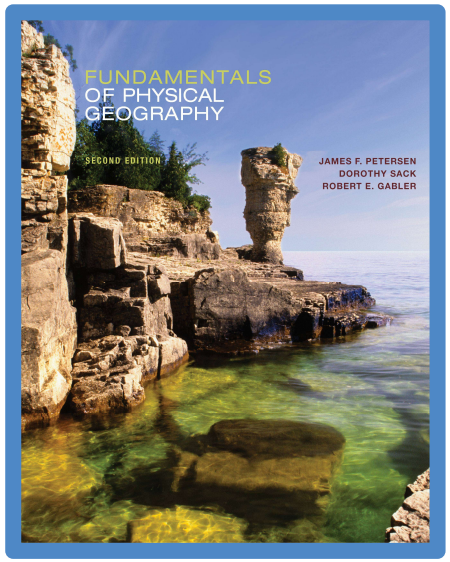
Fundamentals of Physical Geography 2e

Glacial Systems and Landforms

16



- Peterson
  - Sack
    - Gabler

Introduction

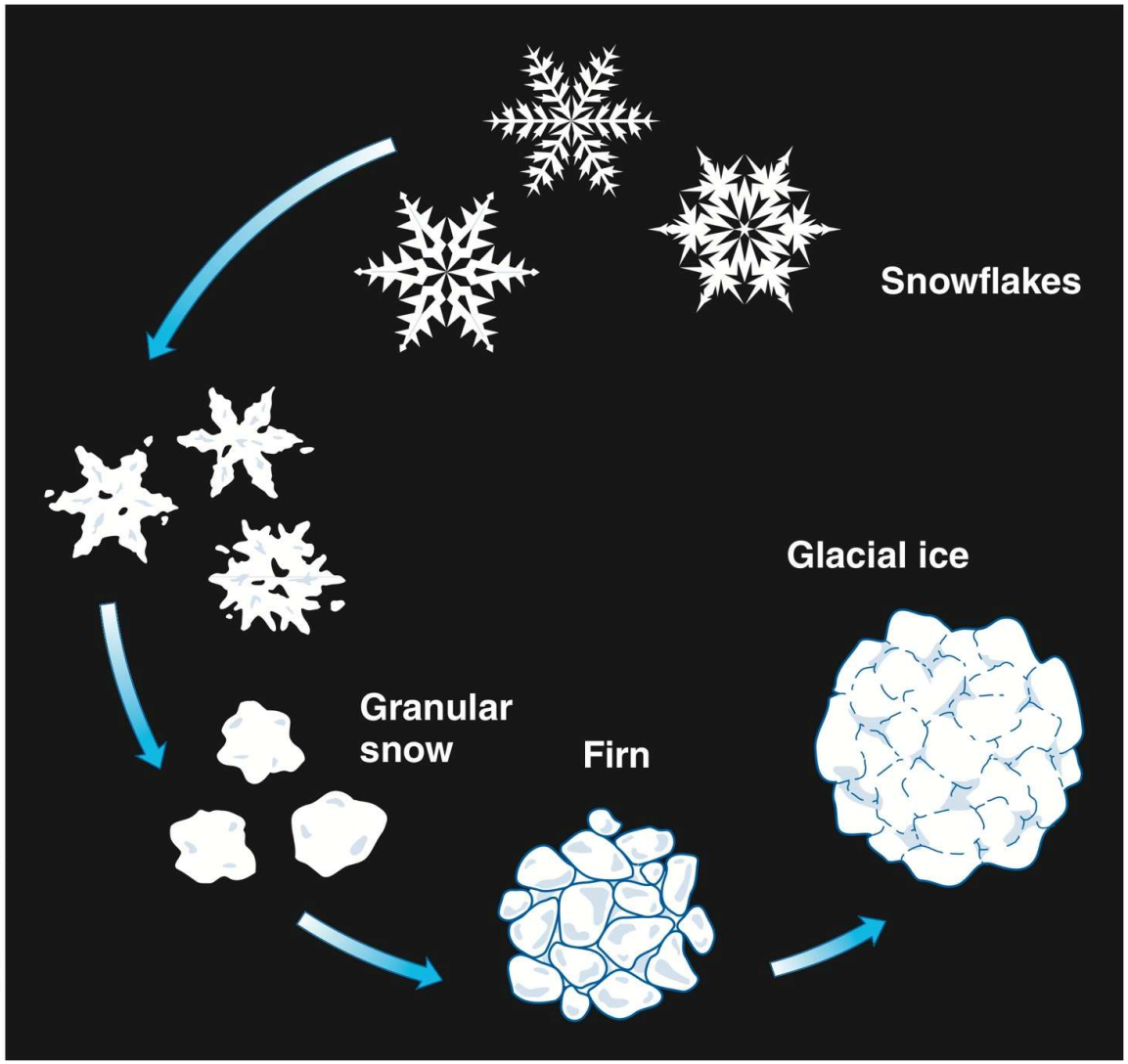
- Glaciers
  - Important roles in Earth system
    - Climate indicators
    - Long-term fresh water storage
    - Record of past climates
  - Studying behavior helps us understand:
    - Present terrain
    - Nature of past climates
    - Some of the potential impacts of ongoing and future climate change

Glacier Formation and the Hydrologic Cycle

- Glaciers
  - Masses of flowing ice that have accumulated on land
    - Annual input (frozen precipitation) exceeded yearly loss (melting, etc.)
- Snowflakes
  - Fall as hexagonal ice crystals
    - Low density: 0.1 g/cm^3
    - Accumulate on land: compact, melt, and refreeze

Glacier Formation and the Hydrologic Cycle

- Snowflakes
  - Become granular snow
    - Continues to compact further under newer snowfalls
  - Becomes firn granules
    - Due to pressure, partial melting, and refreezing: grow together into larger interlocked ice crystals
  - Becomes glacial ice
    - When density reaches 0.9 g/cm^3



How does firn differ from snow?

Glacier Formation and the Hydrologic Cycle (cont'd.)

- Glaciers: open systems
  - Accumulation: addition of frozen water
  - Ablation: removal of frozen water
    - Melting, sublimation, calving, etc.
  - Controlled by two basic climate conditions
    - Frozen precipitation
    - Freezing temperatures
  - Why are there no glaciers in subarctic Alaska and Siberia?

Glacier Formation and the Hydrologic Cycle (cont'd.)

- Ice depth of about 30 meters
  - Pressure enables the solid glacial ice to flow
- Glaciers: important part of Earth's hydrologic cycle
  - 2.25% of Earth's total water
  - 70% of world's freshwater

Glacier Formation and the Hydrologic Cycle (cont'd.)

- What would be the impacts if all of the world's glaciers melted?
- Ice age
  - Period during which significant areas of the middle latitudes are covered by glaciers
- Pleistocene Epoch
  - Nearly a third of Earth's land area
    - Covered by glaciers

Glacier Formation and the Hydrologic Cycle (cont'd.)

- Glacial ice is blue!
  - Successive layers of snow
    - Create pressure: compresses the older layers beneath
  - Low-density snow layers become much denser solid ice layers over time
    - Due to compaction, freezing, and refreezing
  - Dense ice
    - Reflects shorter light wavelengths → blue!

Types of Glaciers

- Two major categories
  - Alpine glaciers
  - Continental glaciers
- Alpine glaciers
  - Exist in high elevations
    - Formed from ice and snow in mountain areas
  - Occupy valleys
    - Previously created by stream erosion
  - Flow downslope due to gravity

Types of Glaciers (cont'd.)

- Alpine glaciers
  - Valley glaciers
    - Occupy former stream valleys
  - Piedmont glaciers
    - Ice extends to lower elevations beyond the mouth of a canyon
  - Alpine cirque glaciers
    - Smallest type of Alpine glacier

USGS/photo by Don Becker

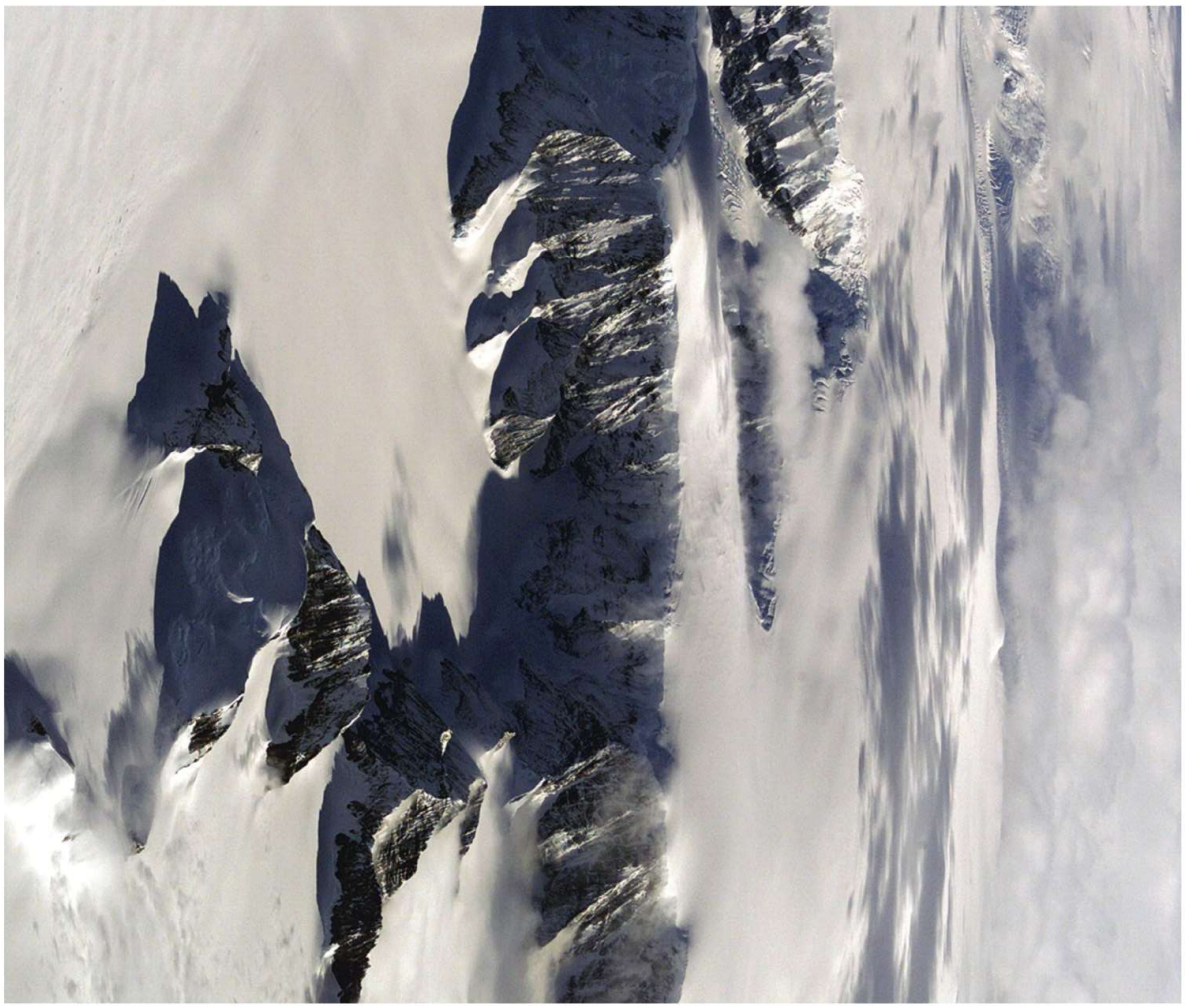
USGS/Austin Post

Why is only part of the ice bright white?

Types of Glaciers (cont'd.)

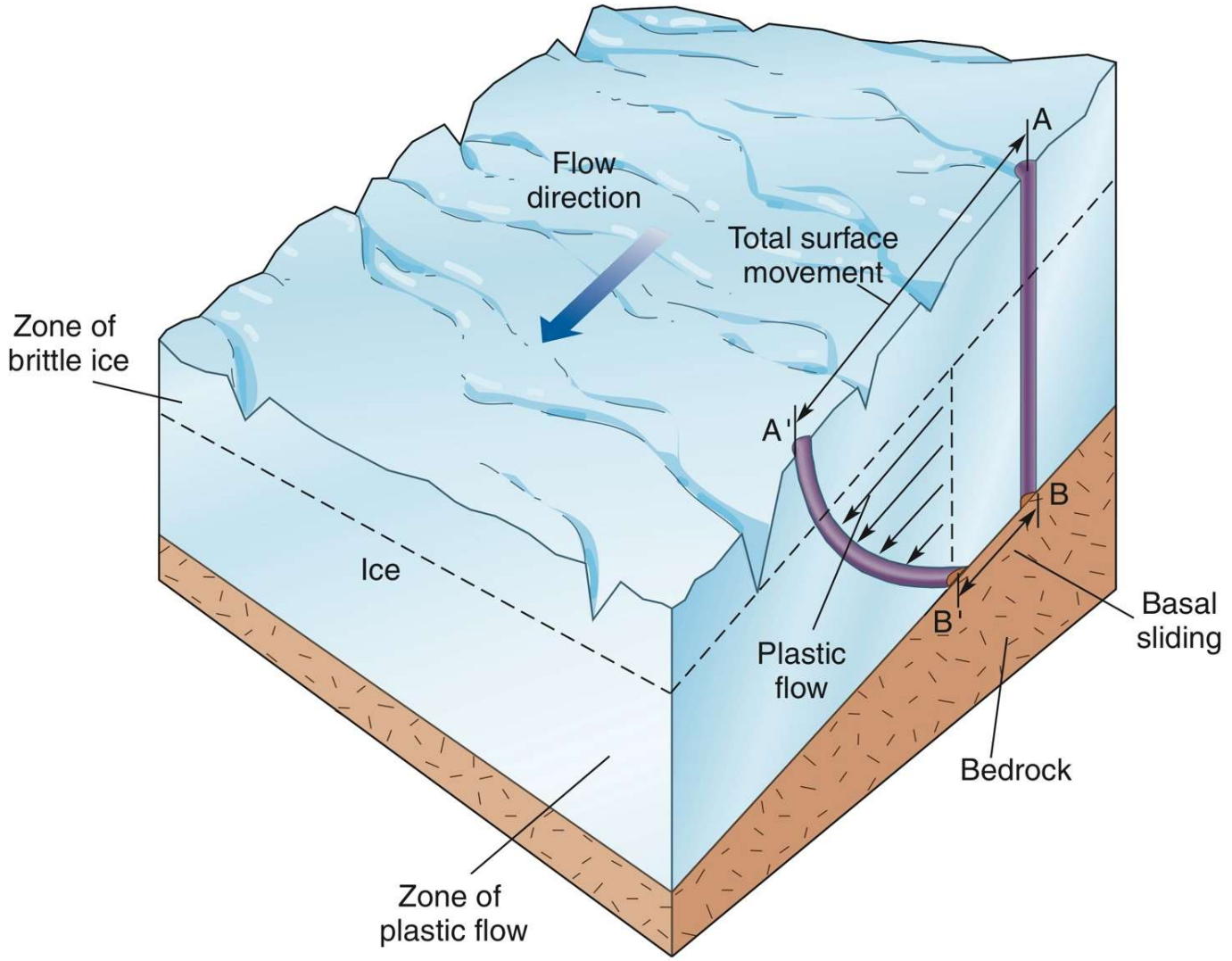
- Continental glaciers
  - Much larger and thicker than alpine types
  - High latitude locations
  - Subdivided by size
    - Polar ice sheets: largest type
    - Ice caps: smaller than 50,000 square kilometers
  - Where are the polar ice sheets located?
  - Direction of flow
    - Radially outward from central area of maximum ice thickness

NASA/Dryden Flight Research Center Photo Collection



Moving Ice as a Geomorphic Agent

- How glaciers flow
  - Internal plastic deformation: dominant process
    - Ice crystals at depth arranged in parallel layers: glide over each other
    - Overlying frozen material exceeds a threshold value of pressure: ice thickness about 30 meters
  - What factors increase the speed of ice flow?
  - Basal sliding
    - Due to meltwater at the base of the ice mass



Why does surface ice move farthest even though internal plastic deformation is only occurring at depth in the ice?

Moving Ice as a Geomorphic Agent (cont'd.)

- How glaciers flow
  - Upper surface of glacier
    - Carried along with the deeper ice
    - Crevasses form
  - Flow rates
    - Fractions of centimeters to 30 meters per day
    - Alpine glaciers typically flow much faster than continental glaciers
    - What accounts for varying flow rates of a particular glacier over time?

What type of force causes crevasses, compressional or tensional?

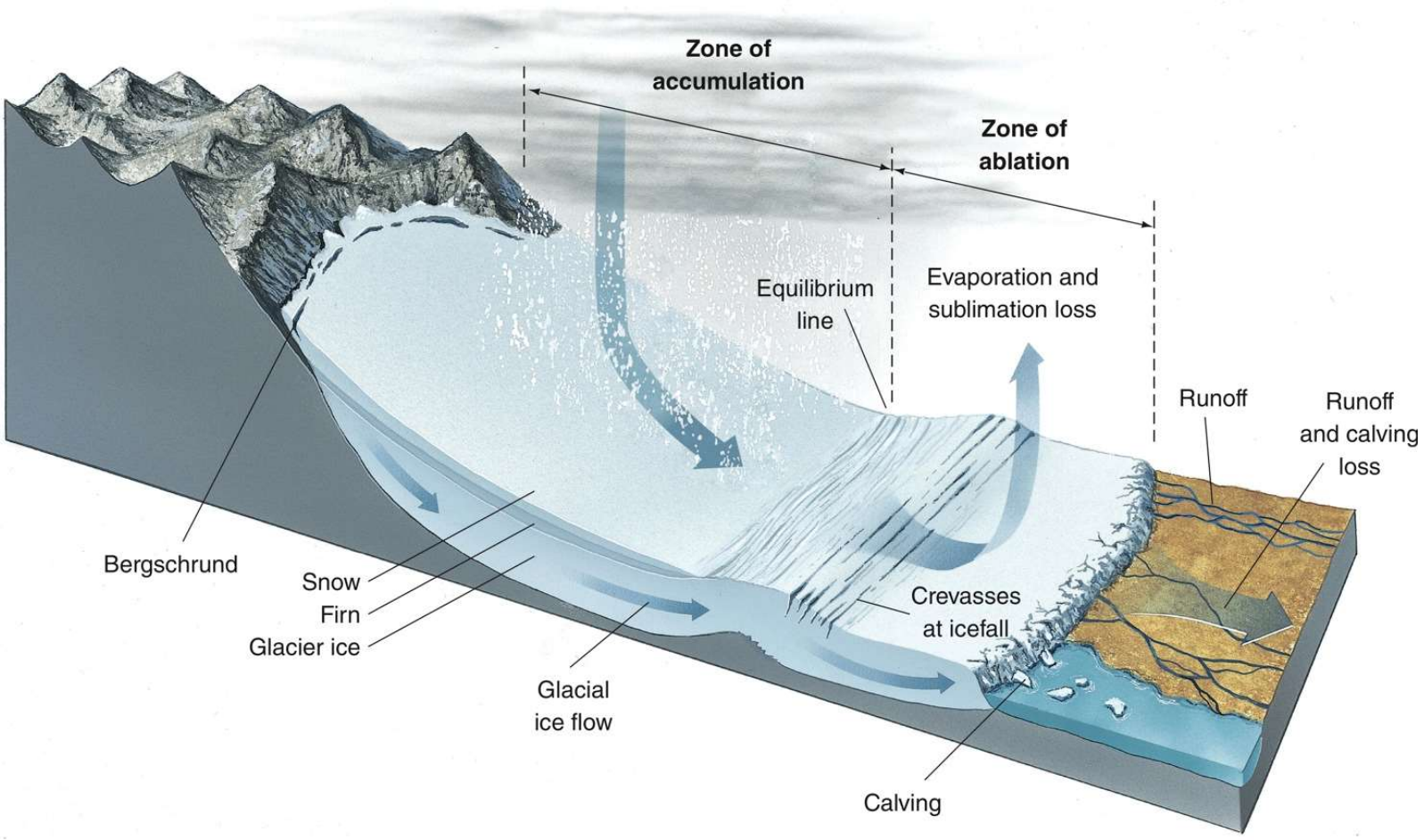
M. Trapasso

Moving Ice as a Geomorphic Agent (cont'd.)

- Glacial erosion
  - Plucking
    - Moving ice freezes onto loosened rocks and sediments, incorporating them into the flow
  - Abrasion
    - Entrained load at the base and sides of the ice: scrape and gouge out more rock material as the glacier moves
- Glacial sediment
  - How does till differ from alluvium?

Alpine Glaciers

- Functional zones
  - Zone of accumulation: upslope portion
    - Annual input exceeds output
  - Zone of ablation: downslope portion
    - Annual ablation exceeds accumulation
  - Equilibrium line
    - Marks the boundary between the zones of accumulation and ablation



Alpine Glaciers (cont'd.)

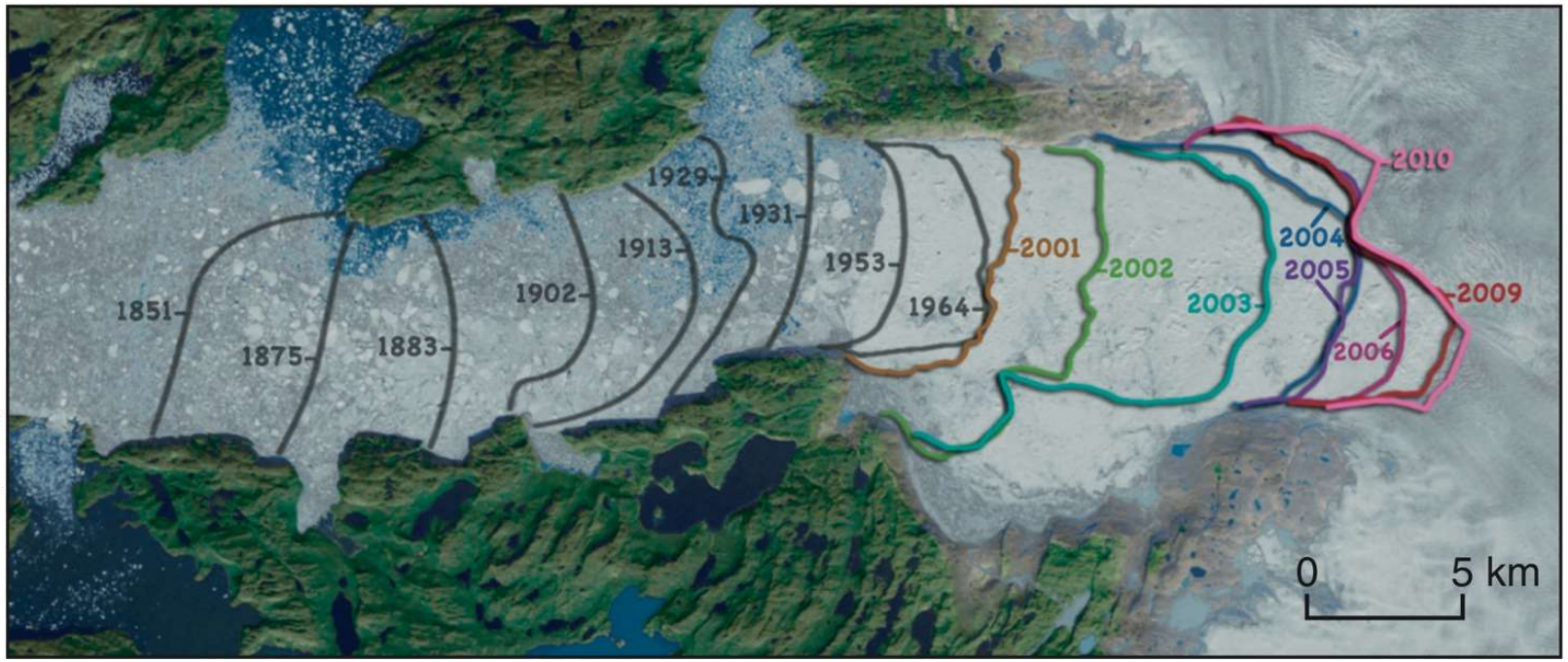
- Equilibrium line location influenced by:
  - Interaction between latitude and elevation
    - Temperature and amount of snowfall
  - Amount of insolation
  - Shade
  - How does wind affect the equilibrium line?

Alpine Glaciers (cont'd.)

- Components
  - Head of the glacier
    - Upslope end of the zone of accumulation
  - Cirque headwall
    - Steep bedrock cliff
  - Bergschrund
    - Can develop between the head of the glacier and the cirque headwall
  - Terminus: glacier toe
    - Downslope end

Alpine Glaciers (cont'd.)

- Equilibrium and the glacial budget
  - Terminus location
    - Recorded annually at the end of ablation season
  - Net change in terminus location
    - Advancing glacier
    - Retreating glacier
    - State of equilibrium
  - What stops downslope movement of a glacier?



NASA/Goddard Space Flight Center Scientific

What was the average annual rate of retreat from 1850 to 2010?

What type of alpine glacier was Chaney Glacier in 2005?

M.R. Campbell, USGS Photographic Library

(a)

B. Reardon, USGS

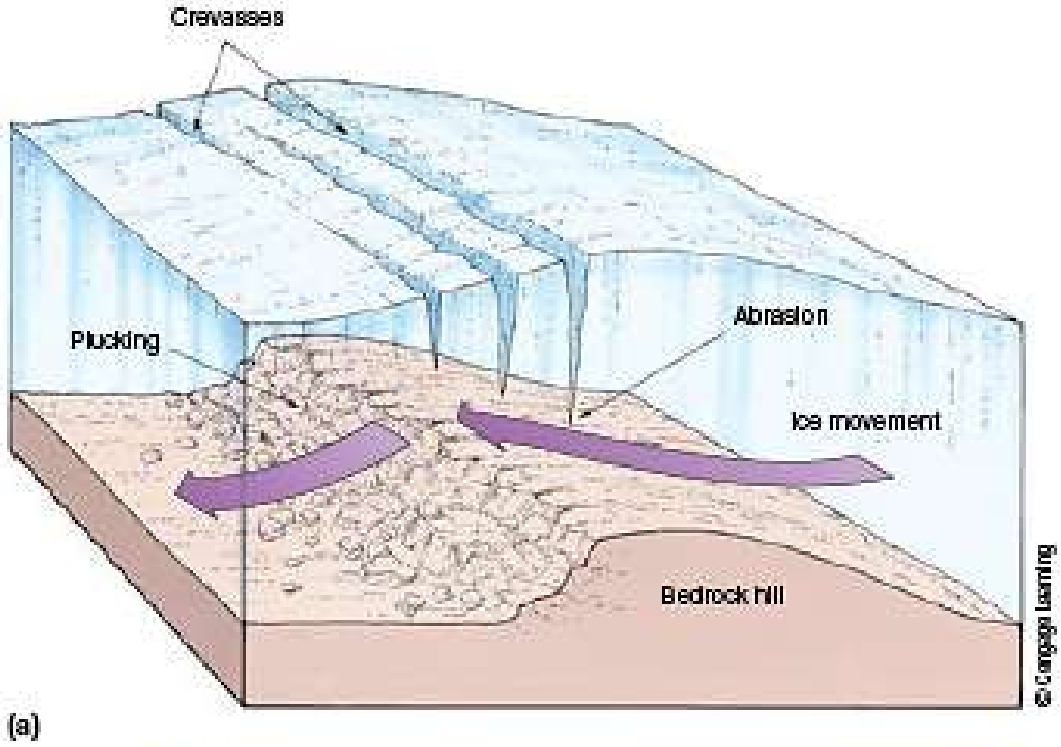
(b)

Alpine Glaciers (cont'd.)

- Erosional landforms of alpine glaciation
  - Striations
    - Linear scratches, grooves, and gouges: glacial abrasion
    - Indicate direction of ice flow
  - Roches moutonnées
    - Asymmetric bedrock hills formed by abrasion and plucking

John Good, NPS

Can the direction of ice flow be determined with certainty from the evidence in this photograph?



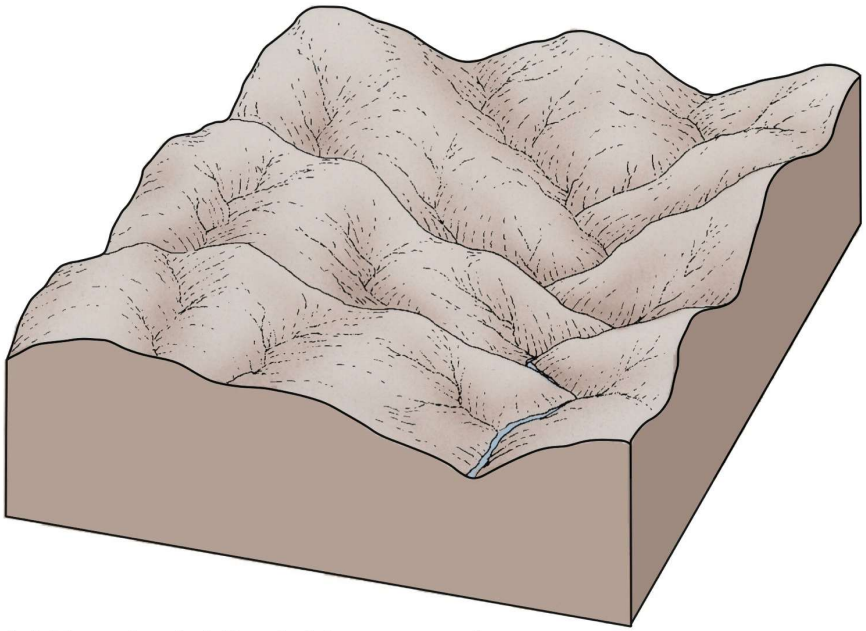
Why would crevasses form in ice flowing above this feature?

Alpine Glaciers (cont'd.)

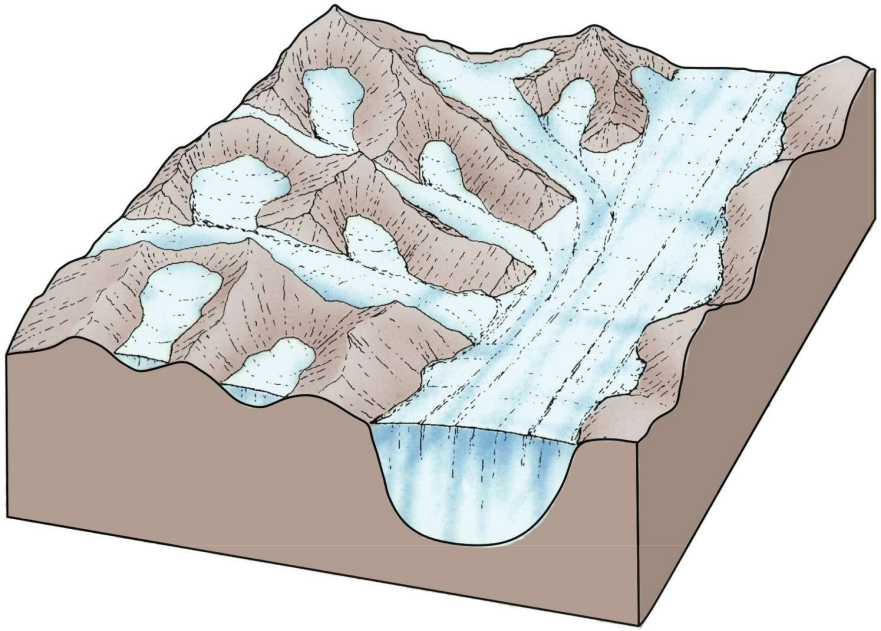
- Erosional landforms of alpine glaciation
  - What conditions lead to the formation of a cirque?
  - Tarns: lakes in cirques
  - Arête: bedrock ridge between cirques or valleys of two adjacent glaciers
  - Horn
    - Three plus circques surround a mountain summit
    - Pyramid shaped peak created by headward erosion

Alpine Glaciers (cont'd.)

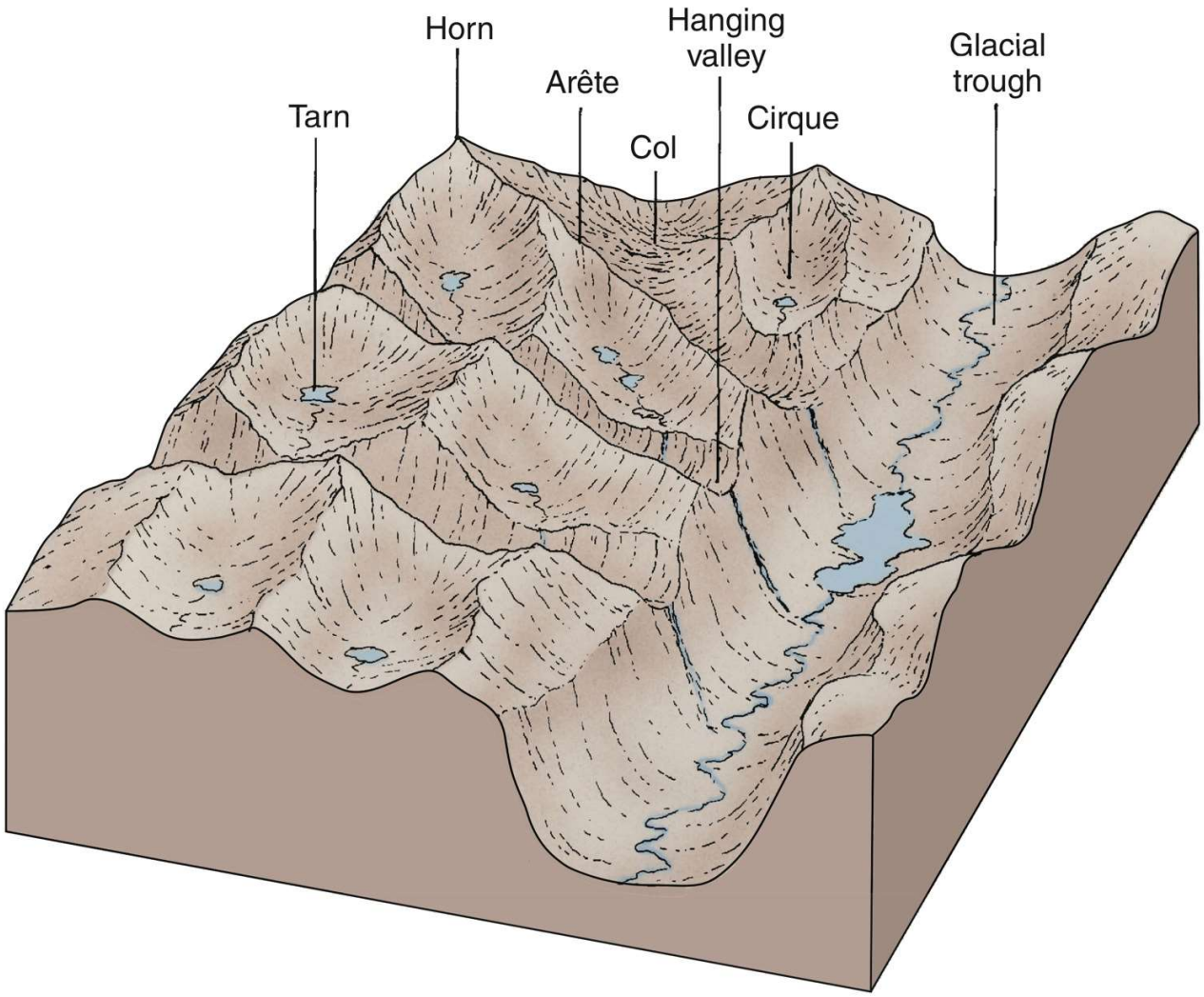
- Erosional landforms of alpine glaciation
  - Col
    - Low saddle in a high mountain ridge or arête
    - Headward erosion: two cirques intersect
  - Glacial trough: why is it U-shaped?
  - Hanging valleys: formed by tributary glaciers
  - Fjords: narrow ocean inlets
    - Climate changes: net ablation and rising sea level



(a) Preglacial fluvial topography



(b) Maximum glaciation

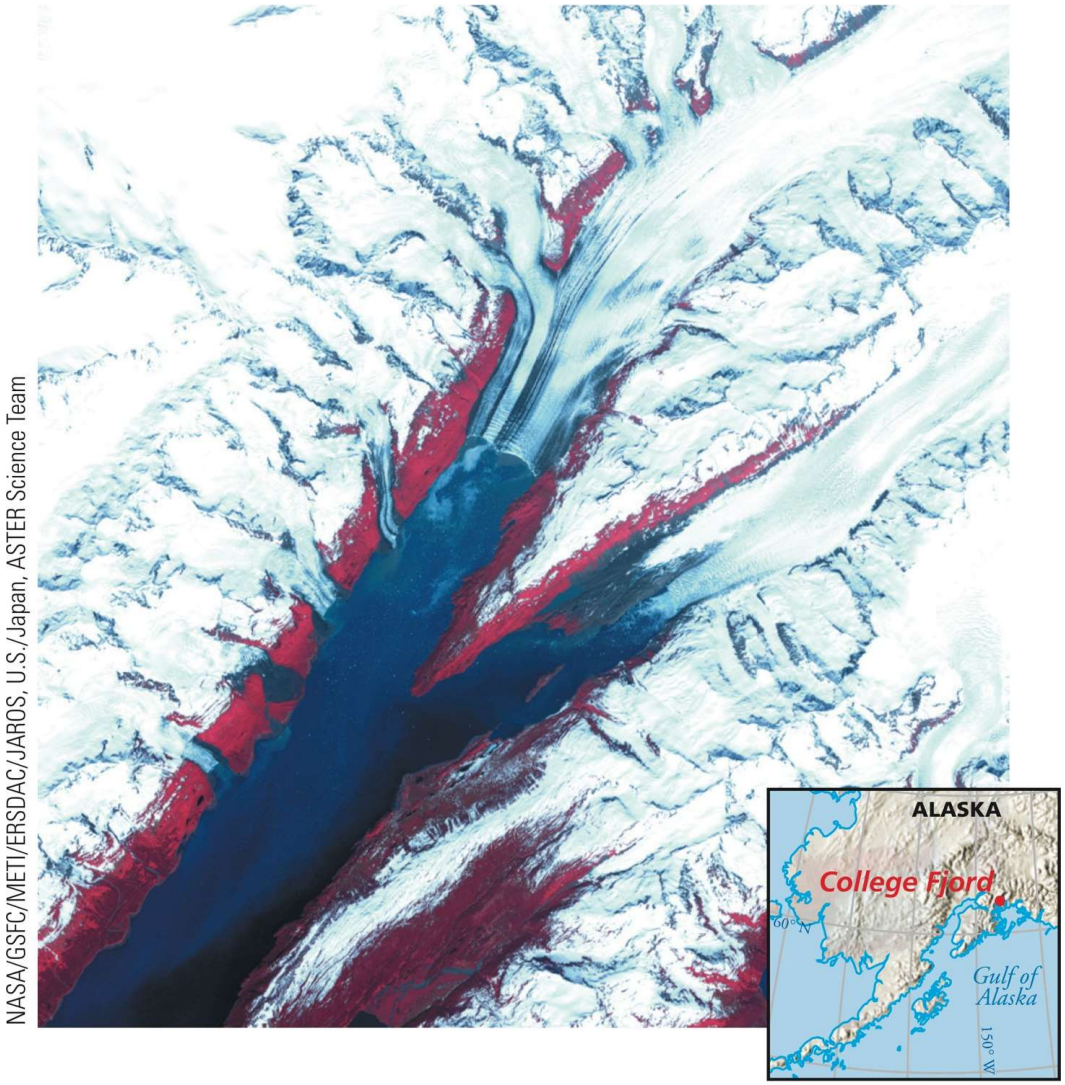


(c) Postglacial topography

How do the stream valley cross sections change from preglacial to postglacial time?

D. Sack

What other glacial landforms do you see in this photo?



NASA/GSFC/METI/ERSDAC/JAROS, U.S./Japan, ASTER Science Team

How many glaciers do you see on this image?

Alpine Glaciers (cont'd.)

- Depositional landforms of alpine glaciation
  - Till
    - Deposited directly by glacial ice
  - Glaciofluvial
    - Fluvial deposits related to glacial meltwater
  - Drift
    - All deposits: glacial ice, meltwater, associated lakes, and related wind

J. Petersen

Why does till have these disorganized characteristics?

Alpine Glaciers (cont'd.)

- Depositional landforms of alpine glaciation
  - Moraines: glacial deposit landforms
    - Lateral moraines, medial moraine, and end moraine (terminal and recessional moraines)
  - Ground moraine
    - Till deposited on the floor of the glacial trough by a retreating glacier
  - Valley train
    - Composed of glacial outwash

USGS/Bruce F. Molnia

(a)

National Park Service

(b)

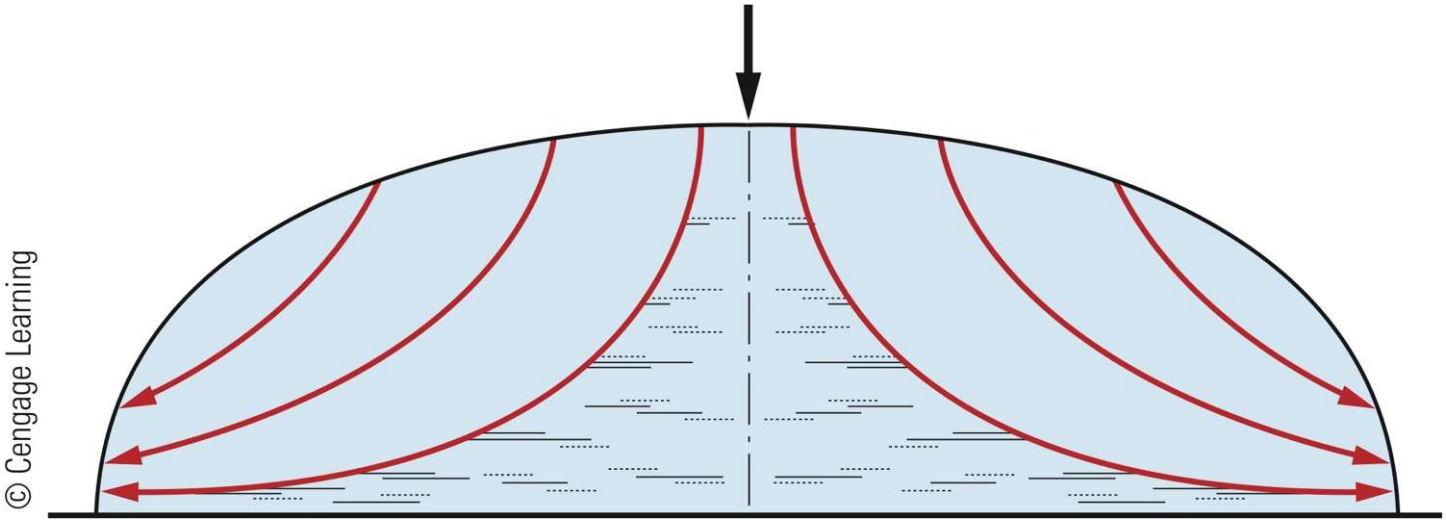
Matt Ebiner

(c)

What can we learn from studying moraines?

Continental Glaciers

- Shape
  - Thicker in the center; thinning toward the edges
- Flow radially outward in all directions
  - From where the pressure is greatest
- Advance and retreat
  - Due to changes in temperature and snowfall
- Movement
  - Path of least resistance



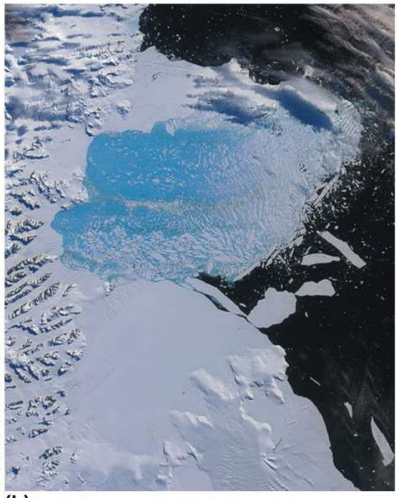
How is this manner of ice flow different from and similar to that of an alpine glacier?

Continental Glaciers (cont'd.)

- Existing continental glaciers
  - Greenland and Antarctica: ice sheets
    - 96% of the area occupied by glaciers today
  - Locations of ice caps
    - Iceland, arctic islands of Canada and Russia, Alaska, and Canadian Rockies
  - Outlet glaciers
  - Ice shelves

Josh Landis, National Park Service

(a)



NASA/GSFC/LaRC/JPL, MISR Team

(b)

Hajo Eicken/Alfred Wegener Institute for Polar and Marine Research

(c)

What portion of an iceberg is hidden below the ocean surface?

Continental Glaciers (cont'd.)

- Pleistocene Epoch
  - 2.6 million years ago to 10,000 years ago
  - Major advances and retreats of ice over large portions of the world's landmasses
    - Interglacial: warmer period between each advance
  - Isostatic rebound
    - Weight of ice removed: land elevation raises
  - Wisconsinan glaciation
    - Last known advance in North America
  - What situation exposed continental shelves?

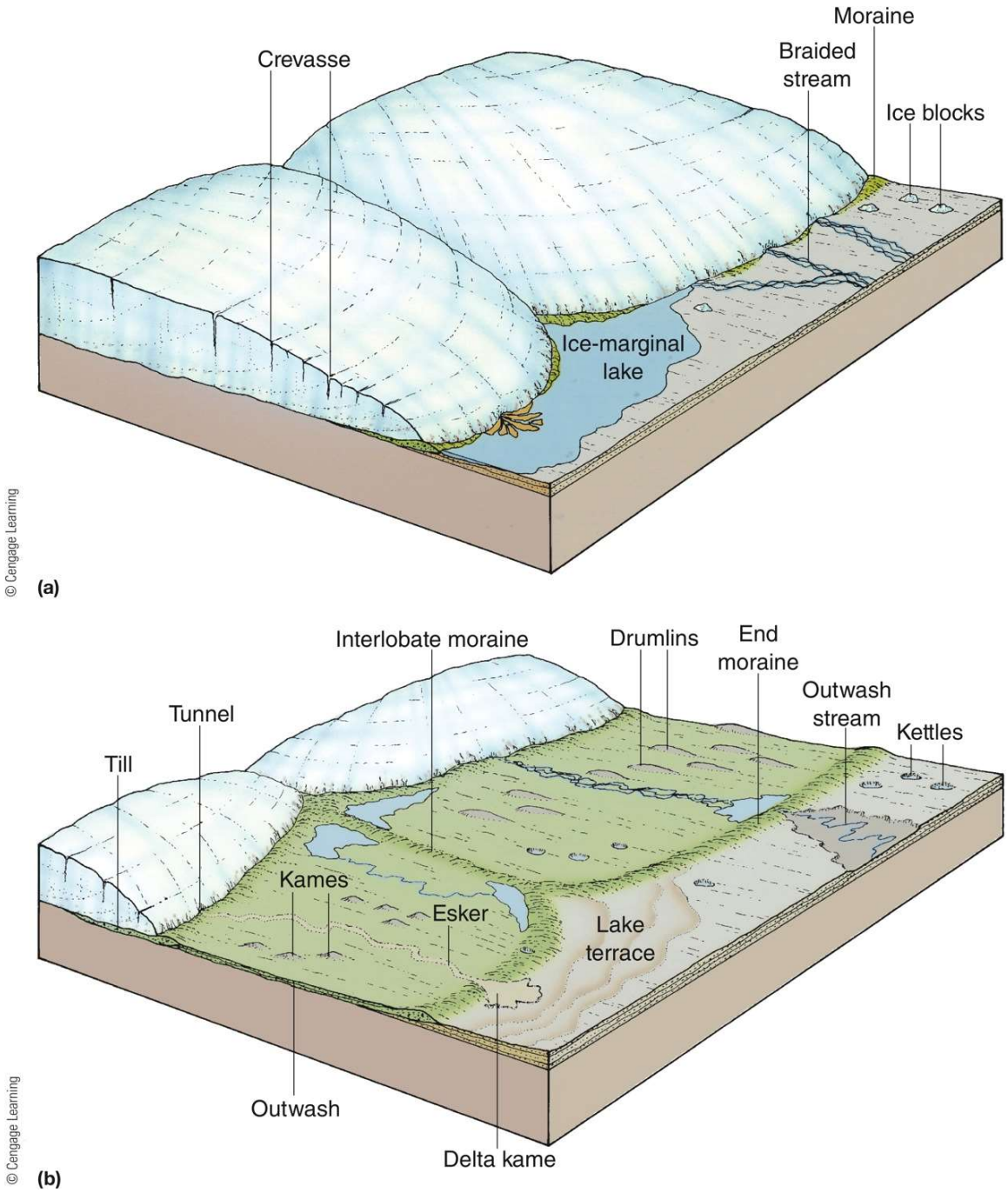
Continental Glaciers (cont'd.)

- Erosional landforms of continental glaciation
  - Plucking and abrasion
  - Landforms created by ice sheets: vast expanses
  - Ice-scoured plains
    - Low, rounded hills, lake-filled depressions, and wide exposures of bedrock

Continental Glaciers (cont'd.)

- Depositional landforms of continental glaciation
  - Terminal and recessional moraines, ground moraines, and glaciofluvial deposits
    - Significantly more extensive than those formed by alpine glaciers
  - Till plain
  - Outwash plains
  - Kettles: Minnesota's 10,000 lakes

How important is liquid water in creating the landforms shown here?



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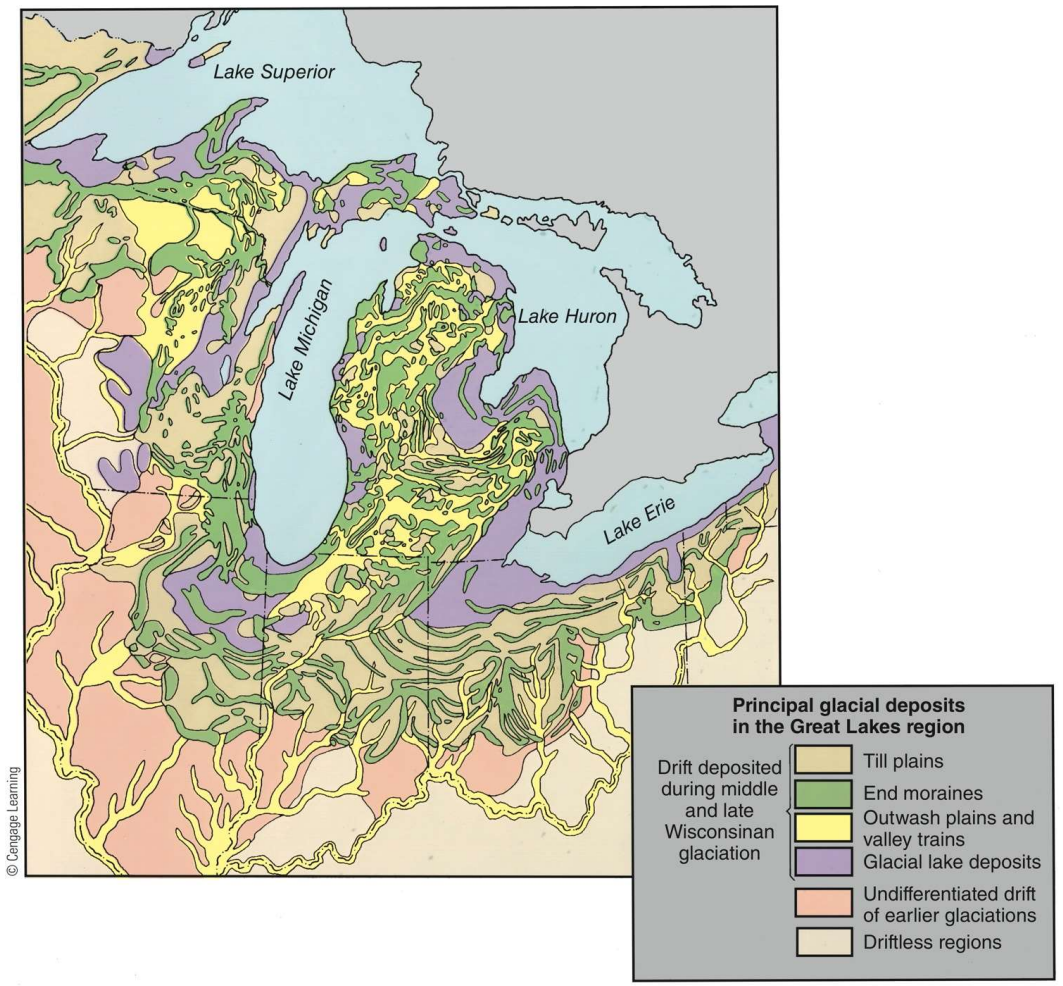
What makes the terrain at the left of the photo appear bumpier compared to the smoother surface of the plain at the right?



Why do the many end moraines have such a curved pattern?

Continental Glaciers (cont'd.)

- Depositional landforms of continental glaciation
  - Ridges and hills
    - Drumlin: elongated, streamlined shape
    - Drumlin fields
    - Esker: long, narrow, winding ridge of glaciofluvial sands and gravels
    - Kames: conical hills of sorted glaciofluvial deposits
    - Kame terrace

What economic importance do eskers have?

Continental Glaciers (cont'd.)

- Depositional landforms of continental glaciation
  - Erratics: large boulders
    - Scattered in and on the surface of glacial deposits or on glacially scoured bedrock

Jim Peaco/NPS

What does this erratic illustrate about the ability of flowing ice to modify the terrain?

Glacial Lakes

- Evidence for glacial paleolakes
  - Shoreline remnants and glaciolacustrine deposits
- Ice-marginal lakes
  - Trapped meltwater
  - Drain and cease to exist

Glacial Lakes (cont'd.)

- Pleistocene glaciation produced
  - Valley of the Red River: North Dakota, Minnesota, and Manitoba
  - Washington's channeled scablands
  - The Great Lakes

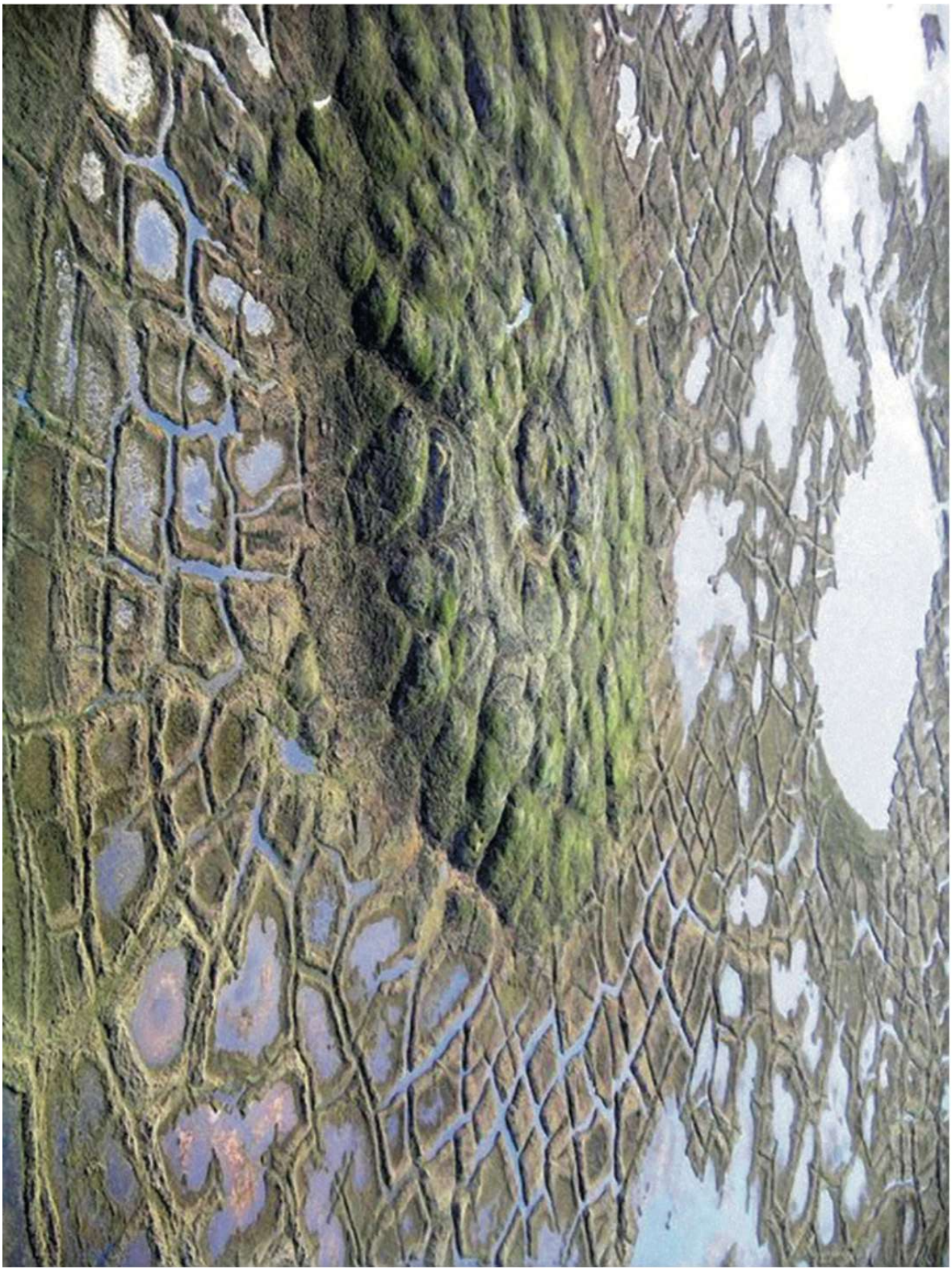
NASA

What characteristics of the bedrock caused ice to form these narrow lake basins?

Periglacial Landscapes

- Periglacial environments
  - Cold regions
    - Lack year-round ice or snow
    - Undergo intense frost action: areas of permafrost
  - Frost action
    - Freezes soil moisture: produces angular, shattered rocks
    - Heaving, thrusting, and size-sorting of stones ► patterned ground

© Emma Pike



Periglacial Landscapes

- Periglacial environments
  - Subject to mass wasting: solifluction
  - Prone to ice accumulation in fissures ► large ice wedges
  - Proper construction techniques
    - Keep permafrost beneath buildings frozen
    - Elevate buildings above ground

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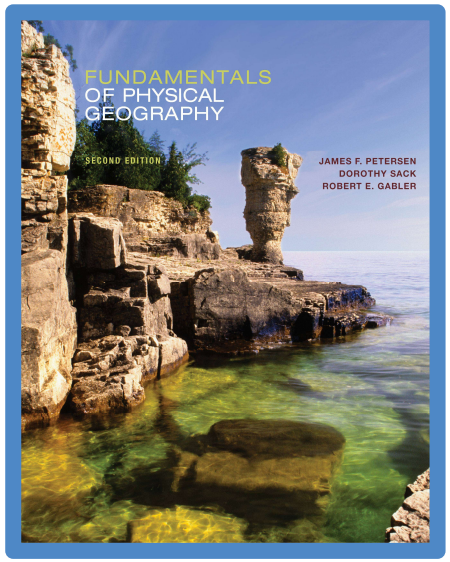

- Peterson
  - Sack
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