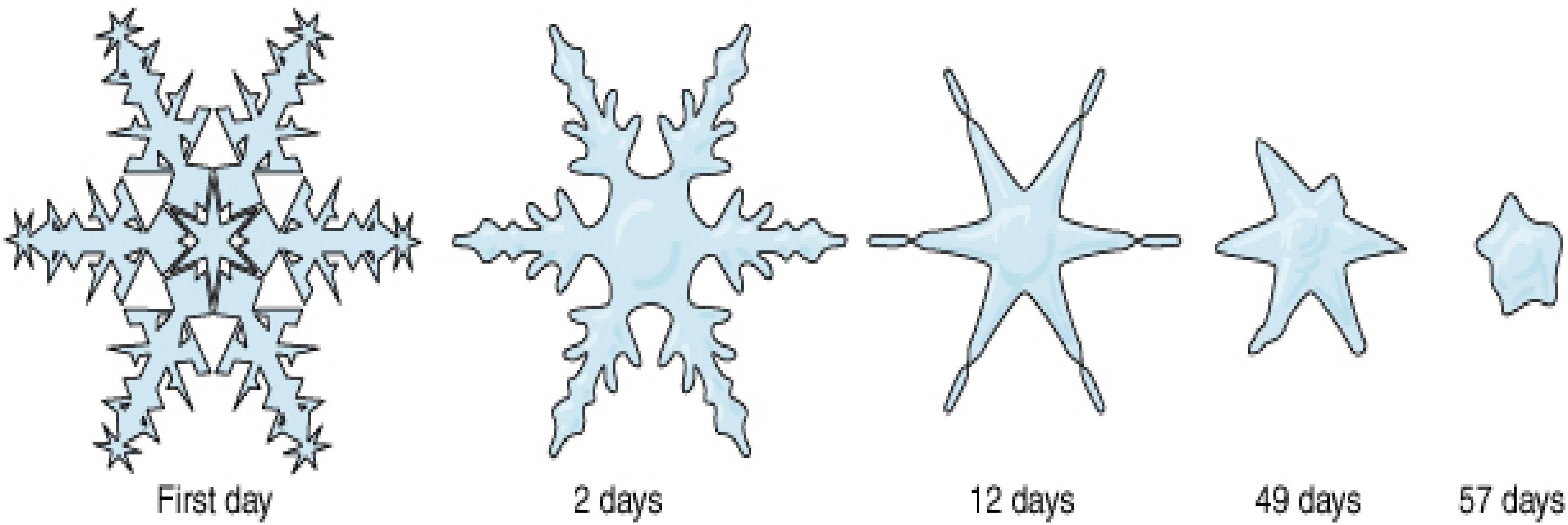
- Understand glacial climates
- Learn how glaciers form and move
- Learn how glaciers shape landscapes
  - Erosion and construction processes = landforms
  - Explore Iowa’s glacial history

# Seriously

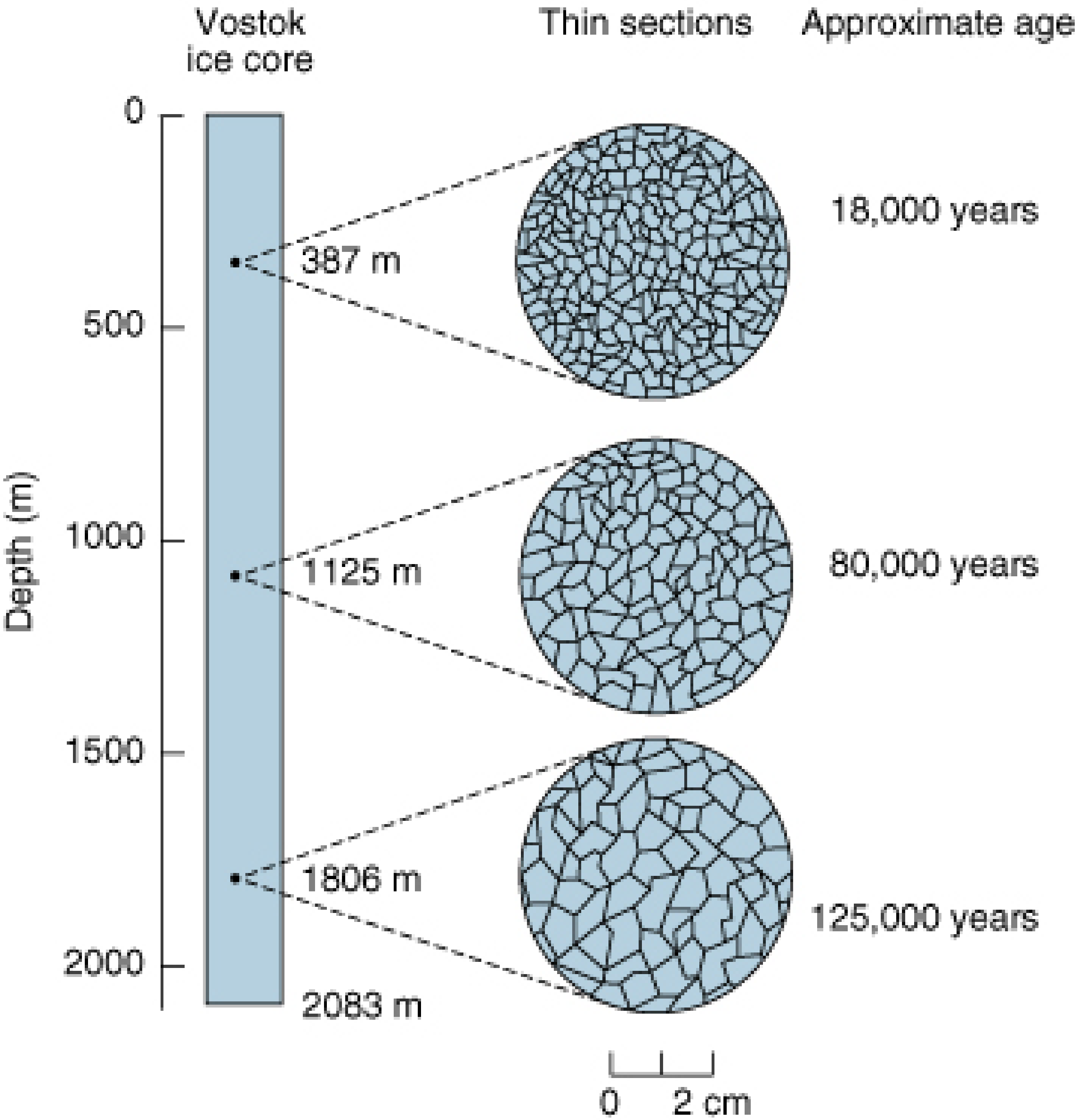
1. **Snow**, precipitation/chemical sediment of ice crystals (Density avg. 0.02 $g/cm^3$)
2. **Firn**, granular ice, product of compaction and melting/refreezing (Density 0.55 $g/cm^3$)
3. **Ice**, granular ice crystals frozen together (Density 0.97 $g/cm^3$)

# Ice

- Ice is a special kind of metamorphic rock.




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




# Ice Depth Vs. Time

# Glaciers

- Defined…on board
- 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.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# Glacial Regimes

- Terms
  - Accumulation zone
  - Equilibrium line
  - Ablation zone

# Zone of accumulation

- Area of positive gain
- Downward vectors of particle motion

# Zone of Ablation

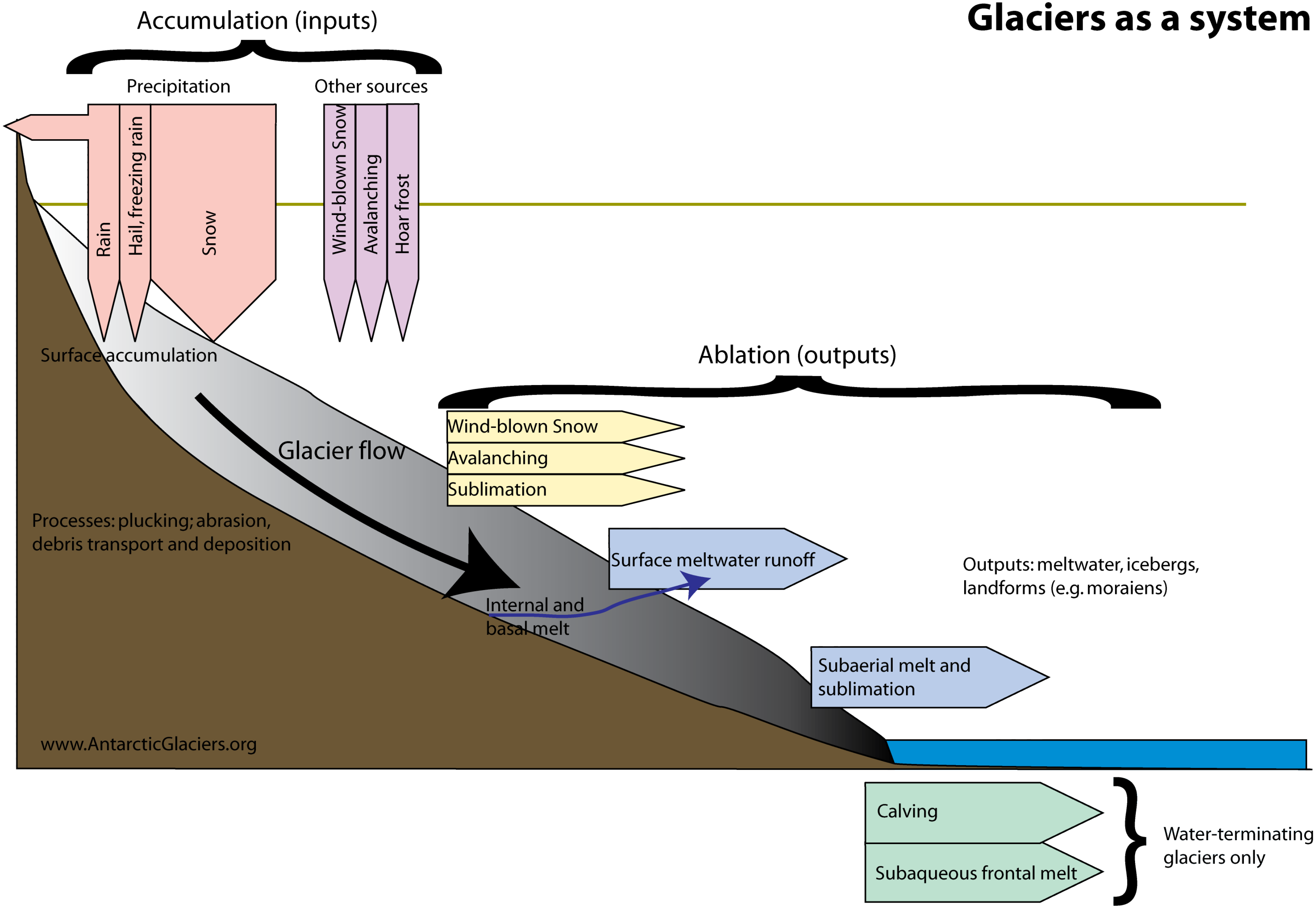
- Area of loss
- The down glacier area ice is lost to melting, sublimation, erosion, and caving into water.

# Firn/equilibrium line/zone

- Area separating the zone of accumulation from zone of ablation

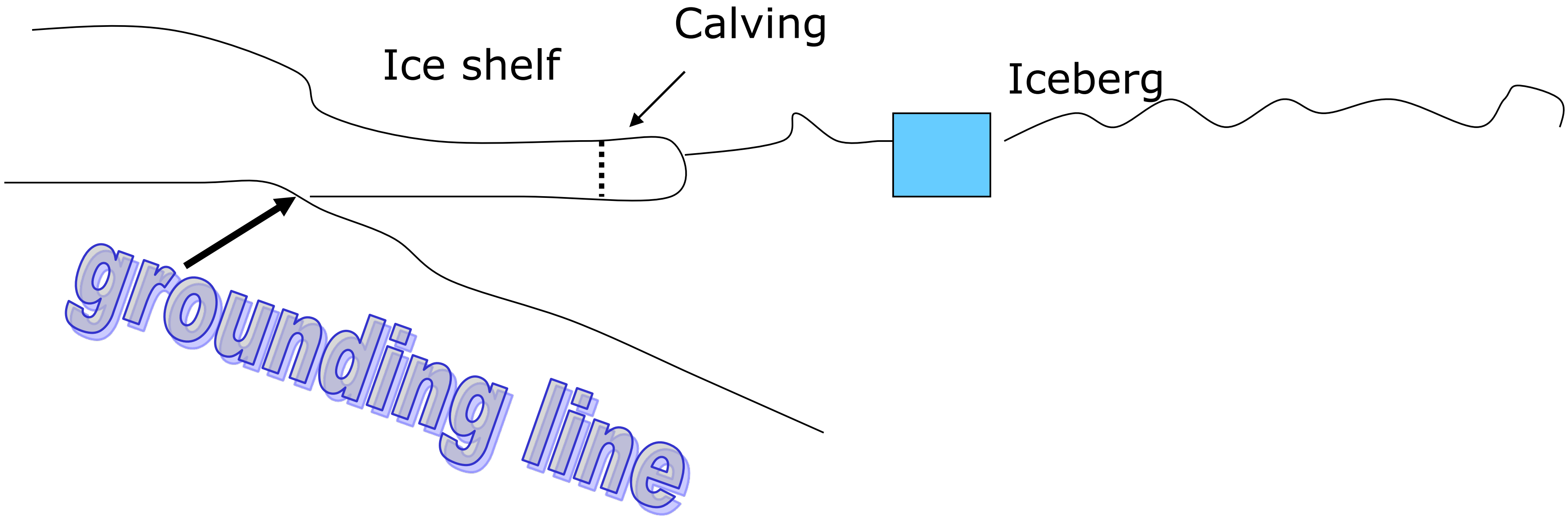
The Dinwoody Glacier  in late summer (Wind River Range, WY)

# Glaciers as a system



# Glacial calving

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

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# Important concept

- When Accumulation >Ablation
- When Accumulation < Ablation
- When Accumulation = Ablation

# Glacial Classifications

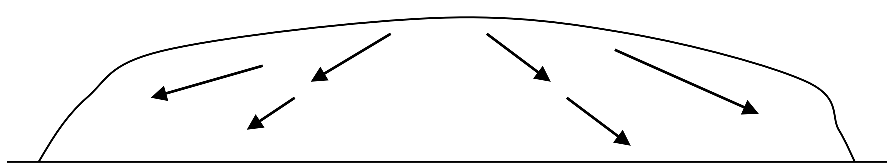
1. Dynamic
2. Morphologic
3. Thermal

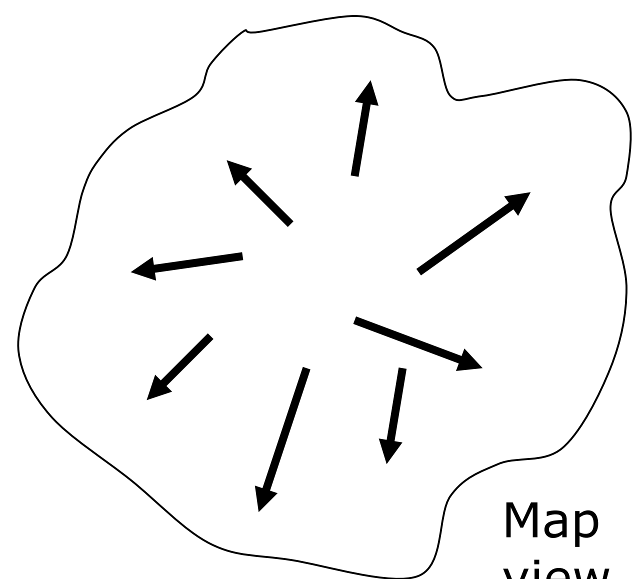
# Dynamic classification of glaciers

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. <u>Continuous sheets</u>; Ice sheets (i.e. continental glaciers) that flow from a central topographic high.




Ice caps are much smaller!!

(~ < 50,000 km$^2$)

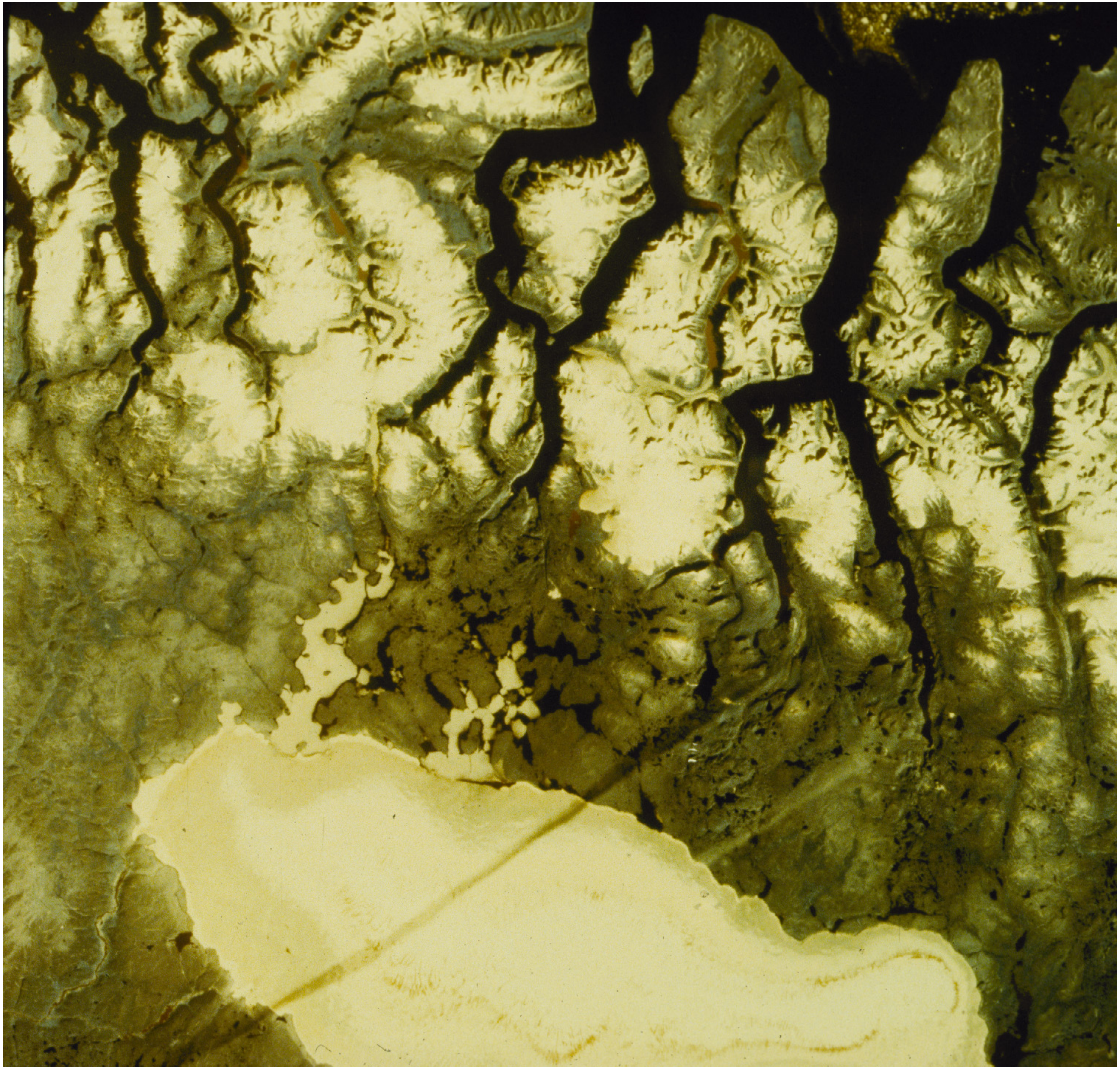
# Ice sheets and caps

- Are unconfined systems
- Develop own orographic precipitation patterns
- Accumulation zone in the center
- Ablation zone lies on the periphery
- Are extremely sensitive to climatic change.

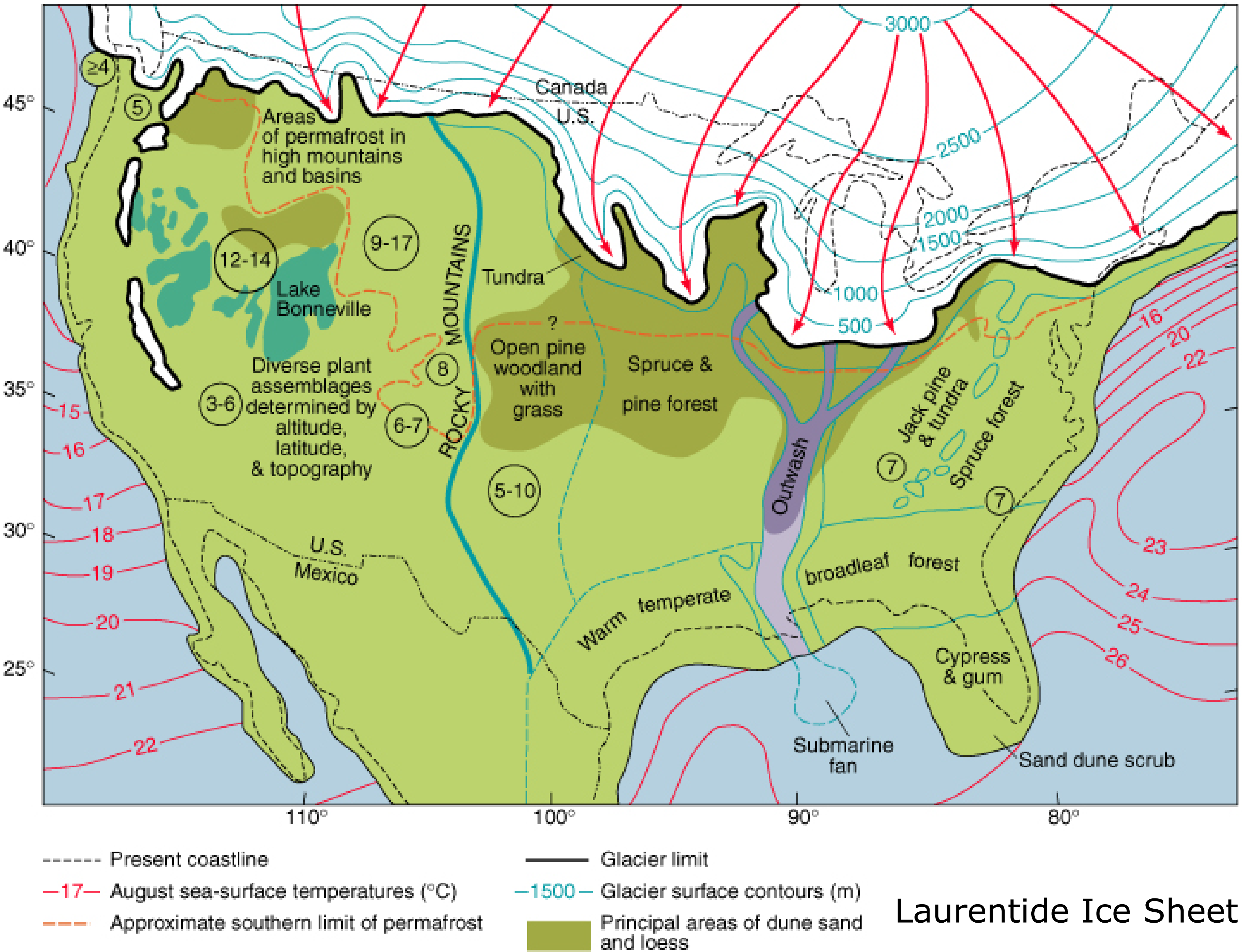
# Ice sheet cont.

- 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




Laurentide Ice Sheet

# Ice sheets are positive feedback systems

- 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 abalation zone
4. Resulting in accelerated growth!

# 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.
- Frequent on northward or eastward facing slope in the Northern Hemisphere
- May join valley glaciers.

# Cirque glaciers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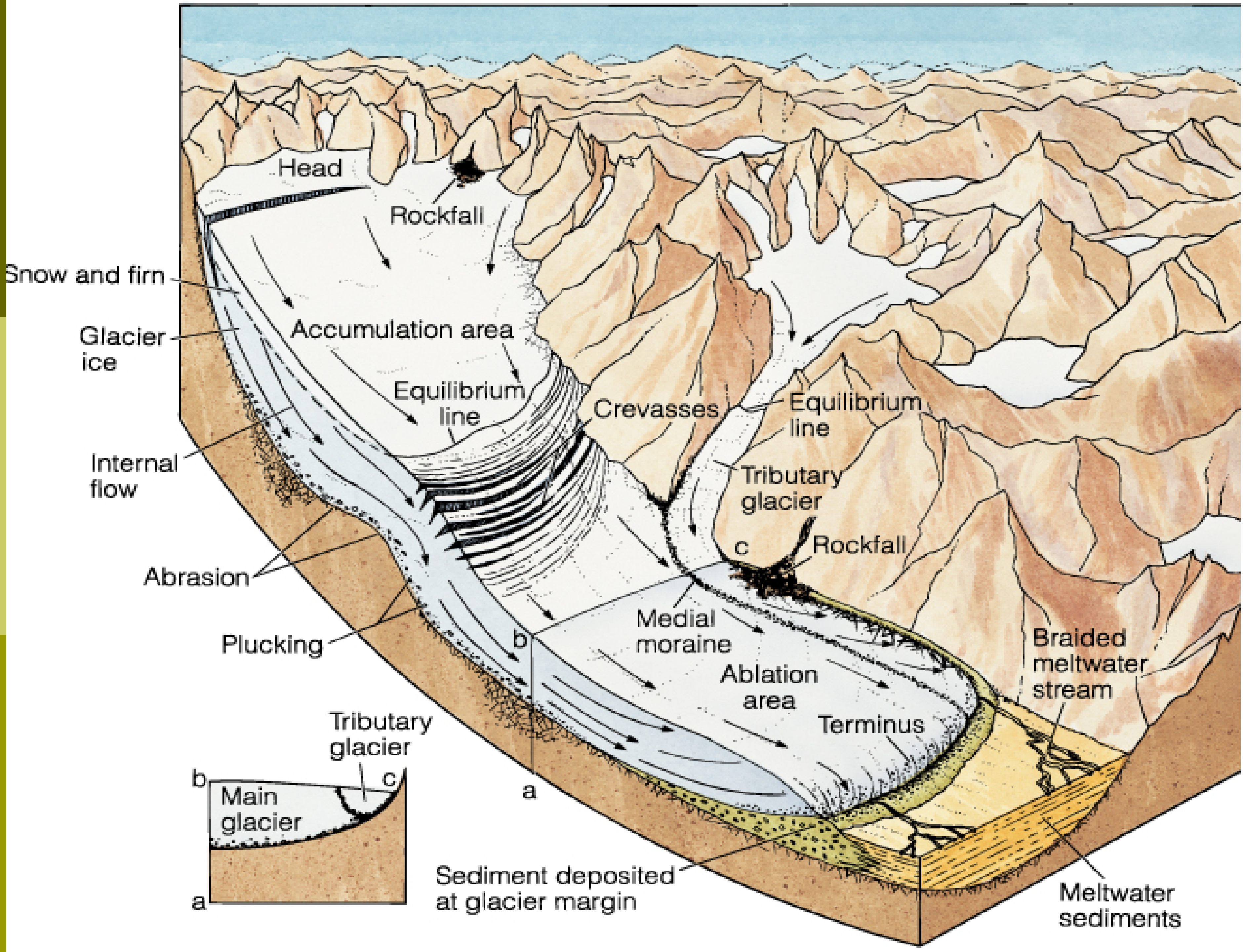
Head
Rockfall
Snow and firn
Glacier ice
Accumulation area
Equilibrium line
Internal flow
Crevasses
Equilibrium line
Tributary glacier
Rockfall
c
Abrasion
Plucking
b
Medial moraine
Ablation area
Terminus
Braided meltwater stream
Tributary glacier
b
c
Main glacier
a
a
Sediment deposited at glacier margin
Meltwater sediments

# 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

# Characteristics

- Mountain valleys
  - High elevation
  - Cold
  - High precipitation levels
- Valley glaciers are often feed by cirque systems
- 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 lobe, radially flowing lobe onto plains at the foot of mountains

- Piedmont glaciers may also extend into standing bodies of water.


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# Piedmont Glacier, Baffin Island

# 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)
- The transition from Firn to Ice is relatively fast.

# 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
- Ablation, only by calving, wind erosion, or sublimation.

# Sub-polar glaciers

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

# Glacial Movement

# Ice Behavior

- Applied stress vs. Ice response
  - Elastic
  - Plastic
  - Brittle

- Factors
  - Type of stress applied (tensional, compressional, shear, or hydrostatic)
  - Amount of applied stress
  - Rate at which the stress is applied
  - Temperature rates/variations

# Elastic

- The amount of strain (deformation) is proportional to the stress applied.
  - Once the stress decreases the 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 lead to substantial deformation (strain).
  - Ice will no longer be able to return to its original shape, even after the stress subsides.

# Brittle

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

# Cool concept

- Average crushing strength of ice is 30 $kg/cm^2$.
- Prolonged application of stress as low as 1 $kg/cm^2$ is capable of producing large amounts of deformation.
  - Ice will behave plastically even under low stress conditions.

# The Glen-Nye Equation

- $E = A\,\tau^n$
  - E = Strain rate
  - A = Temperature dependent coefficient
  - T = shear stress
  - n= related to crystal orientations

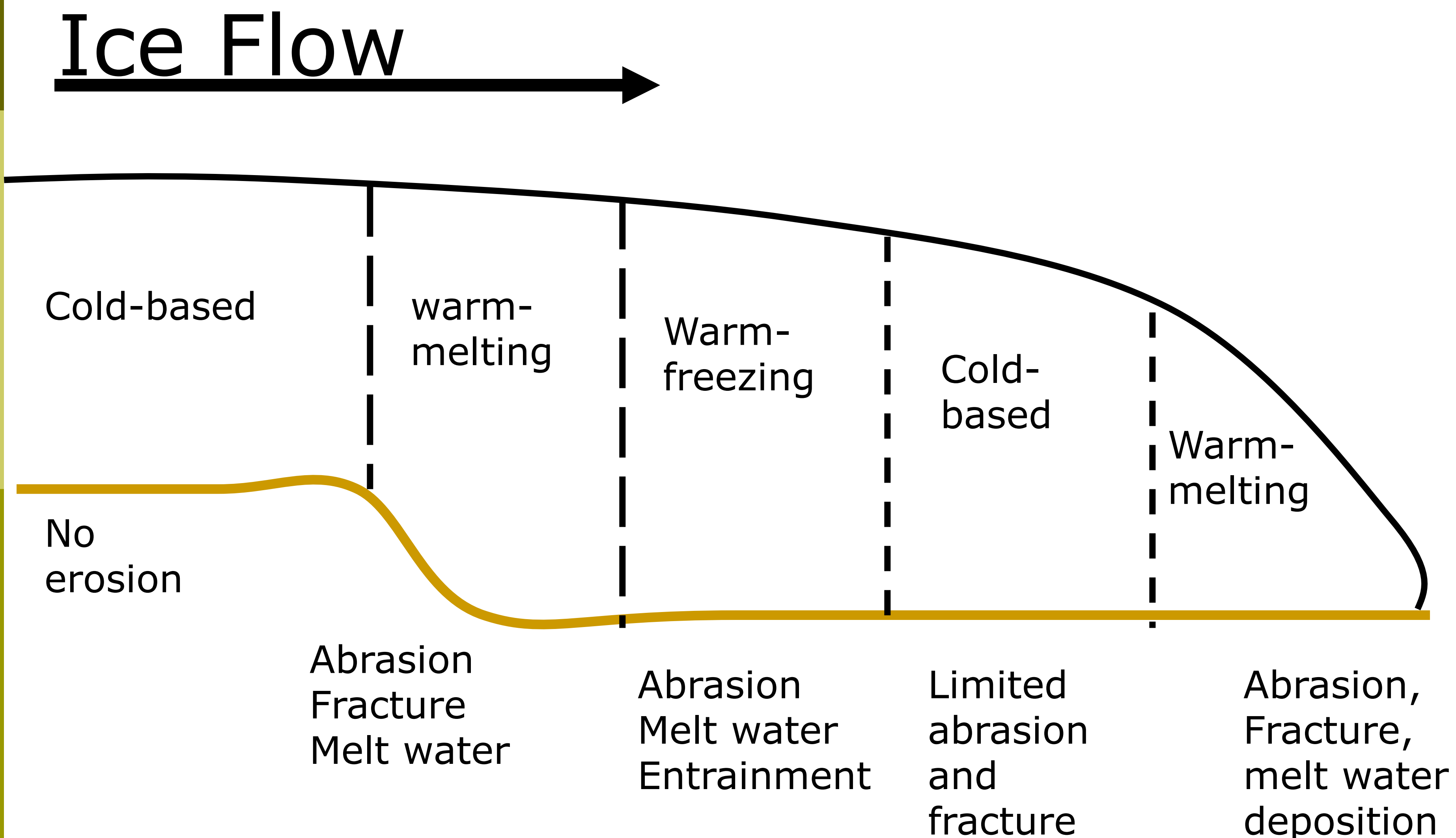
# Bigger, faster, stronger?

- The thicker the glacier = The steeper the slope
- Faster flow = increased plastic deformation

# Temperature's role

- Warmer ice deforms more easily than colder ice.
- Temperate glaciers at or near their (PMP), exhibit higher rates of plastic flow than do polar glaciers whose ice is well below the freezing point.

# Summary of Basal Thermal Regimes

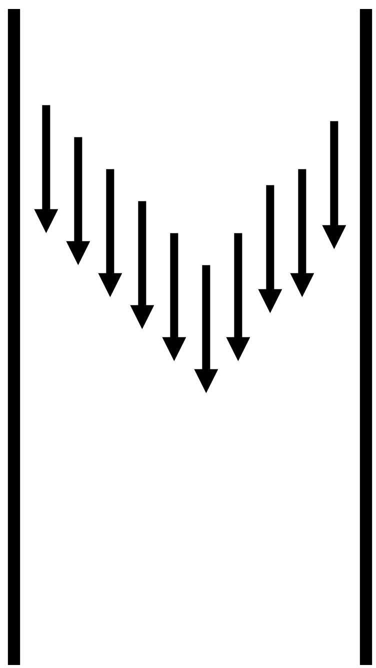


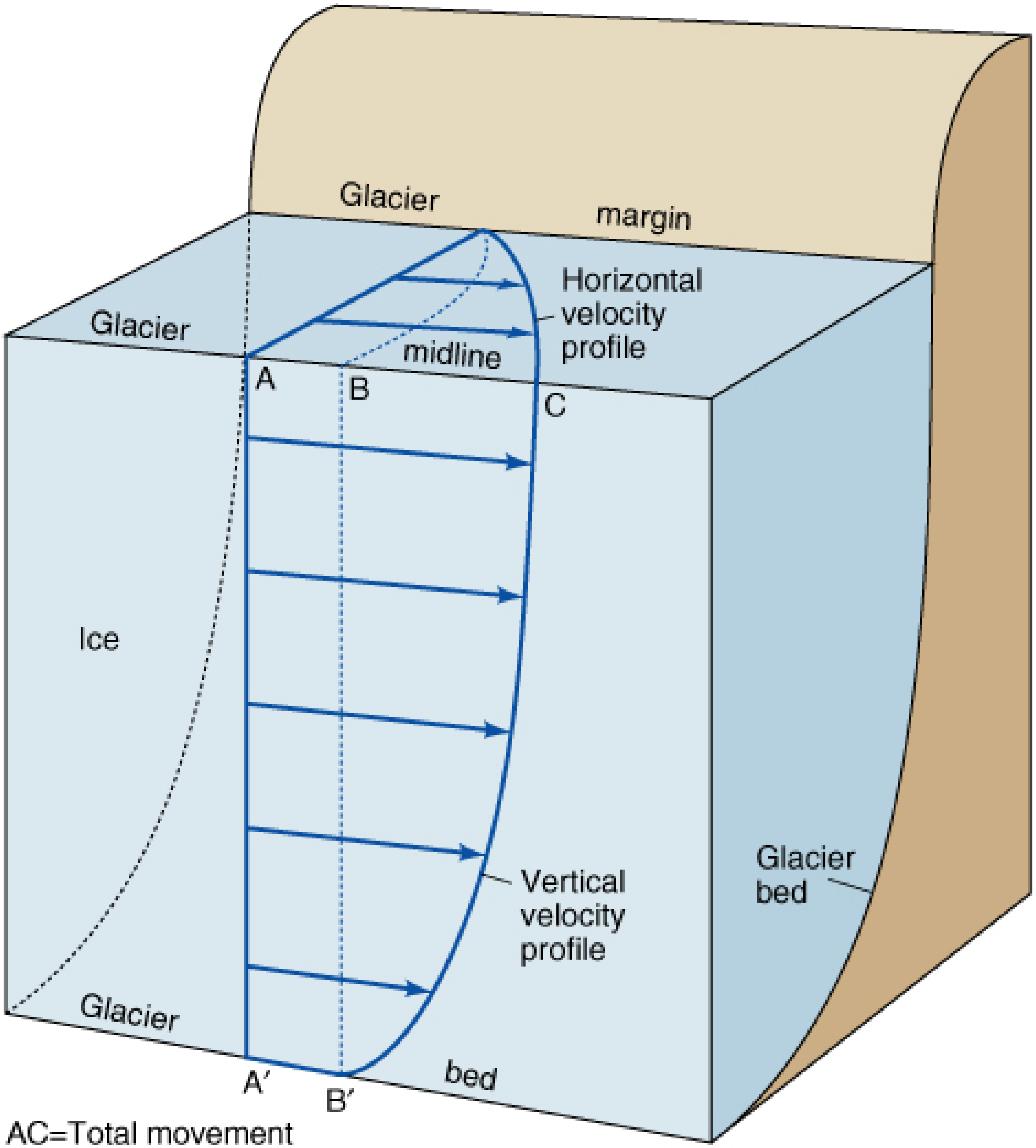
# Glacial Velocities

- 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

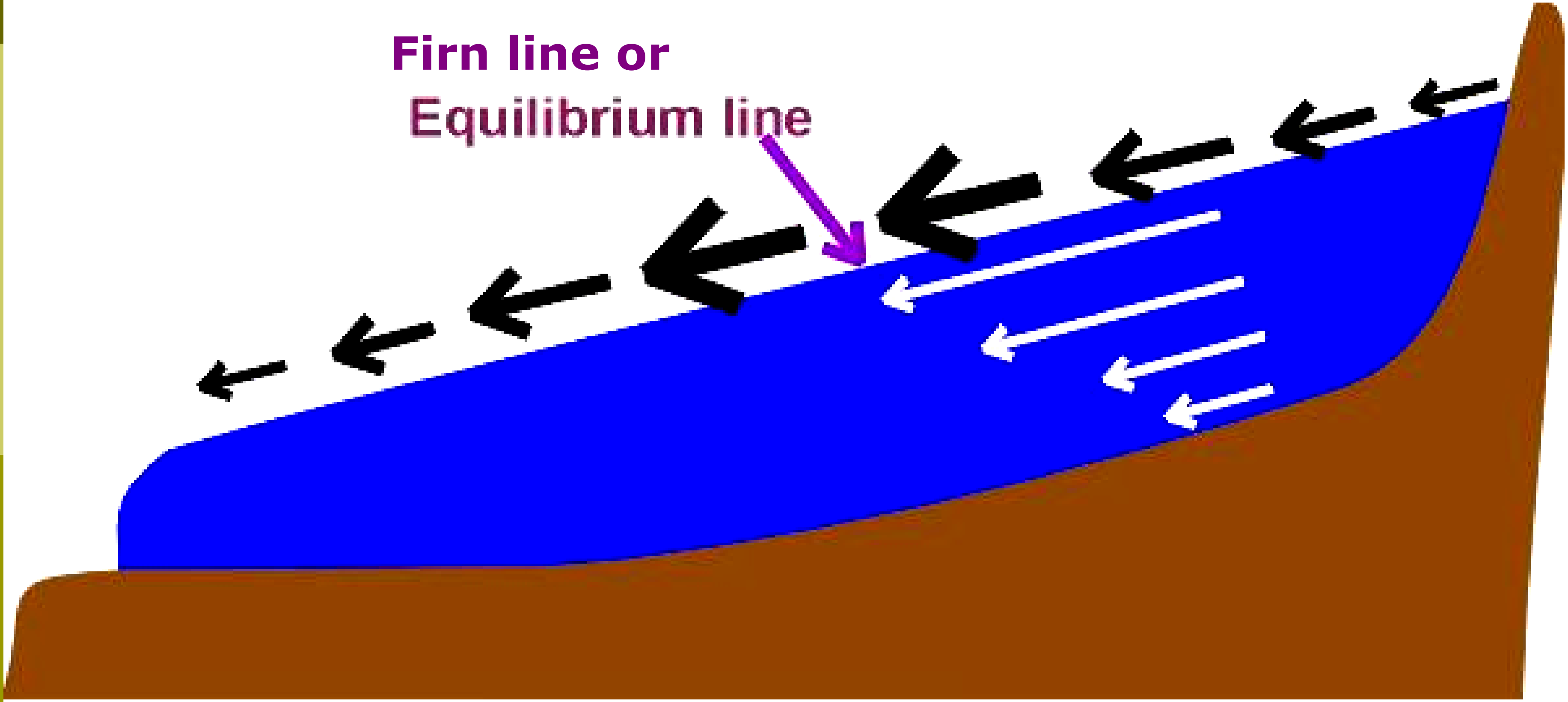
- Greatest near glaciers mid-line
- Lowest near the glaciers base and sides






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

# Velocities, Accumulation Vs. Abalation Zones



# Movement types

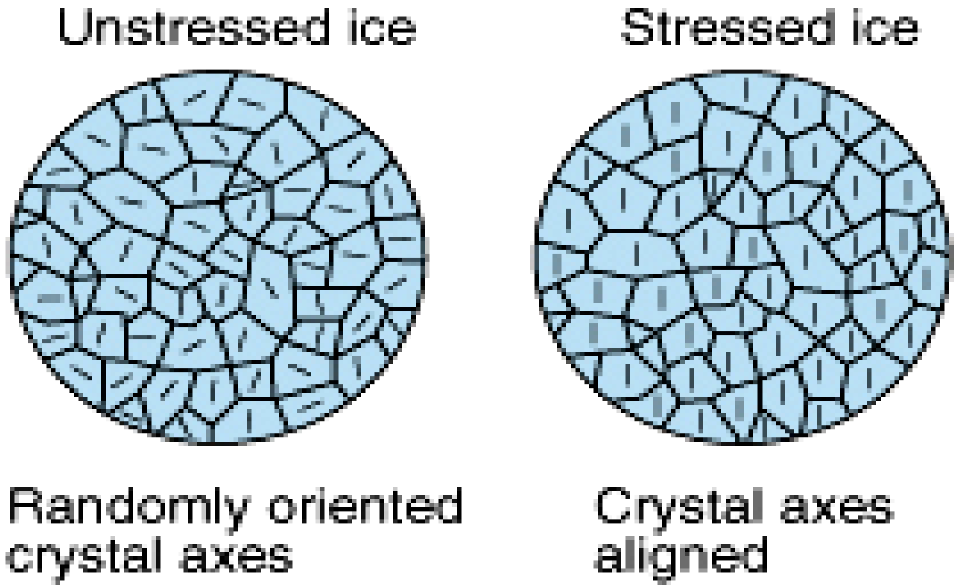
- Basal Sliding
- Plastic Flow
- Internal Shearing

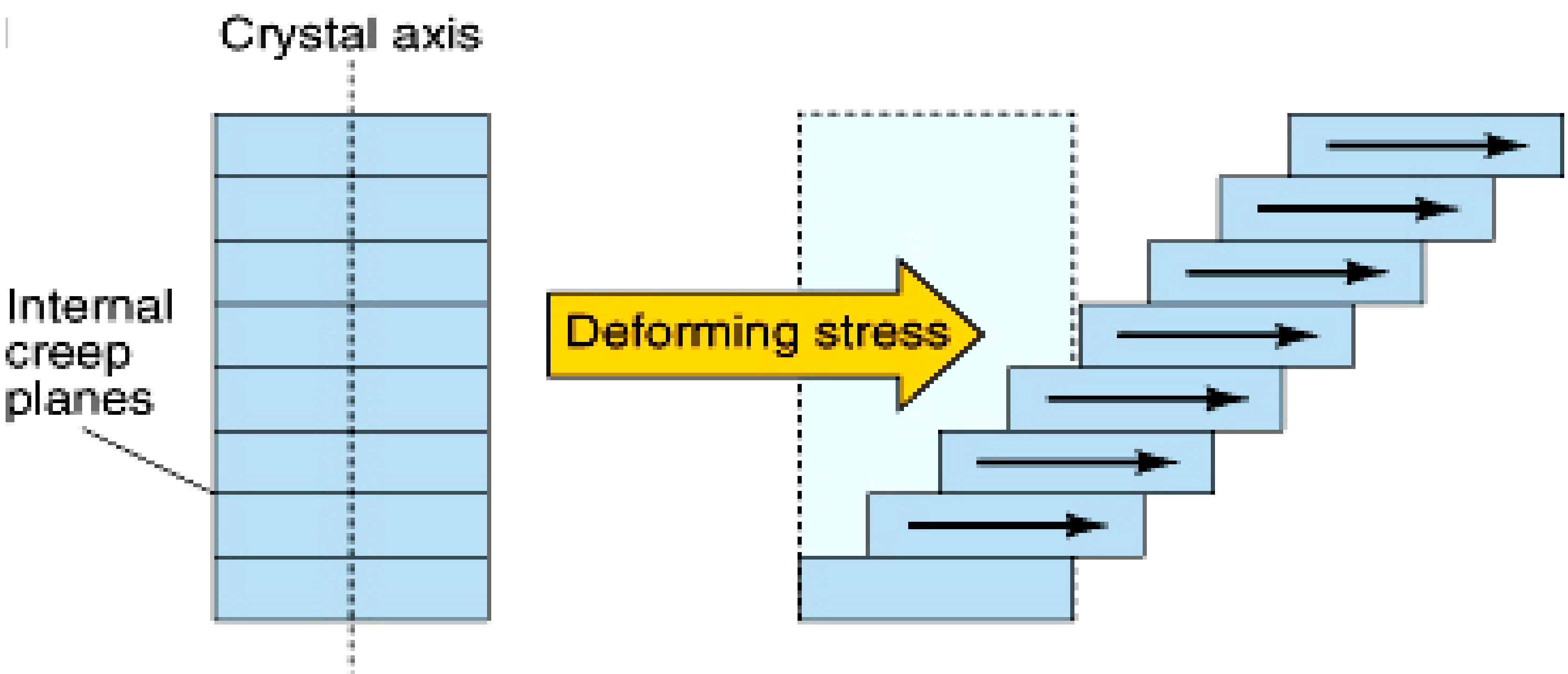
# Basal Sliding

- Temperate glacial systems
- Greatest in thin glaciers on steep slopes
- Occurs in ‘jerky’ movements
  - Produces percussion marks, deep parallel groves, 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
  - Recryastalization

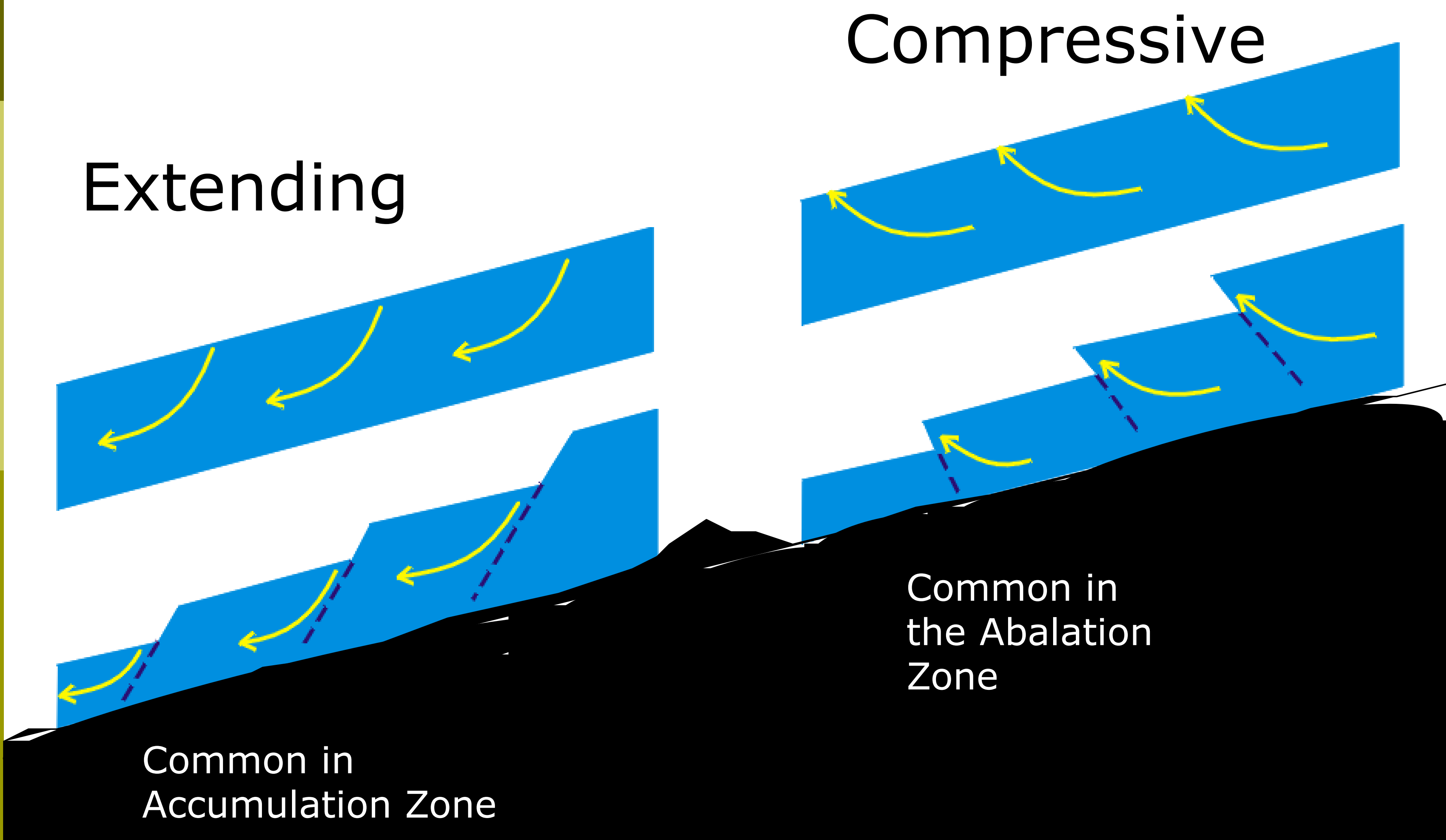

Unstressed ice
Stressed ice
Randomly oriented crystal axes
Crystal axes aligned


Crystal axis
Internal creep planes
Deforming stress

# Plastic flow cont.

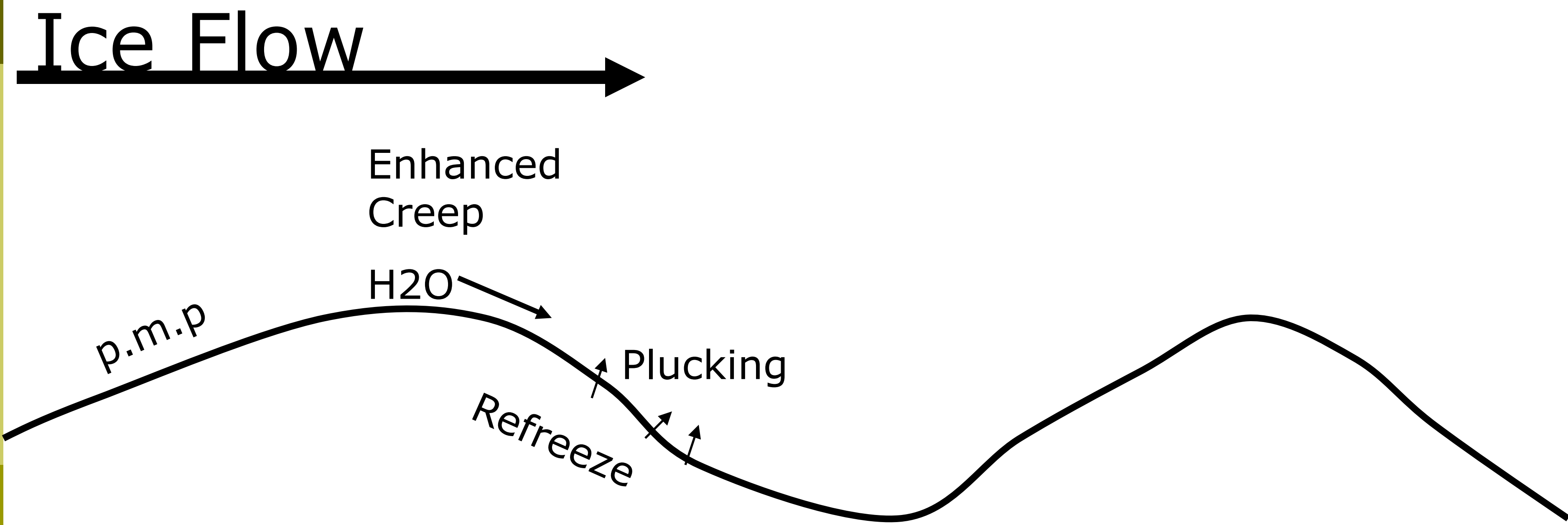
- Recrystallization of ice facilitates downglacier transfer of material.
- Compressive Vs. Extending plastic flow

# Compressive and Extending Plastic Flow



# 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.


Ice Flow
Enhanced
Creep
H2O
p.m.p
Plucking
Refreeze