Foundations of Earth Science

Eighth Edition

Glacial and Arid Landscapes

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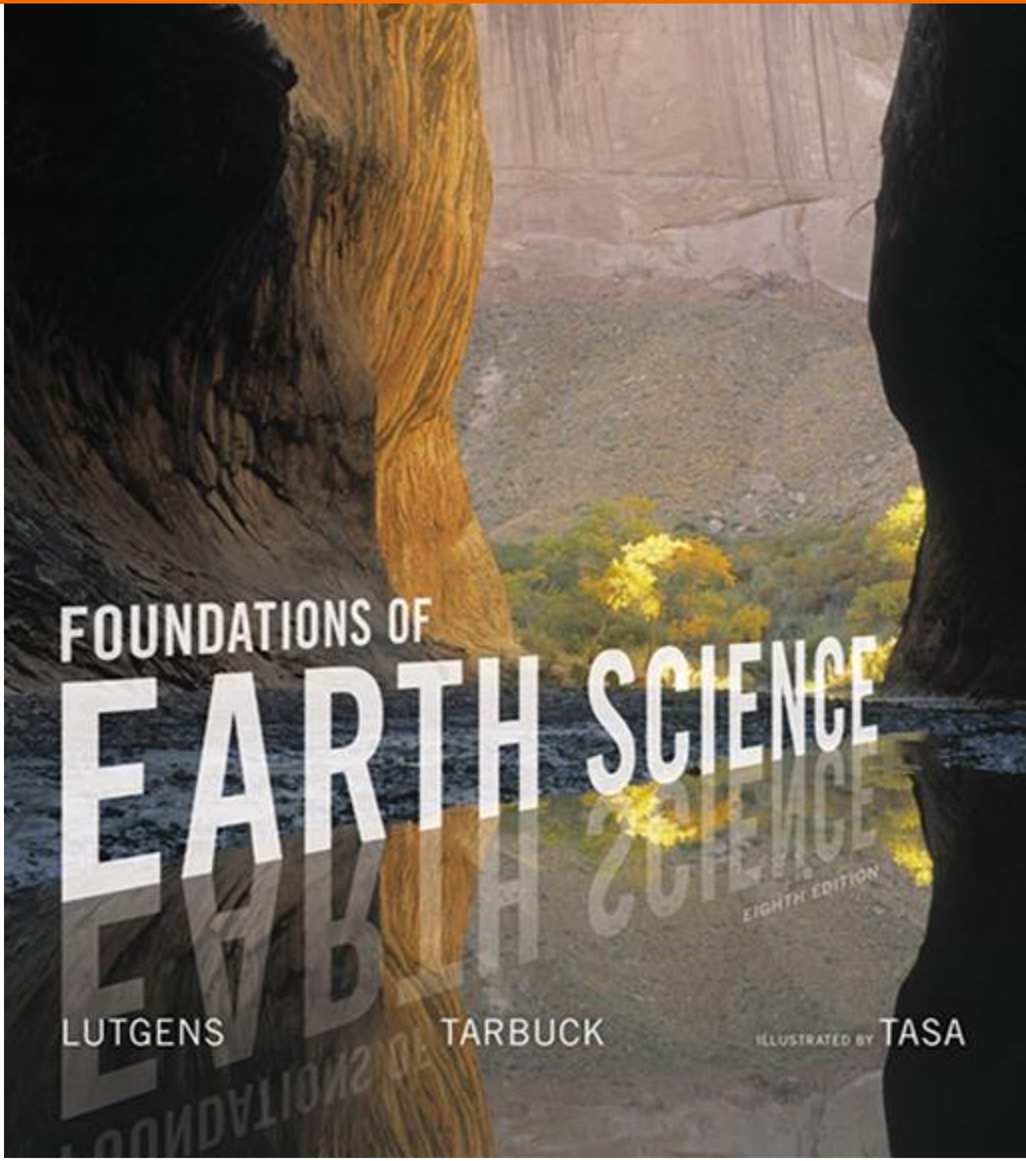
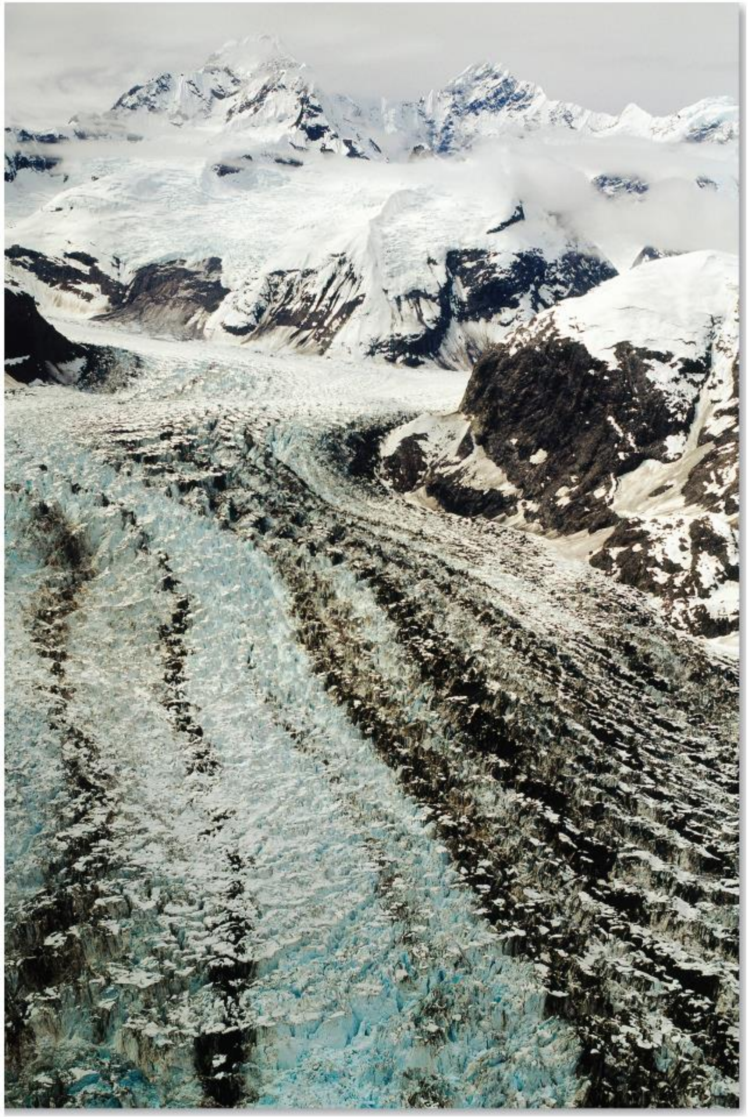


Focus Questions 4.1

- Explain the role of glaciers in the hydrologic and rock cycles.
- Describe the different types of glaciers and their present-day distribution.

Glaciers and the Earth System

- A **glacier** is a thick mass of ice formed over 100s or 1000s of years
  - Originates by accumulation, compaction, and recrystallization of snow
- Glaciers move slowly because of gravity
  - Accumulate, transport, and deposit sediment

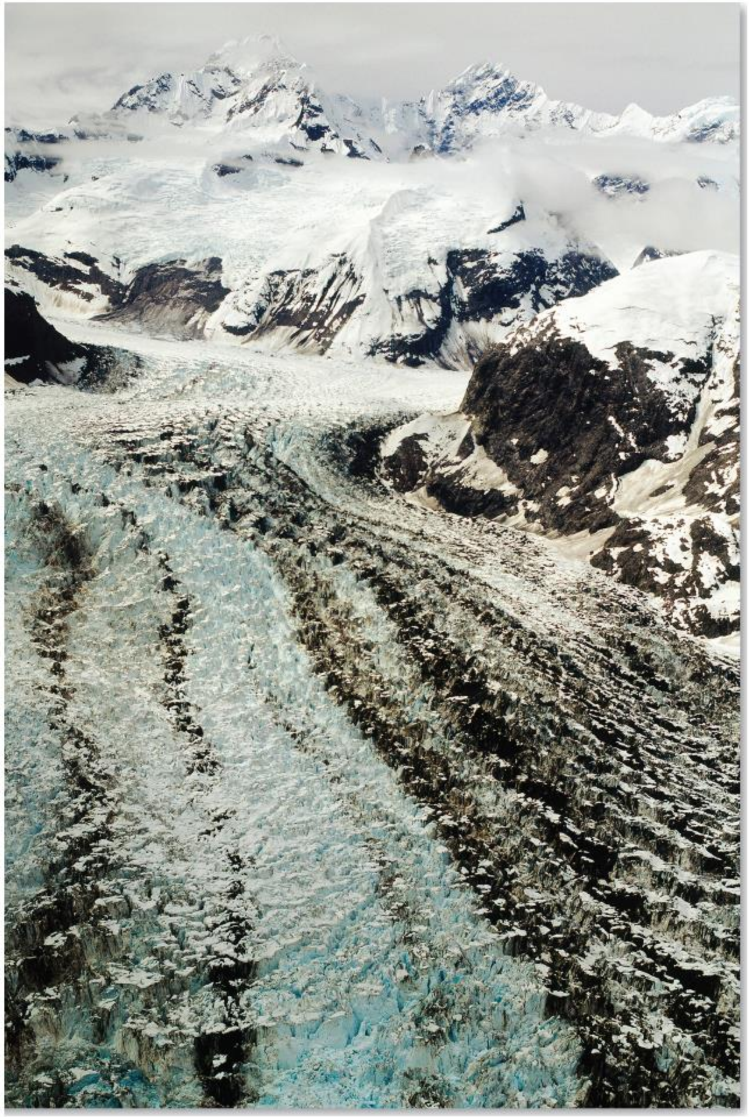


Glaciers and the Earth System

- Many landscapes were shaped by glaciers during the last Ice Age
  - Alps, Cape Cod, Yosemite Valley, Long Island, the Great Lakes, fiords of Norway and Alaska…
- Glaciers play an important role in both the hydrologic cycle and the rock cycle
  - Precipitation can be trapped in glaciers for thousands of years
  - Ice is an agent of mechanical weathering

Valley (or Alpine) Glaciers

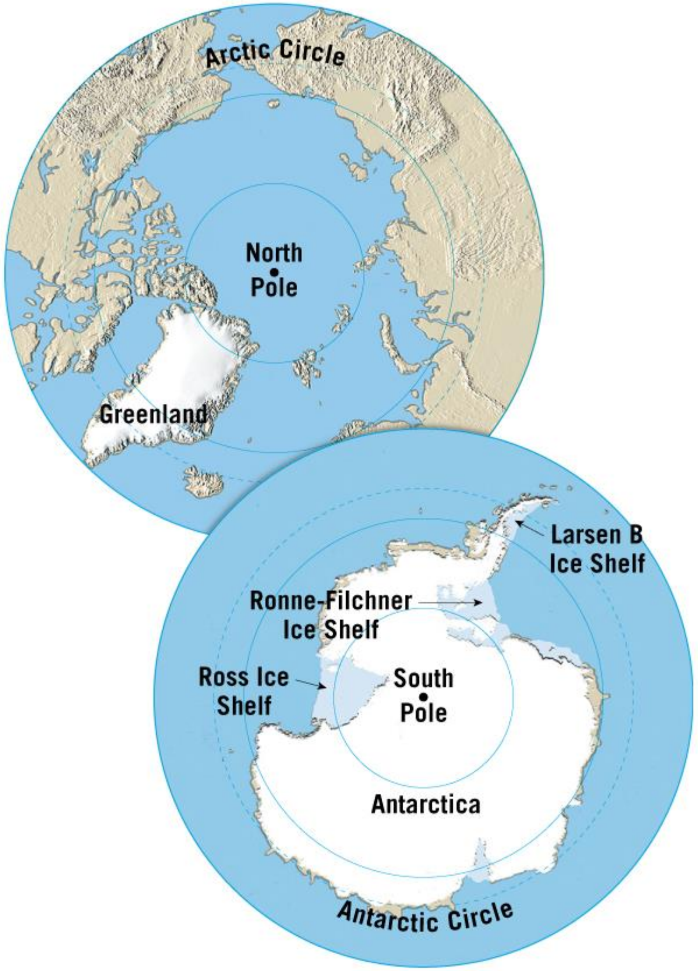
- **Valley** or **alpine glaciers** occur in valleys in high mountains
  - Relatively small
  - Advance slowly (a few cm per day)
  - Flow down valley from an accumulation center
  - Generally, width is narrow relative to length



Ice Sheets

- **Ice sheets** are found at the poles
  - Flow out in all directions from a center of snow accumulation
  - Large-scale, obscure underlying terrain
  - Greenland and Antarctica

Greenland's ice sheet occupies 1.7 million square kilometers (663,000 square miles), about 80 percent of the island.



The area of the Antarctic Ice Sheet is almost 14 million square kilometers (5,460,000 square miles). Ice shelves occupy an additional 1.4 million square kilometers (546,000 square miles).

Ice Sheets

- Extensive ice sheets during the Last Glacial Maximum (~18,000 years ago)
  - Also covered North America, Europe, and Siberia
- Ice sheets have advanced and retreated several times over the last 2.6 million years

Ice Sheets

- The Arctic Ocean is covered by **sea ice** (frozen seawater)
  - Floats
  - Ranges from a few cm to 4 m thick
  - Expands and contracts with the seasons
- **Ice shelves** form when glacial ice flows into the ocean
  - Large, relatively flat
  - Attached to land and flow outward away from coast
  - Become thinner seaward

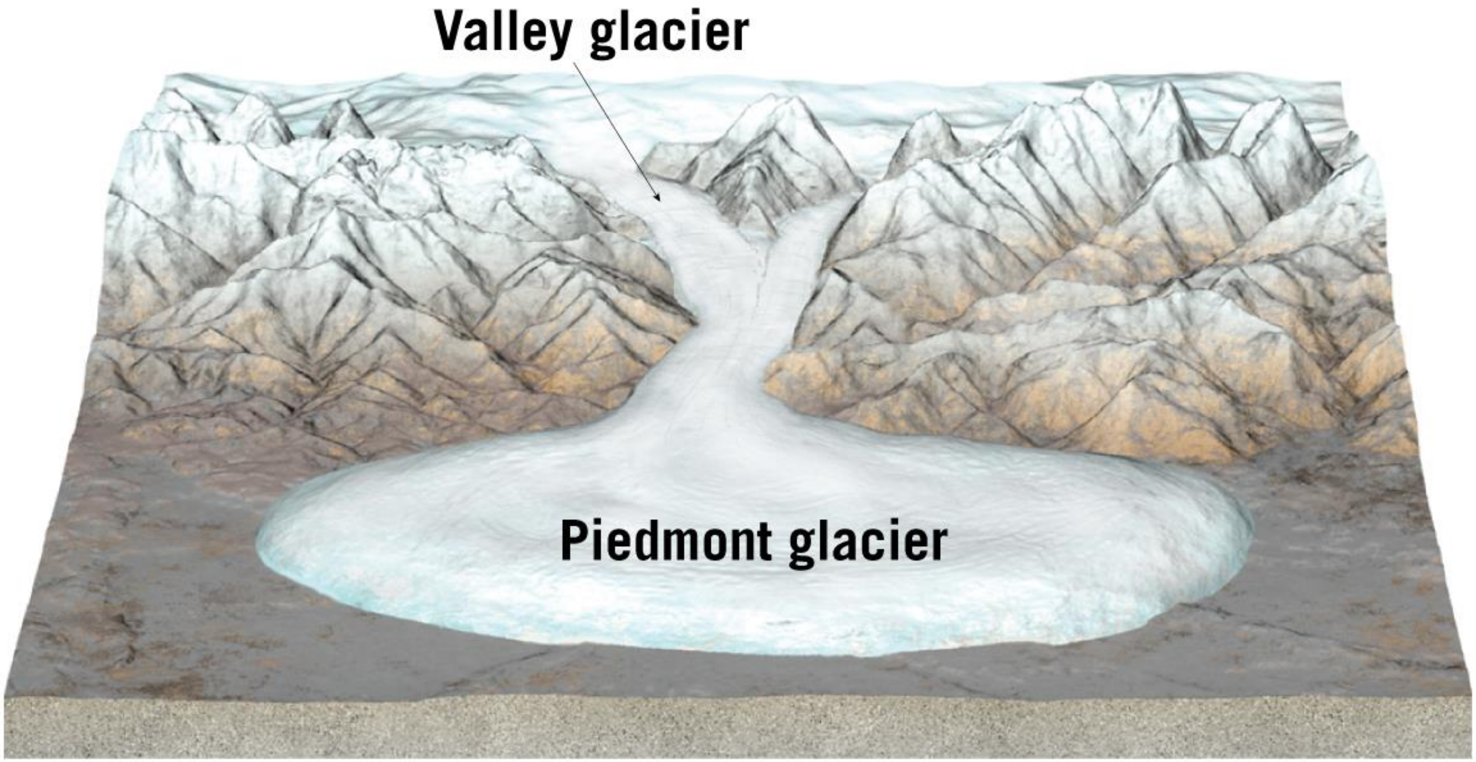
Other Types of Glaciers

- **Ice caps**
  – Cover uplands and high plateaus
  – Smaller than ice sheets but bury underlying terrain
- **Piedmont glaciers**
  – Form in broad lowlands at the base of mountains
  – Form when glaciers emerge from the confining walls of a valley
- **Outlet glaciers**
  – Extend out from ice caps and ice sheets

Other Types of Glaciers

Ice caps completely bury the underlying terrain but are much smaller than ice sheets.

Other Types of Glaciers



When a valley glacier is no longer confined, it spreads out to become a piedmont glacier.

Focus Question 4.2

- Describe how glaciers move, the rates at which they move, and the significance of the glacial budget.

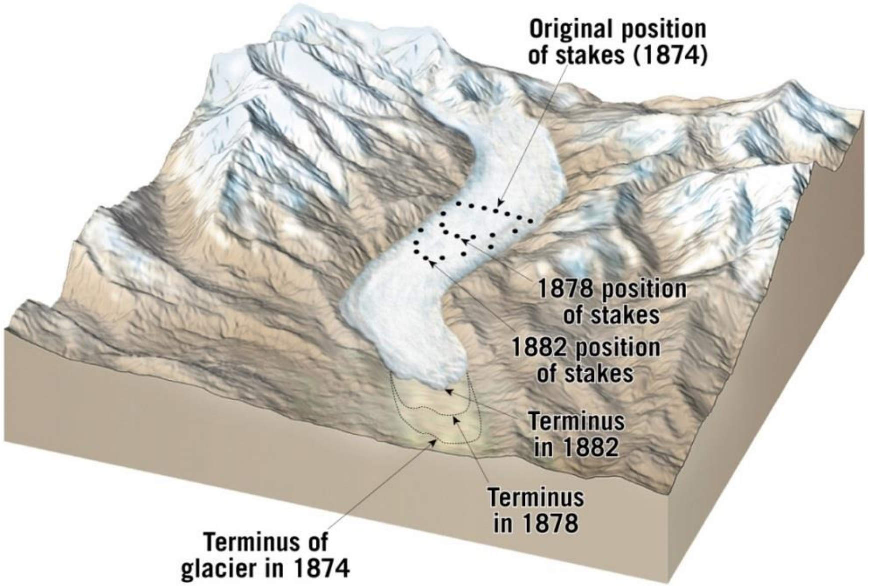
How Glaciers Move

- Glaciers move in two ways
  - Plastic flow within the ice
    - Bonds between layers of ice are not as strong as bonds within a layer
    - Layers remain intact but slide over one another
  - The entire body of ice slips along the ground
  - Uppermost 50 m of ice is the zone of fracture
    - Low pressure so ice behaves as a brittle solid
    - Tension creates cracks called **crevasses**

How Glaciers Move

Observing and Measuring Movement

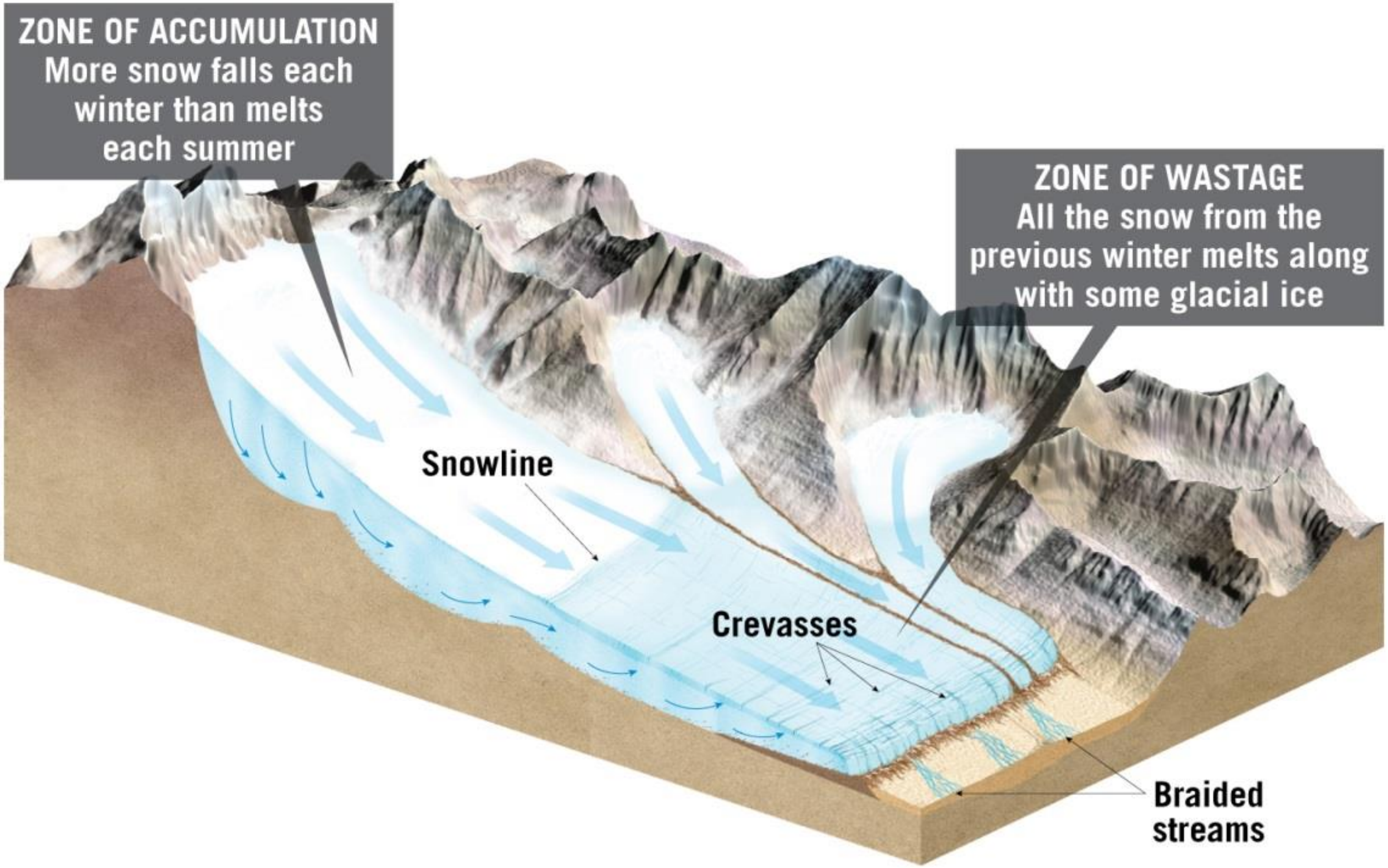
- Glacial movement is slow
  - <2 $^{m}/_{year}$ to >800 $^{m}/_{year}$
  - Occasional rapid advances (surges)
- Flow is greatest at the center
  - Drag along valley walls and floor slows flow at edges



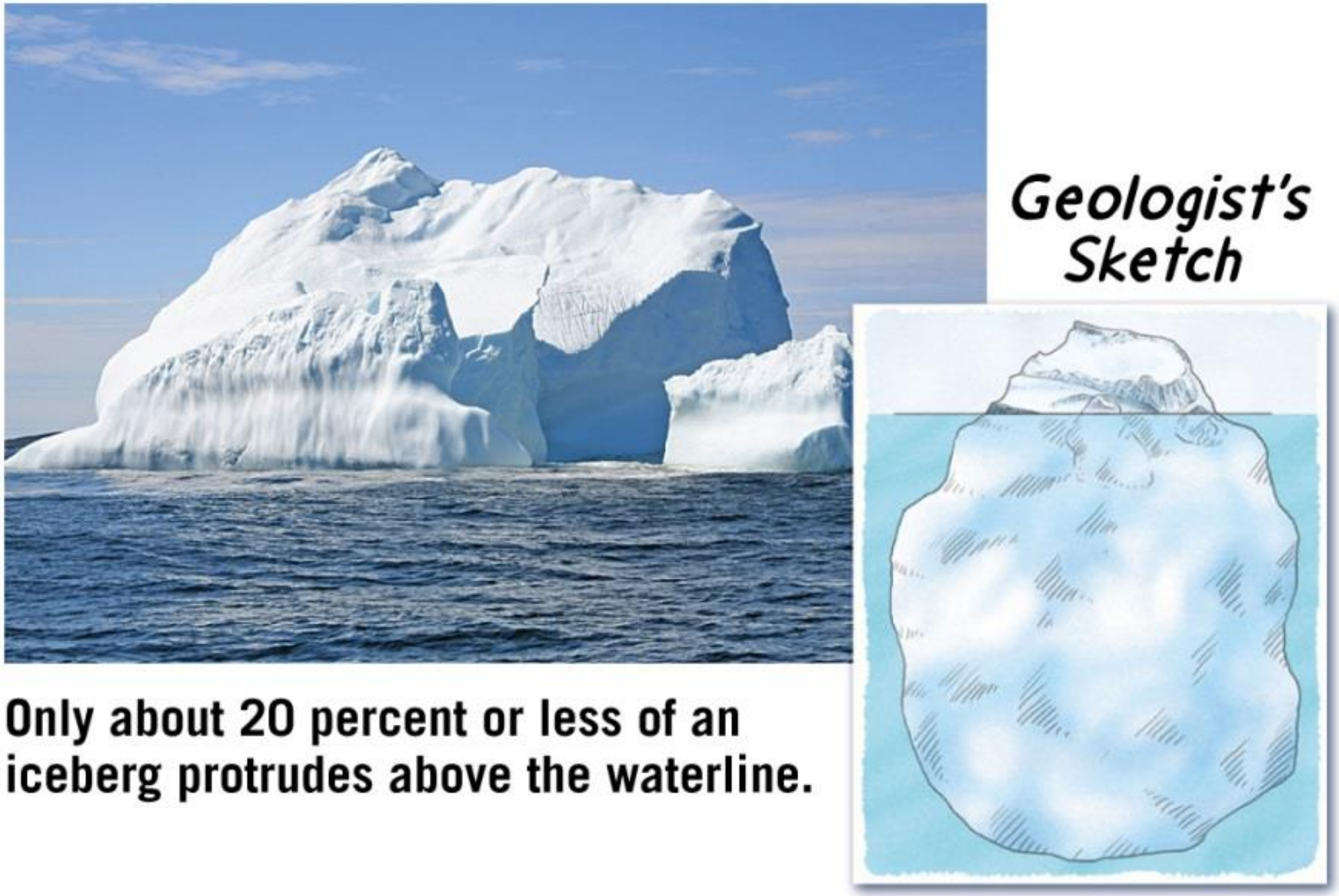
Budget of a Glacier: Accumulation Versus Wastage

- Glaciers form when winter snowfall is greater than summer snowmelt
  - Net accumulation of snow
- Snow accumulation and ice formation occur in the **zone of accumulation**
- Area where there is a net loss to the glacier is the **zone of wastage**
- Glaciers also lose ice because of calving
  - Generates **icebergs**

Budget of a Glacier: Accumulation Versus Wastage



Budget of a Glacier: Accumulation Versus Wastage



Only about 20 percent or less of an iceberg protrudes above the waterline.

Budget of a Glacier: Accumulation Versus Wastage

- **Glacial budget**
  - Balance or lack of balance between accumulation and wastage
  - Accumulation > wastage = glacial advance
  - Accumulation = wastage = stationary terminus
  - Accumulation < wastage = glacial retreat
- Even if front is retreating, ice is always flowing

Budget of a Glacier: Accumulation Versus Wastage

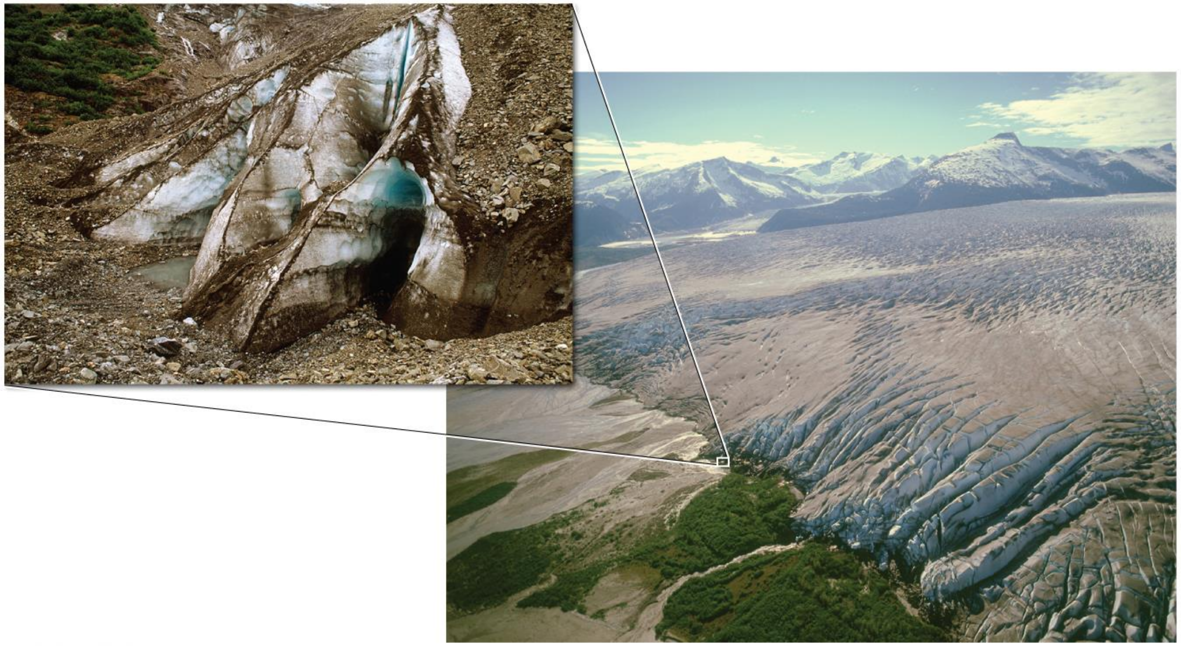
- Glaciers are very sensitive to temperature change
  - Almost all glaciers are retreating at unprecedented rates

Focus Question 4.3

- Discuss the processes of glacial erosion and the major features created by these processes.

Glacial Erosion

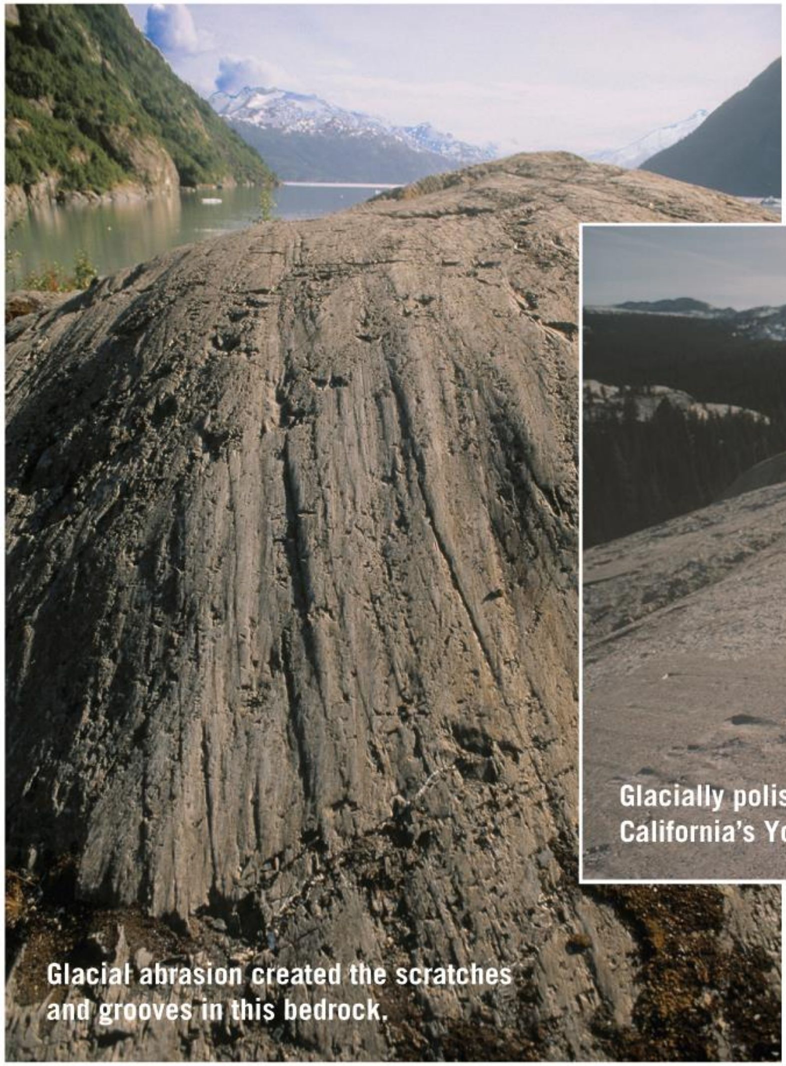
- Glaciers erode and transport tremendous volumes of rock
  - Debris cannot settle out like sediment carried by water or wind
  - Capable of carrying very large pieces of debris



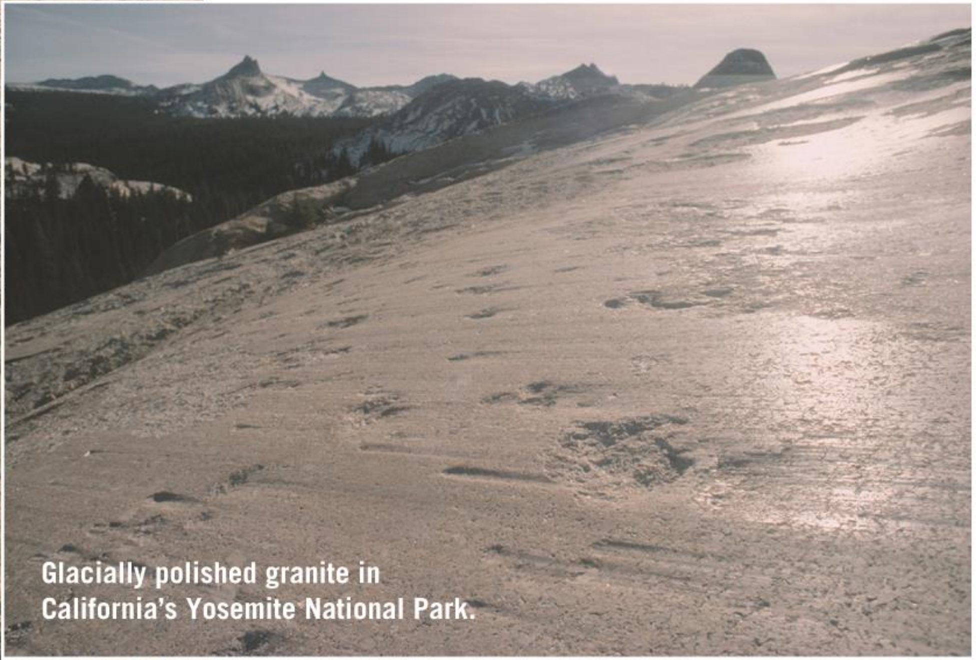
How Glaciers Erode

- Glaciers erode land in two primary ways:
  - **Plucking**
    - Flowing ice lifts fractured blocks of bedrock from the surface
    - Meltwater penetrates cracks and expands when it refreezes
    - Rocks break loose and are carried away by the glacier
  - **Abrasion**
    - Ice grinds bedrock and polishes the surface
    - **Rock flour** is finely ground bedrock
    - **Glacial striations** form when large rock fragments scrape scratches and grooves in the bedrock
    - Linear features provides evidence for direction of flow

How Glaciers Erode



A.



B.

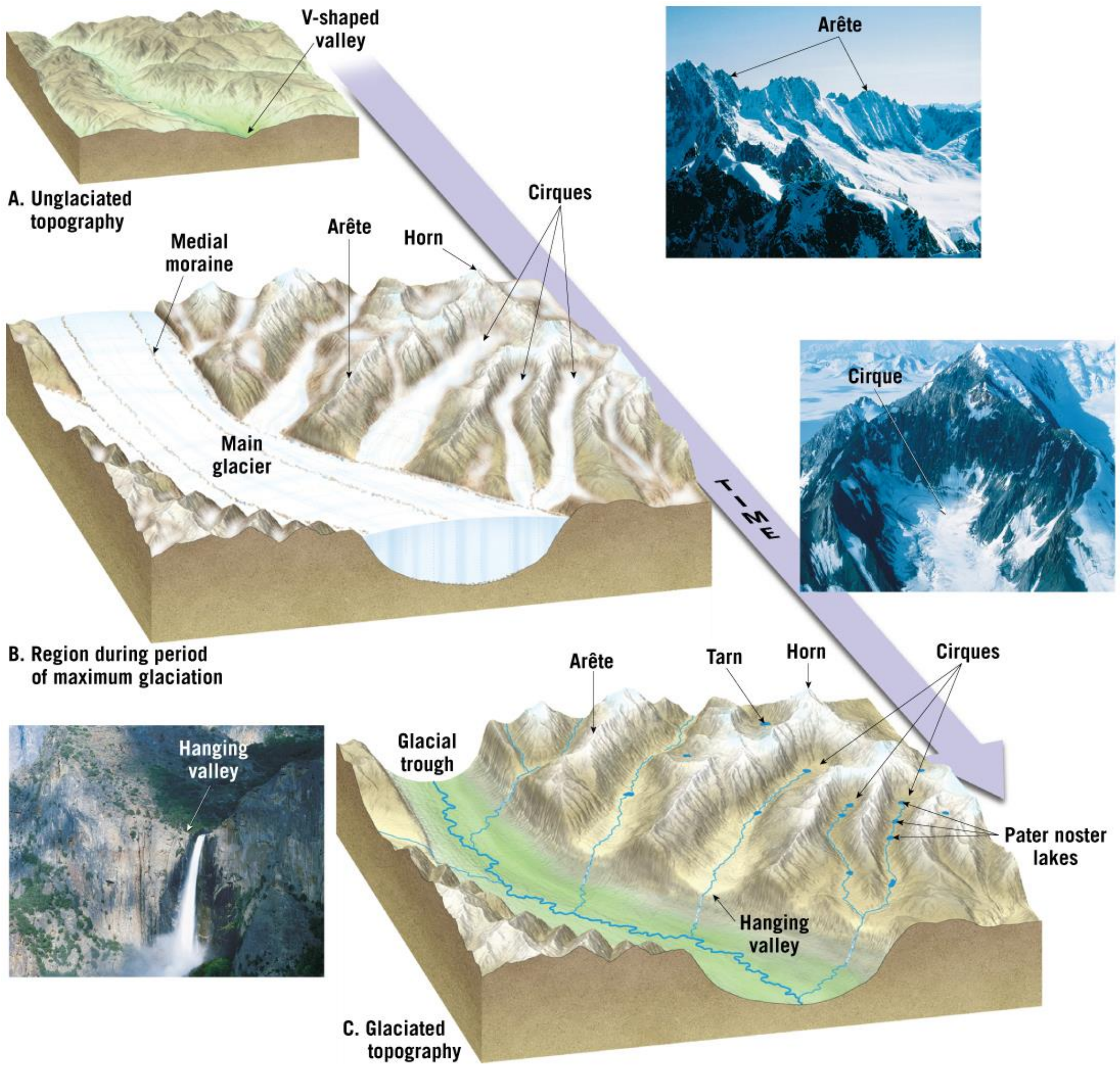
How Glaciers Erode

- Rate of glacial erosion depends on
  - Rate of glacial movement
  - Thickness of ice
  - Shape, abundance, and hardness of rock fragments carried in the ice
  - The erodability of the surface beneath the glacier

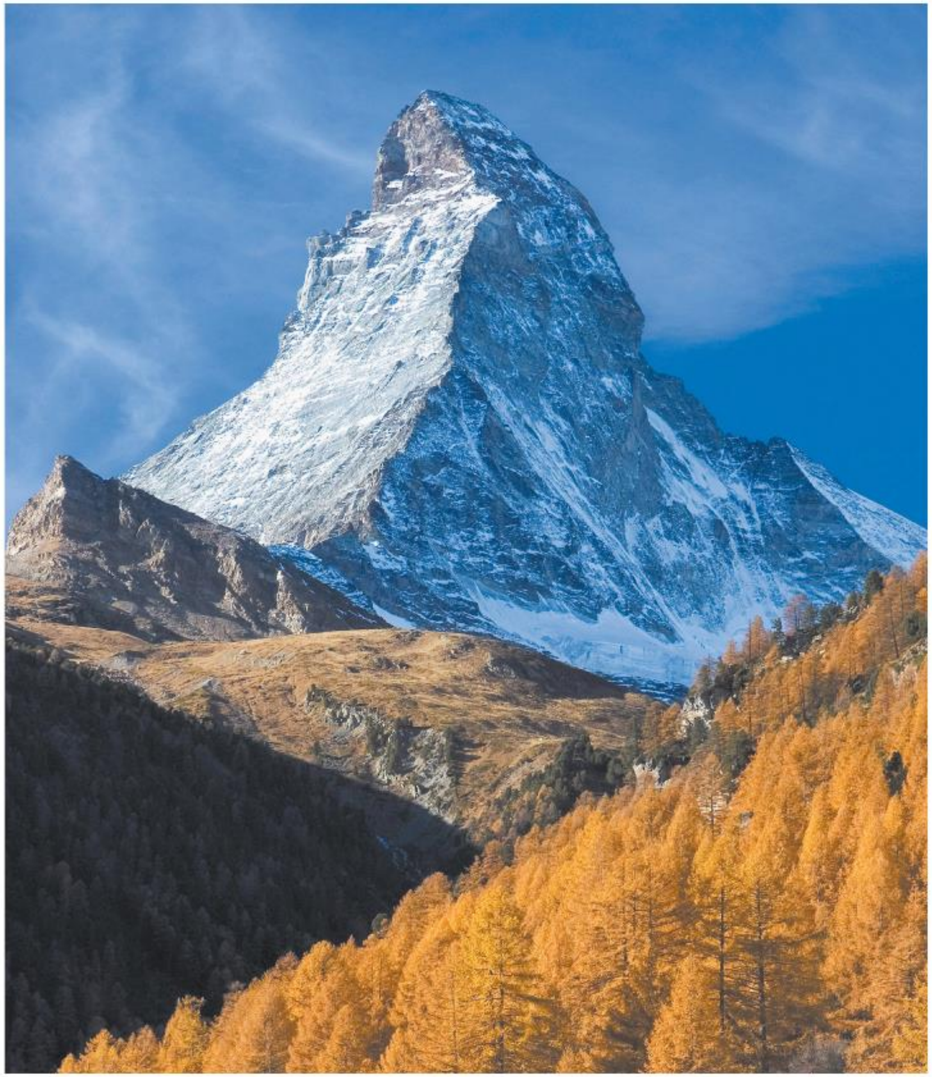
Landforms Created by Glacial Erosion

- Glacial landforms created by valley (alpine) glaciers are more pronounced than those created by ice sheets
  - Ice widens, deepens, and straightens valleys into U-shaped **glacial troughs**
  - Tributary glaciers create **hanging valleys**
  - **Cirques** are bowl-shaped depressions at the head of a glacial valley
  - **Arêtes** are sharp ridges and **horns** are pyramid-like peaks associated with enlarged cirques
  - **Fiords** are deep, steep-sided inlets of the sea

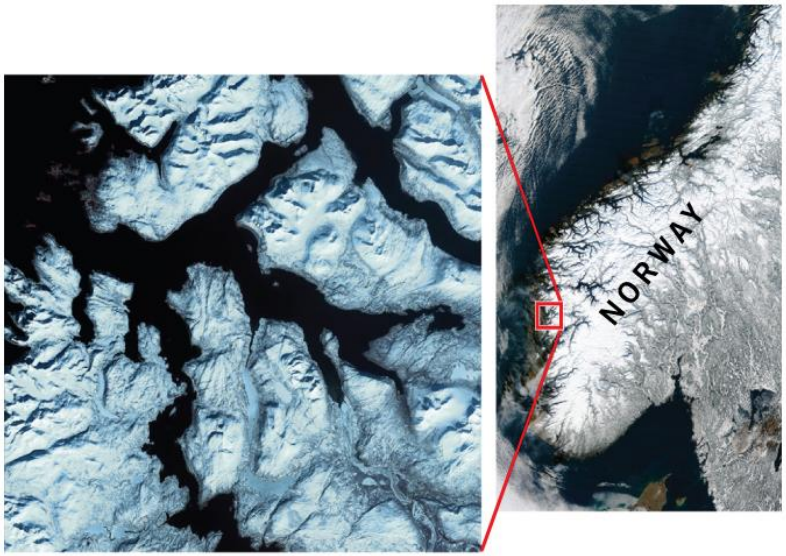
Glacial Erosion



Glacial Erosion



Glacial Erosion



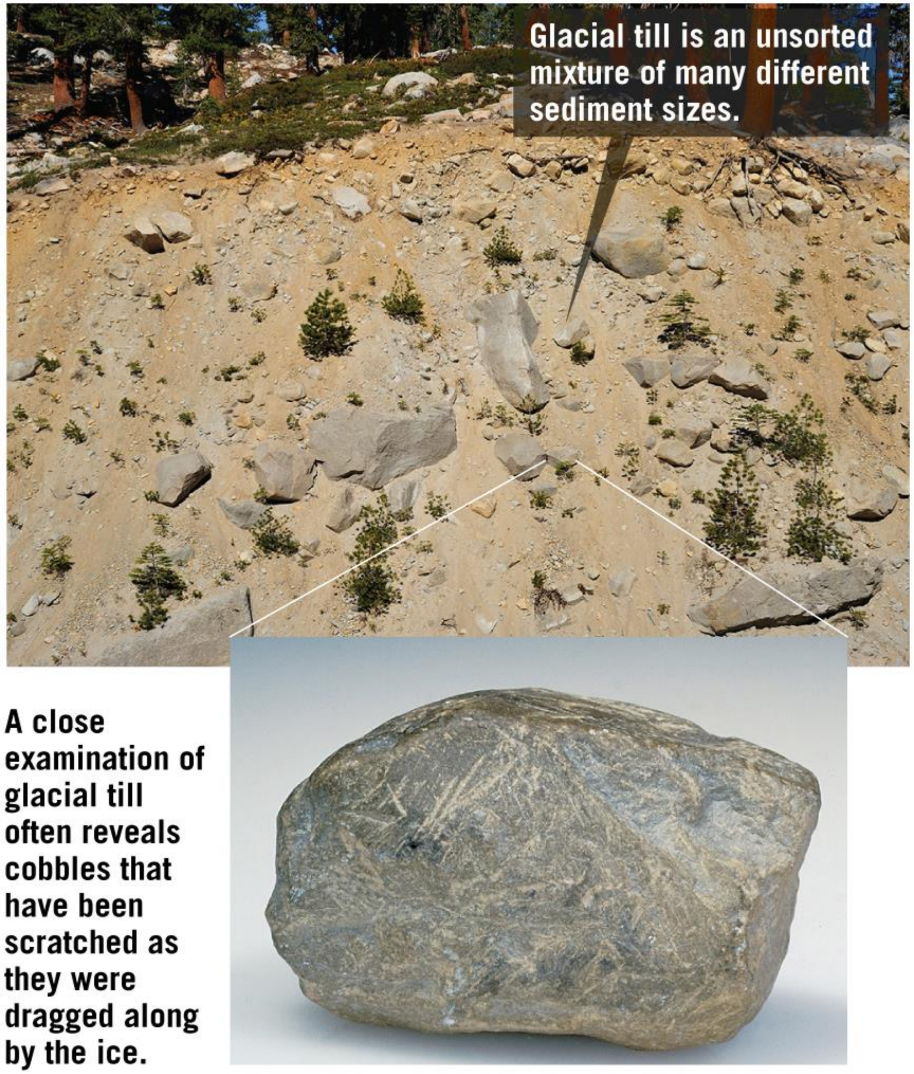
Focus Questions 4.4

- Distinguish between the two basic types of glacial deposits.
- Briefly describe the features associated with each type.

Types of Glacial Drift

- Material picked up by glaciers is eventually deposited when they melt
  - **Glacial drift**
    - Any sediment of glacial origin
  - **Till**
    - Material deposited directly by ice when it melts
  - **Stratified drift**
    - Sorted and deposited by glacial meltwater
  - **Glacial erratics**
    - Boulders different from bedrock below found in the till or lying on the surface

Types of Glacial Drift



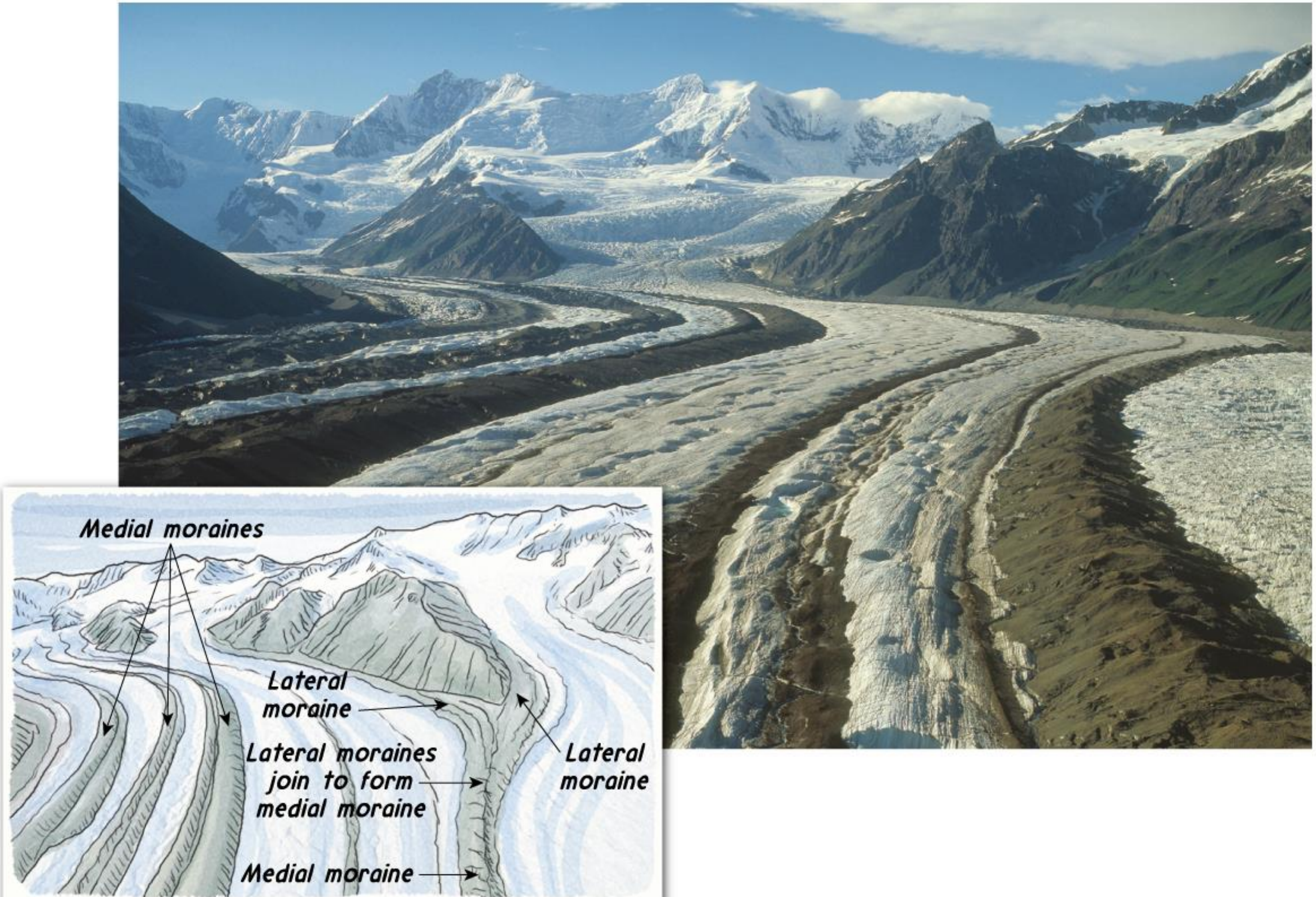
A close examination of glacial till often reveals cobbles that have been scratched as they were dragged along by the ice.

Types of Glacial Drift

Moraines, Outwash Plains, and Kettles

- Moraines are layers or ridges of till
  - **Lateral moraines** form along the sides of the valley
  - **Medial moraines** form between two advancing glaciers
    - Dark stripe of debris within the glacier
  - **End moraines** form at the terminus of a glacier
    - Deposited while glacial balance in equilibrium
  - **Ground moraines** are gently rolling layers of till deposited as the terminus retreats

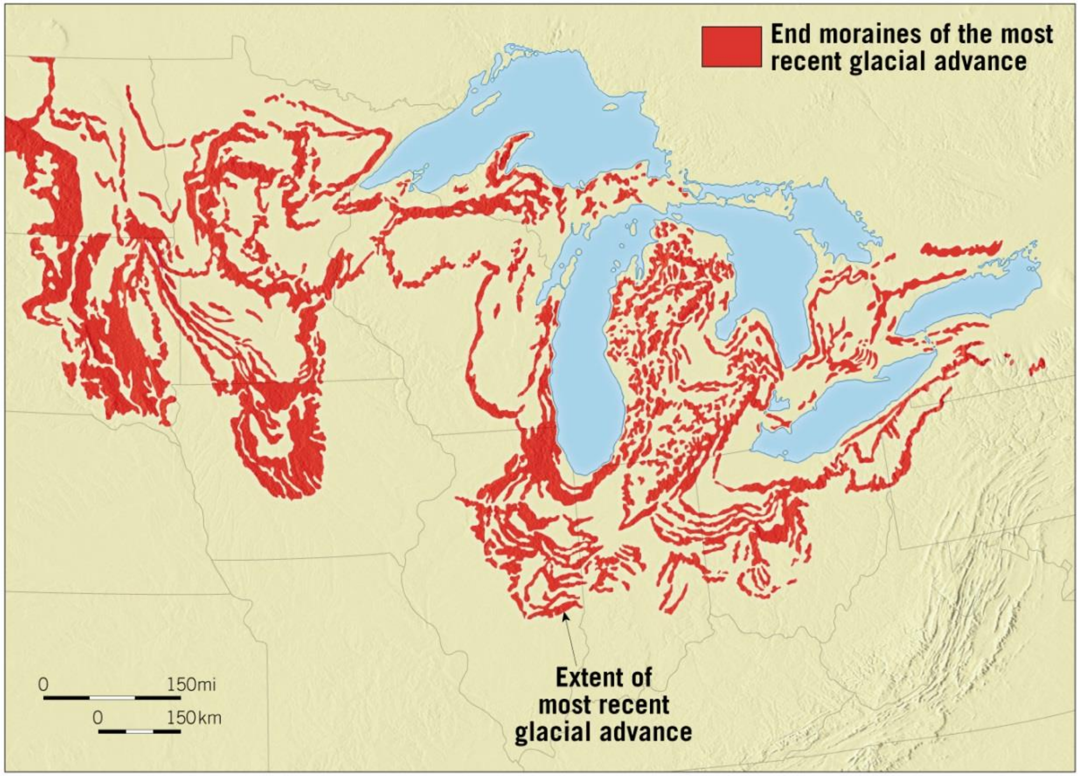
Moraines, Outwash Plains, and Kettles



Geologist's Sketch

Moraines, Outwash Plains, and Kettles

- End moraines from the last Ice Age are prominent in the Midwest and Northeast
  - Kettle Moraine near Milwaukee, Long Island, and Cape Cod



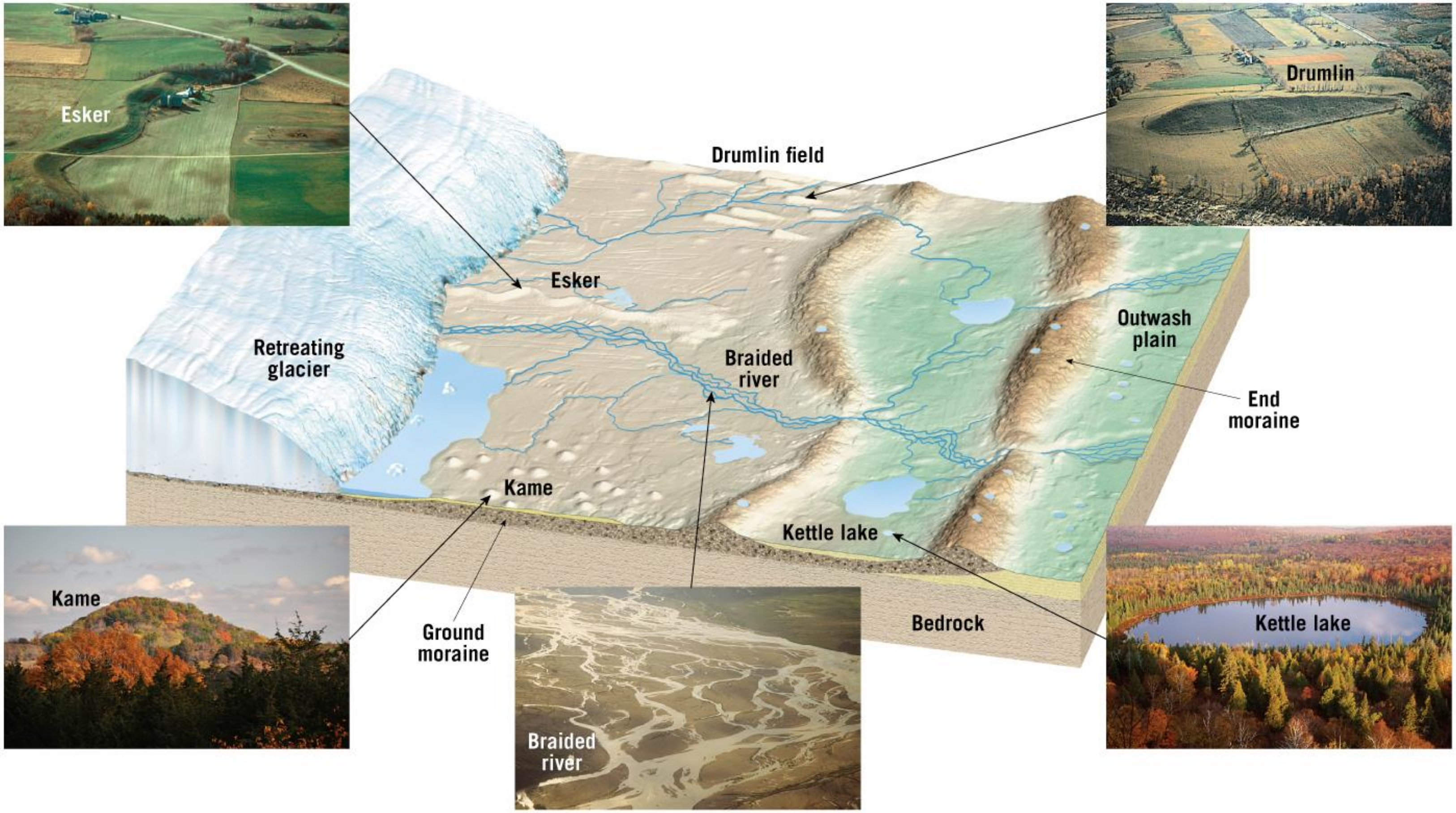
Moraines, Outwash Plains, and Kettles

- Braided meltwater streams form a broad ramp of stratified drift
  - **Outwash plains** associated with ice sheets
  - A **valley train** is confined to a mountain valley
- **Kettles** are basins or depressions in the outwash plain formed by buried ice that eventually melts
  - Typically <2 km in diameter and <10 m deep

Glacial Deposits

- **Drumlins**
  - Streamlined asymmetrical hills made of till
  - Steep side faces direction of ice advance and gentle side indicates direction of ice flow
  - Occur in clusters (drumlin fields)
- **Eskers**
  - Sinuous ridges of sand and gravel made by streams flowing in tunnels underneath the ice
- **Kames**
  - Steep-sided hills of stratified drift

Glacial Deposits



Focus Question 4.5

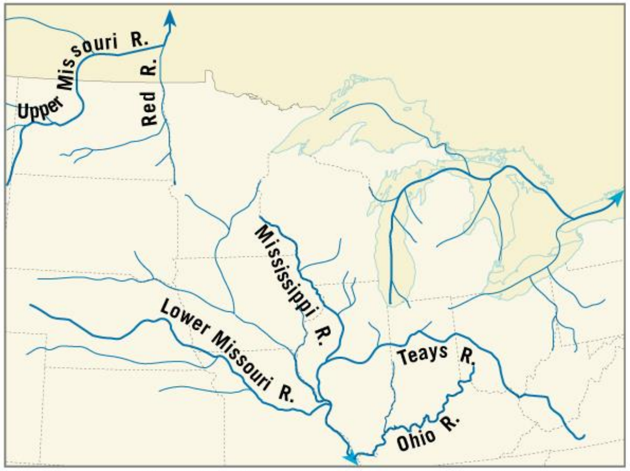
- Describe and explain several important effects of Ice Age glaciers other than the formation of erosional and depositional landforms.

Other Effects of Ice Age Glaciers

- Forced migration of animals
- Alterations in stream courses
- Rebounding of land
- Ice sheets dam meltwater and create lakes
  - **Proglacial lakes**
- World-wide change in sea level
  - Up to 100 m lower during the Ice Age
- **Pluvial lakes** formed during cooler, wetter climates

Other Effects of Ice Age Glaciers

A. This map shows the Great Lakes and the familiar present-day pattern of rivers. Quaternary ice sheets played a major role in creating this pattern.

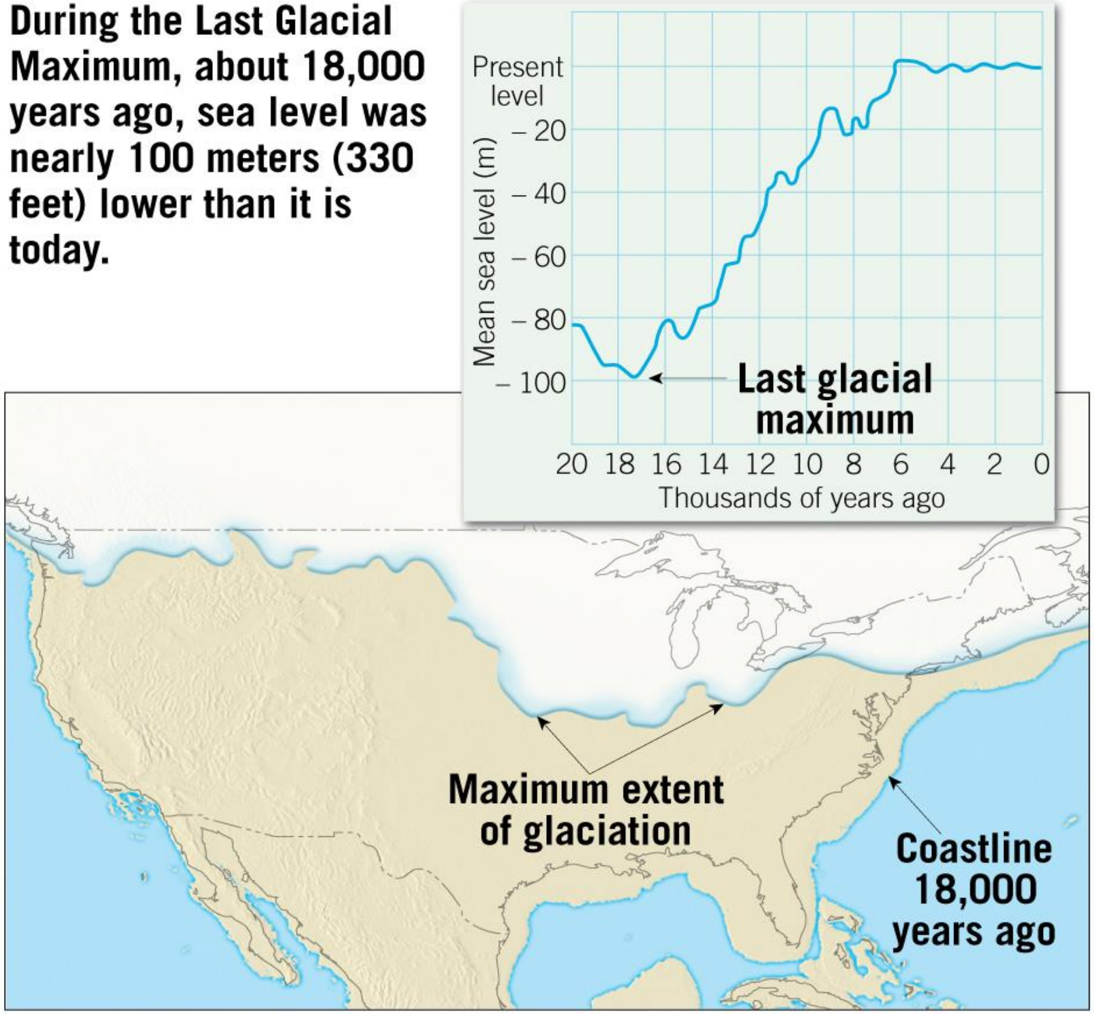


B. Reconstruction of drainage systems prior to the Ice Age. The pattern was very different from today, and the Great Lakes did not exist.

Other Effects of Ice Age Glaciers

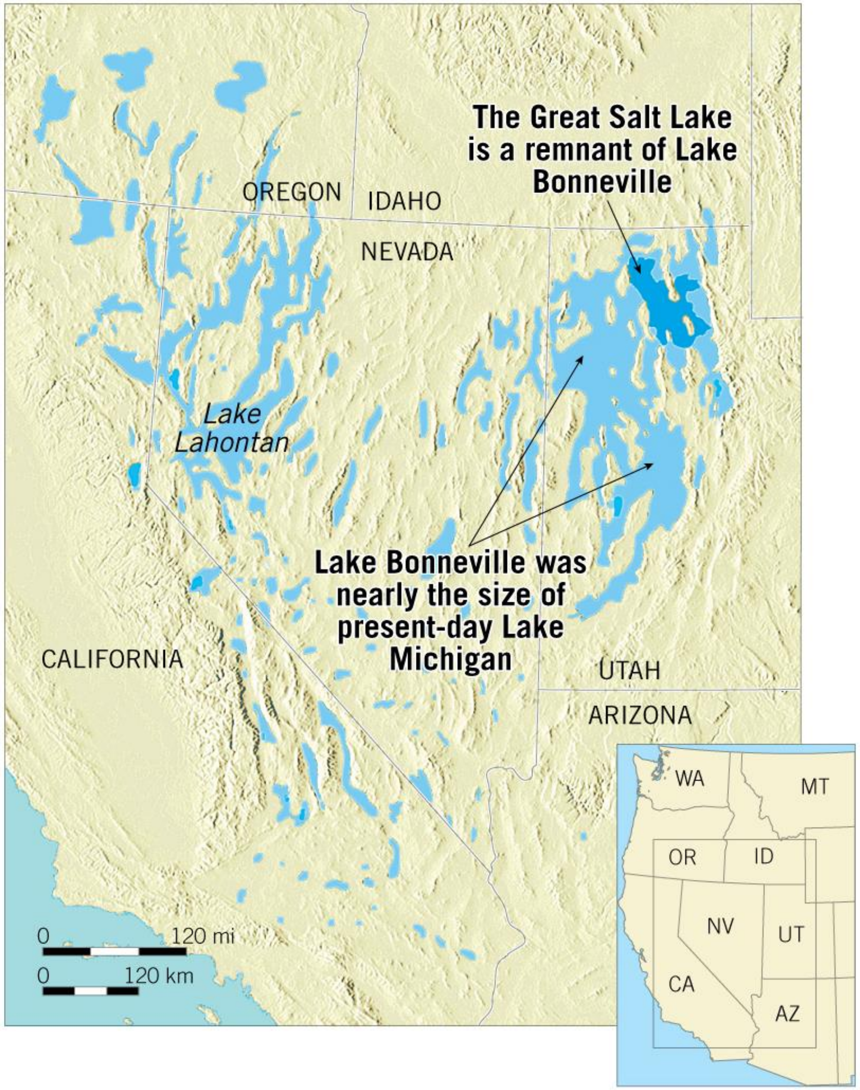
Other Effects of Ice Age Glaciers

During the Last Glacial Maximum, about 18,000 years ago, sea level was nearly 100 meters (330 feet) lower than it is today.



During the Last Glacial Maximum, the shoreline extended out onto the present-day continental shelf.

Other Effects of Ice Age Glaciers



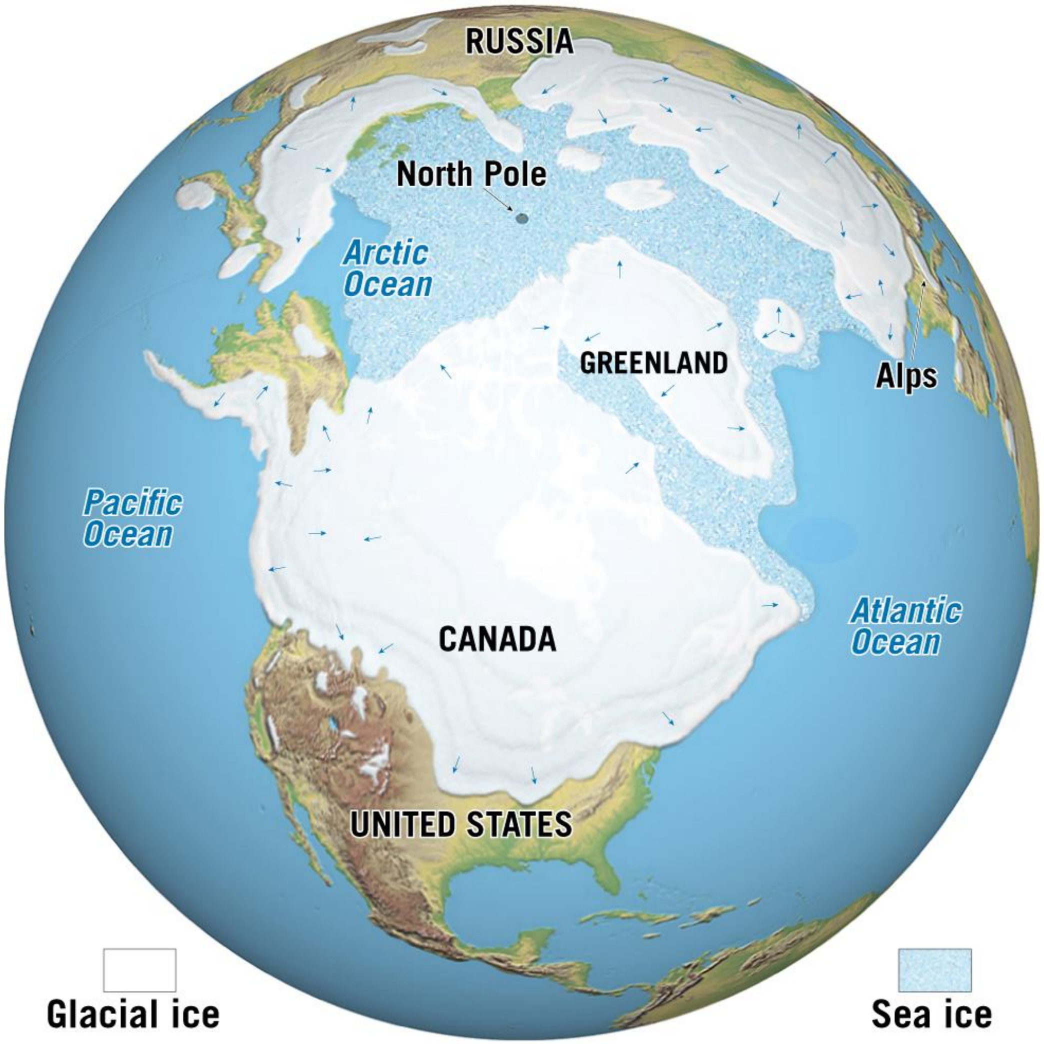
Focus Question 4.6

- Discuss the extent of glaciation and climate variability during the Quaternary Ice Age.

Extent of Ice Age Glaciation

- Last ice age began between 2 and 3 million years ago during the **Quaternary period**
  - Antarctic Ice Sheet formed at least 30 million years ago
- Ice sheets and alpine glaciers were far more extensive than they are today
  - Almost 30% of Earth’s land was glacially influenced

Extent of Ice Age Glaciation



Focus Questions 4.7

- Describe the general distribution and causes of Earth’s dry lands.
- Describe the role that water plays in modifying desert landscapes.

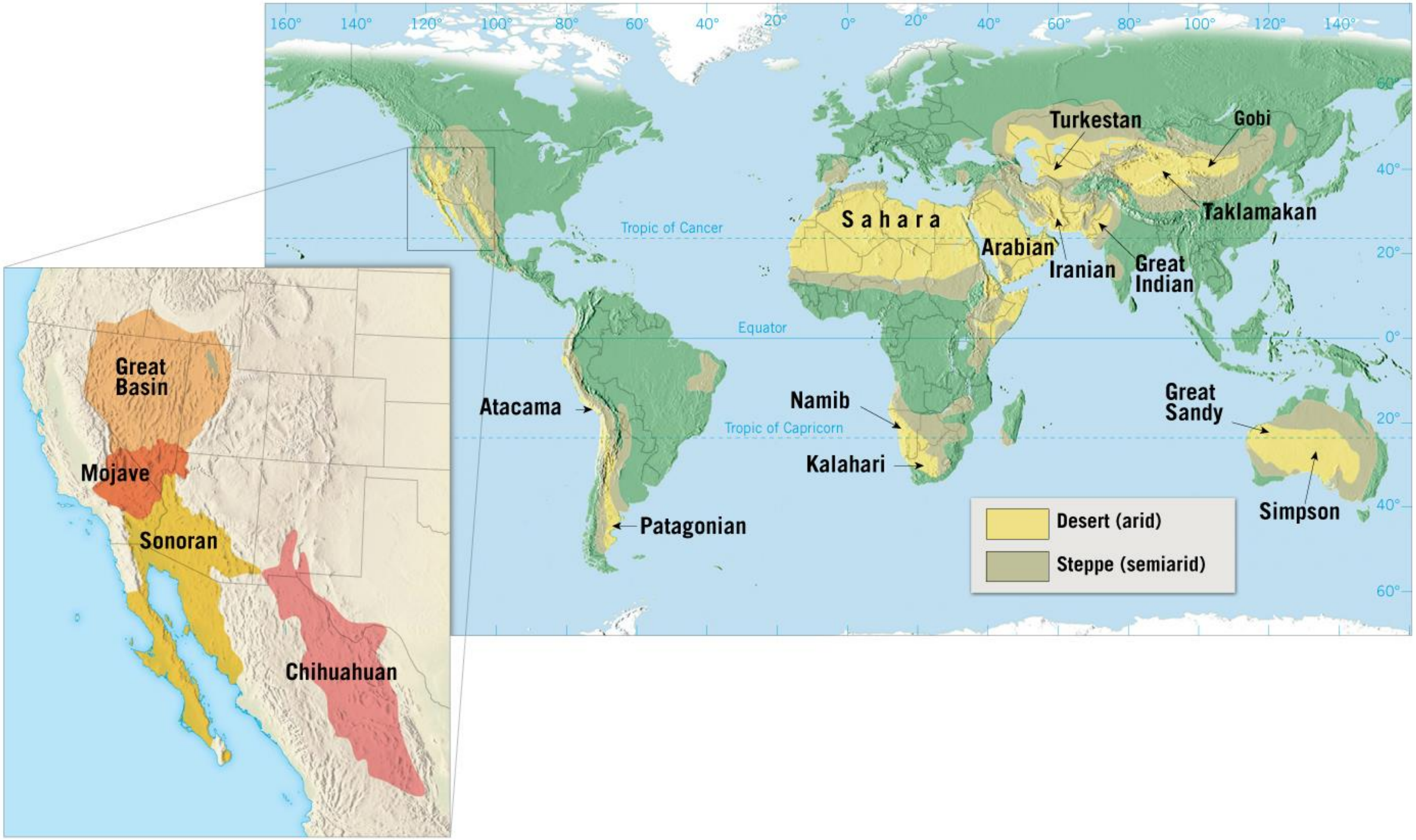
Deserts

- 30% of Earth's land surface is arid
- Affected by many geologic processes
  - Mountain building, running water, wind

Distributions and Causes of Dry Lands

- **Dry climate**
  - Yearly precipitation less than the potential loss of water by evaporation
  - **Desert** (arid)
  - **Steppe** (semiarid)
    - Marginal and more humid variant of desert
    - Transition zone that surrounds the desert
  - Concentrated in subtropics and middle latitudes

Distributions and Causes of Dry Lands



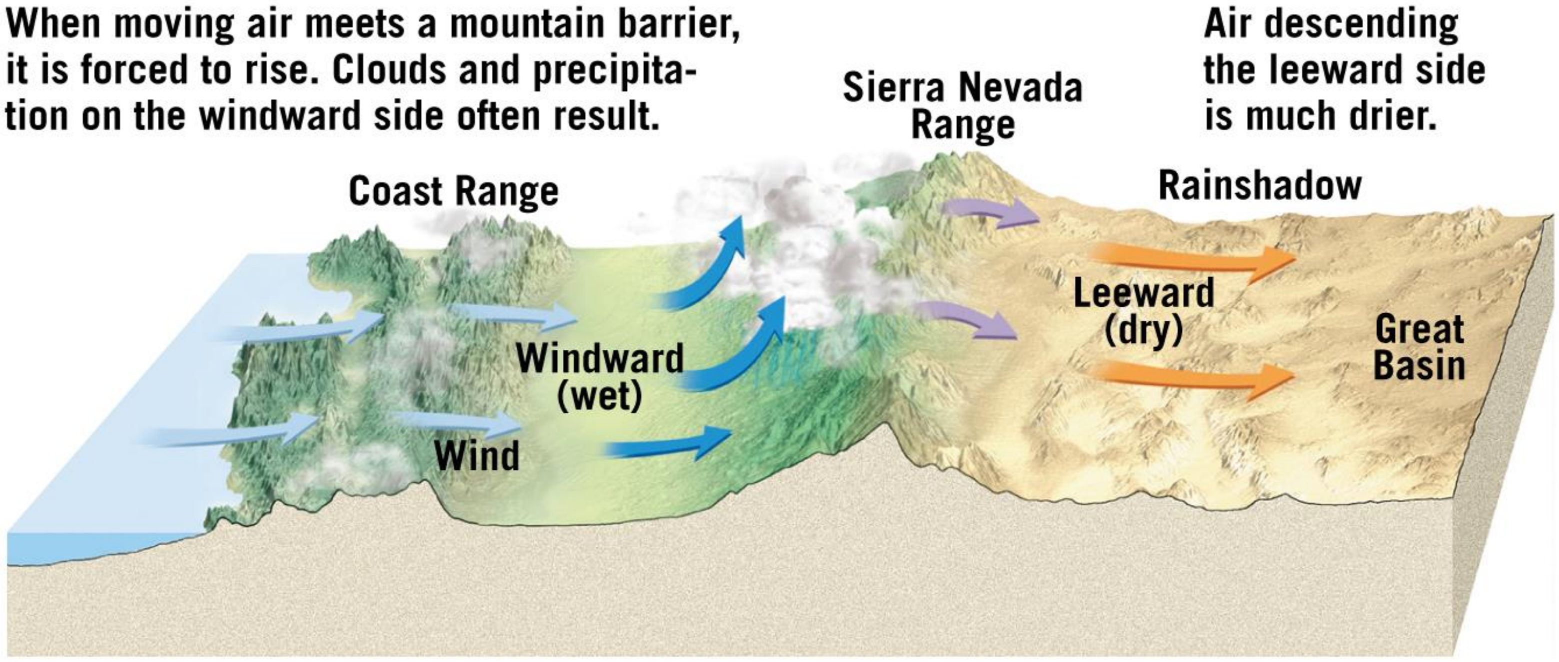
Distributions and Causes of Dry Lands

- African, Arabian, and Australian deserts are a result of prevailing winds
  - Subtropical highs in the lower latitudes
  - Subsiding air is compressed and warmed
    - Creates clear skies and ongoing dryness
- Middle-latitude deserts and steppes occur in the deep interiors of large landmasses
  - Little precipitation because of distance to oceans
  - Example of how geologic processes (mountain building) can affect climate

Distributions and Causes of Dry Lands

In this view from space, the Sahara Desert, the adjacent Arabian Desert and the Kalahari and Namib deserts are clearly visible as tan-colored, cloud-free zones. The band of clouds across central Africa and the adjacent oceans coincides with the equatorial low-pressure belt.

Distributions and Causes of Dry Lands



The Role of Water in Arid Climates

- **Ephemeral streams** only carry water during specific rainfall events
  - Little vegetation to mediate runoff
  - Flash floods are common
  - Responsible for most erosion in deserts
    - Wind primarily transports sediment

The Role of Water in Arid Climates

A. Most of the time desert stream channels are dry.

B. An ephemeral stream shortly after a heavy shower. Although such floods are short-lived, they cause large amounts of erosion.

A familiar sign in desert areas. Roads dip into washes which can rapidly fill with water following a heavy rain.

Focus Question 4.8

- Discuss the stages of landscape evolution in the Basin and Range region of the western United States.

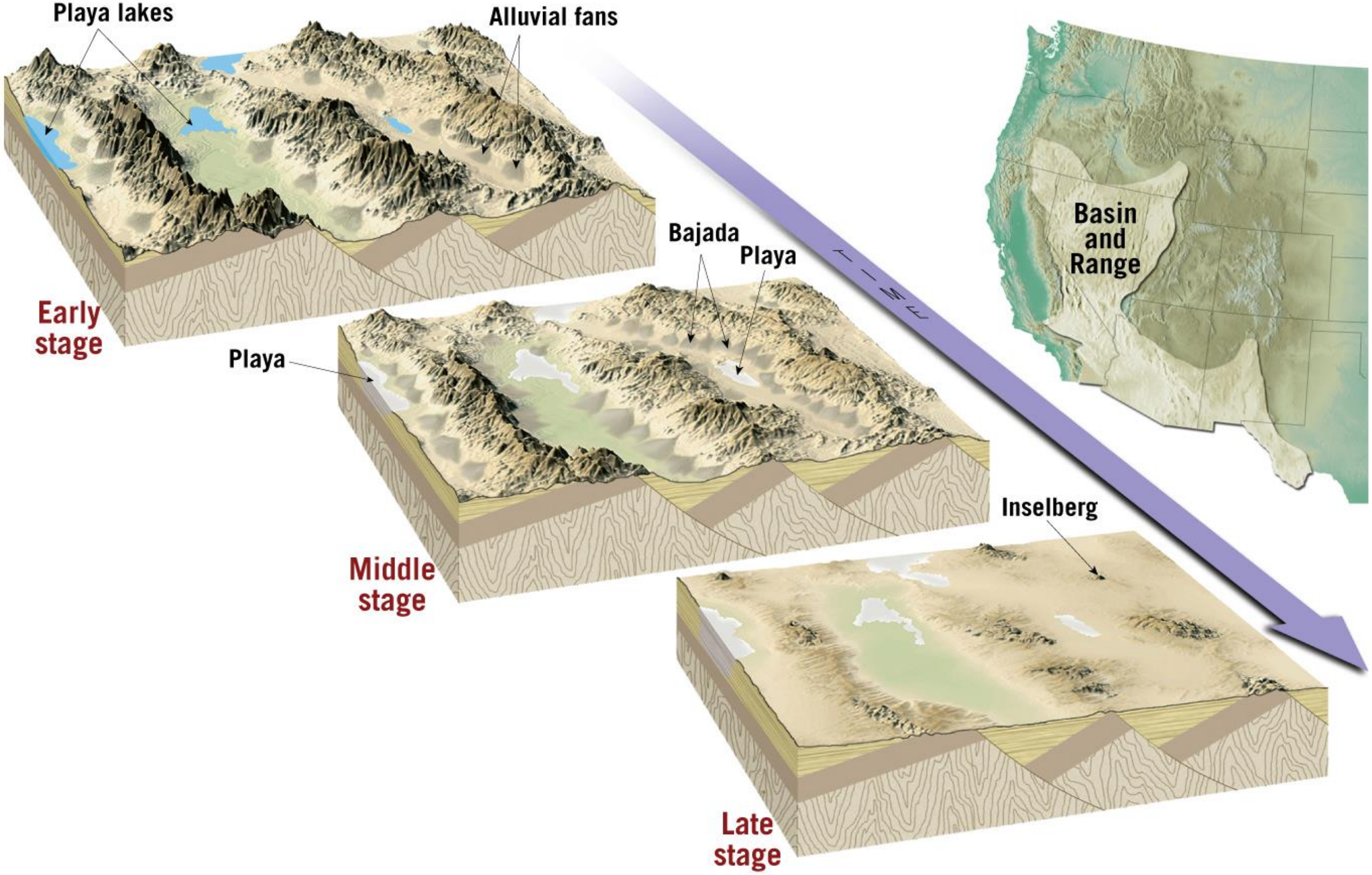
Basin and Range: The Evolution of a Mountainous Desert Landscape

- Regions with **internal drainage** have ephemeral streams that do not flow out of the basin in to the ocean
  - E.g., Basin and Range region in western U.S.
    - Characterized by over 200 small fault-block mountain ranges separated by basins
    - Water causes erosion following uplift

Basin and Range: The Evolution of a Mountainous Desert Landscape

- Occasional heavy rain loads rivers with sediment
- **Alluvial fans** deposited at mouth of a canyon
- A **bajada** is created when several alluvial fans from adjacent canyons merge
- A **playa lake** forms when rainfall is sufficient to cover the basin floor
  - Salt flats can form when water evaporates
- Continued erosion gradually diminishes local relief
  - Eventually only bedrock knobs called inselbergs remain

Basin and Range: The Evolution of a Mountainous Desert Landscape



Basin and Range: The Evolution of a Mountainous Desert Landscape

Focus Questions 4.9

- Describe the ways in which wind transports sediment and the features created by wind erosion.
- Distinguish between two basic types of wind deposits.

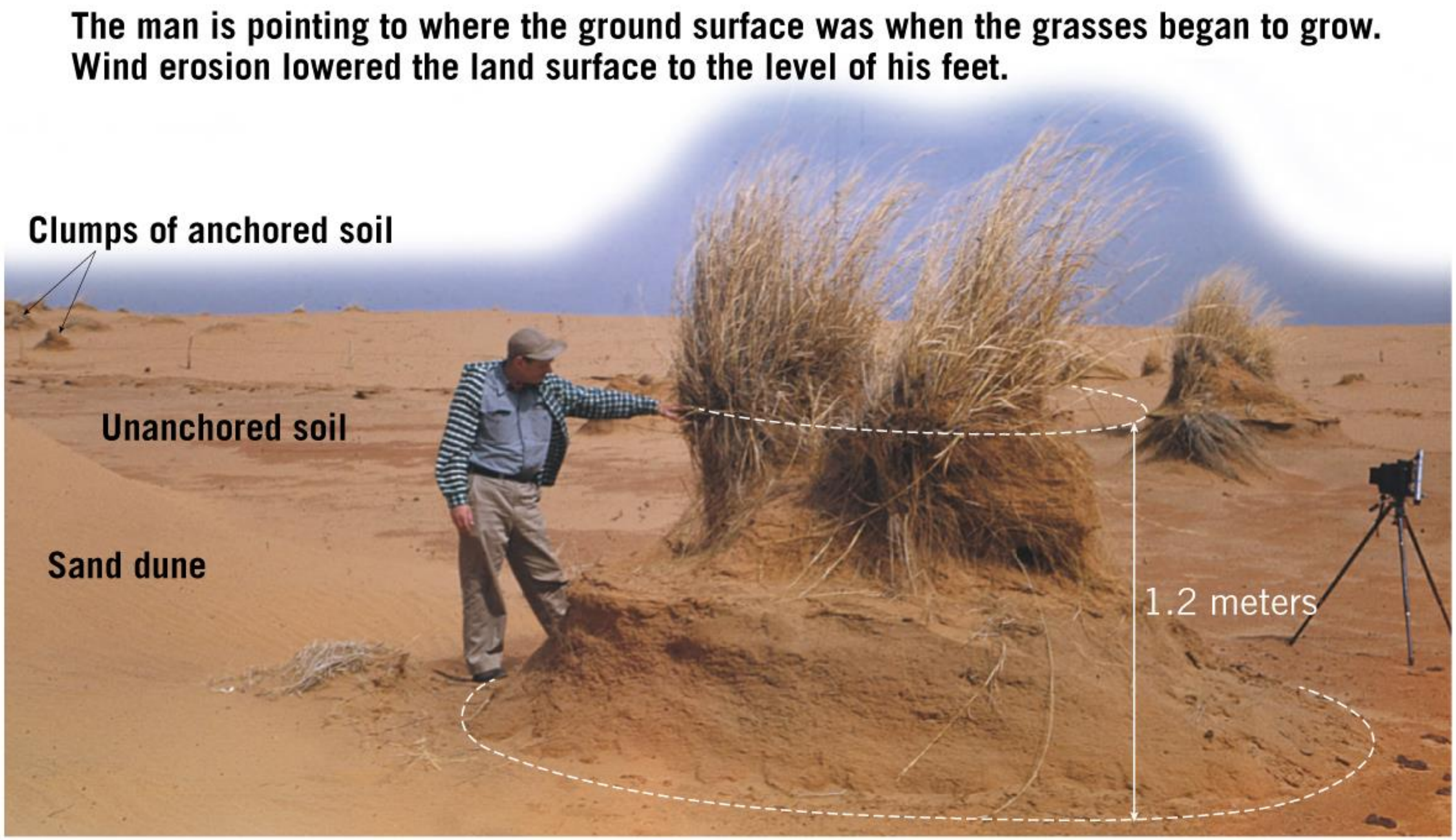
Wind Erosion

- Moving air can pick up and transport loose material
  - Similar to a river
    - Velocity of wind increases with height above surface
    - Transports fine particles in suspension and heavier particles as bed load
  - Different from a river
    - Less capable of transporting coarse material
    - Not confined to a channel
- Relatively insignificant erosional agent

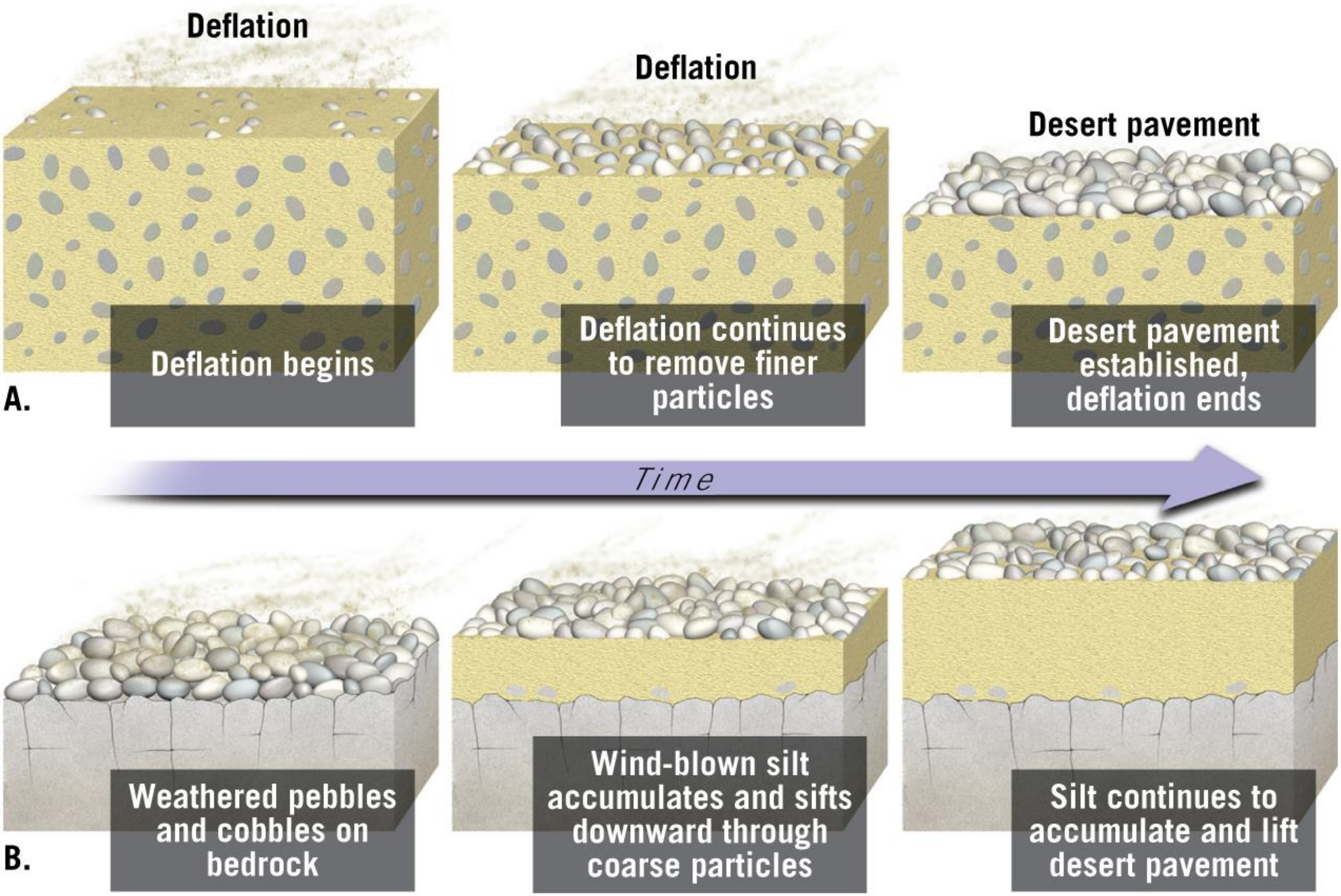
Wind Erosion

- **Deflation**
  - Lifting and removal of loose material
  - Clay and silt only
- **Saltation**
  - Rolling or skipping of larger particles along the surface
- **Blowouts**
  - Shallow depressions caused by deflation
- **Desert pavement**
  - Stony veneer left behind after deflation removes finer material

Wind Erosion



Wind Erosion



Wind Erosion

- Wind can also erode via abrasion
  - Occurs in dry regions and along some beaches
  - Windblown sand polishes exposed rock surfaces
  - Generally <1 m above the surface

Wind Deposits

- Generally two distinctive types:
  - Extensive blankets of silt from suspended load called **loess**
  - Mounds and ridges of sand from bed load called **dunes**

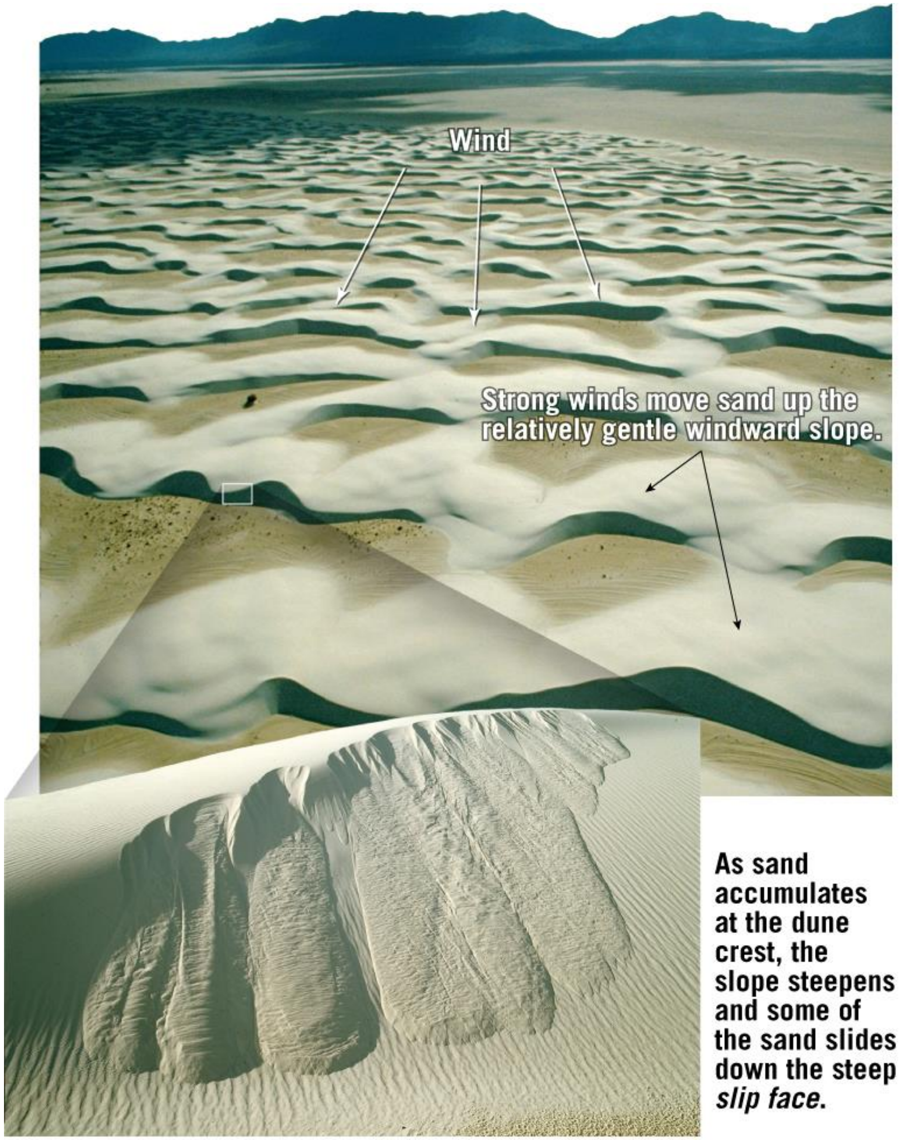
Wind Deposits

- Loess is windblown silt
  - Tends to erode in vertical cliffs
  - Lacks bedding
- Deserts and glacial deposits of stratified drift are primary sources of silt

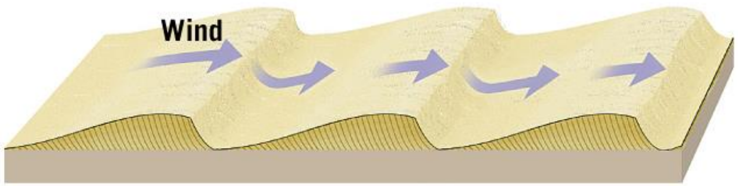
Wind Deposits

- Sand accumulates in mounds and ridges where the path of wind is obstructed
- Many dunes have asymmetrical profiles
  - Leeward (sheltered) slope is steep and windward slope is gently inclined
    - Sand accumulates on the **slip face** (leeward side) because wind velocity is reduced just beyond the crest of the dune
    - Dunes migrate slowly in windward direction
- Inclined layers in the windward direction are called **cross bedding**

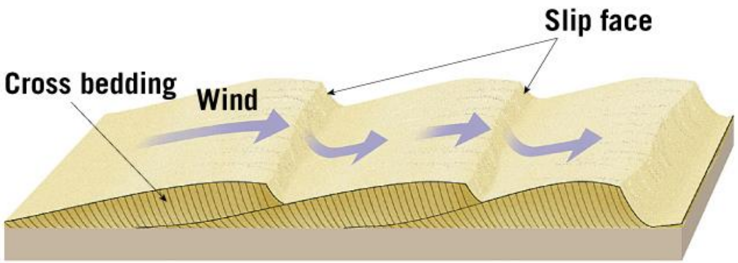
Wind Deposits



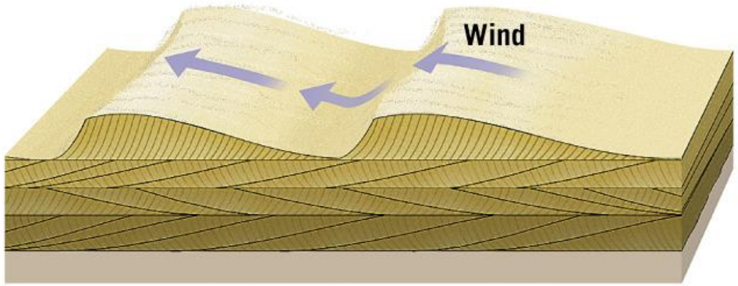
Wind Deposits



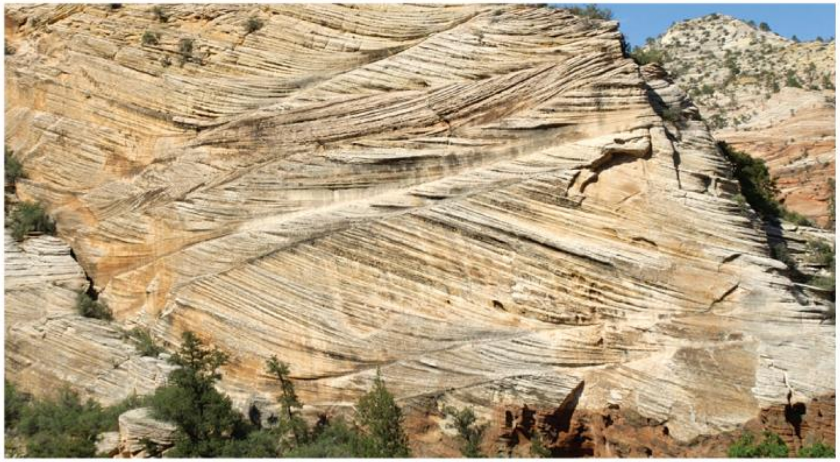
Dunes commonly have an asymmetrical shape and migrate with the wind.



Sand grains deposited on the slip face at the angle of repose create the cross bedding of dunes.



When dunes are buried and become part of the sedimentary rock record, the cross bedding is preserved.



Cross bedding is an obvious characteristic of the Navajo Sandstone in Zion National Park, Utah.