**Glaciers**
- Large, long-lasting mass of ice, formed on land that moves.
- Driving force for glacier movement is **gravity**.
- Importance of glaciers:
  - Record of climate / atmospheric change
  - Economic deposits of sand and gravel
  - Freshwater reservoirs and aquifers
  - Landscape formation

**Distribution of Glaciers**
At present, there are two major glacial regions:
1. **Antarctica**
   - ~85% of glacial ice is on Antarctica
   - Antarctica ice sheet is up to 5 km thick and is as large as the U.S. and Mexico combined.
2. **Greenland**
   - ~10% of glacial ice is on Greenland
   - Greenland ice sheet is ~1.5 km thick.

**Types of Glaciers**
A. Confined to valleys
   - **Valley** glaciers
     - Associated with **Alpine** (mountain) glaciation.
     - Flow from higher to lower elevation like water in a stream channel.
B. Not confined to valleys
   - **Ice cap** - covers area <50,000 km²
   - **Ice sheet** - covers area >50,000 km²
     - Associated with **continental** glaciation
     - Flow downward and outward from central highpoint largely unconfined by underlying topography
   - See fig. 12.3
Formation Glacial Ice

- As snow is buried and compressed by the weight of overlying snow it changes from:
  - snow → granular snow → firn → glacial ice
- During the transformation, the density increases and the amount of trapped air decreases.
- See fig. 12.4

Formation of Glaciers

- Glaciers form in regions where the amount of snow that falls during winter exceeds amount that melts during summer.
- Need combination of cold and moisture.
  - Polar regions (high latitudes)
  - High elevations (high altitude)
  - Area of high winter snowfall.

Glaciers form when...

“Accumulation exceeds Ablation”
- Accumulation is addition of snow by precipitation.
- Ablation (wasting) is loss of snow/ice by:
  - Melting
  - Calving
  - Sublimation
Glacial Budget

- **Zone of Accumulation**
  - Upper portion of glacier where some snow remains from previous year.

- **Zone of Ablation (Wasting)**
  - Lower part of glacier where there is net loss of glacial snow/ice during the year.

- **Snowline**
  - Boundary between permanent snow and seasonal snow (zones of accumulation and ablation).

- **Terminus**
  - Extremity or lower edge of glacier.

  *See fig. 12.16*

Glacial Budget and Movement

- **Advancing glaciers**
  - Positive budget, terminus advancing

- **Receding glaciers**
  - Negative budget, terminus retreating.

Glacial Movement

- Glaciers flow due to gravitational forces acting on them.
- Flow at the base and sides of glaciers is greatly inhibit by friction.
- Rates of flow vary with:
  - Slope steepness
  - Precipitation
  - Temperature
- Typical rates are cm’s to m’s per day, but glaciers can ‘surge’ at speeds of hundreds of meters per day.
Mechanisms of Movement

- **Basal slip**
  - Entire glacier slides over bedrock. Water at base can greatly accelerate rate.
- **Plastic (internal) flow**
  - Glacier moves by plastic deformation of ice grains in response to the stress of overlying mass.
- **Brittle fracture**
  - Upper part of glaciers (top 50 m) represents a rigid zone where glacial ice fractures due to tensional forces, forming open fissures called crevasses.
- See figs. 12.8, 12.10

Glacial Erosion

- At base of glacier
  - Plucking
  - Abrasion
    - Glacial Striations
    - Rock flour
  - See fig. 12.14
- At top and sides of glacier
  - Frost wedging and erosion of slopes
  - See fig. 12.21

Erosional Landforms

- **Alpine Glaciers**
  - U-shaped valleys
  - Hanging valleys
  - Cirque
  - Tarns
  - Horn
  - Arete
  - See fig. 12.16
- **Continental Glaciers**
  - Striations and grooves in rock
  - Rounded hills and mountains
Glacial Deposits

- **Drift** - all rock and sediments transported and deposited by a glacier.
  - **Till** - drift deposited directly from glacial ice. Typically poorly sorted.
  - **Striated drift (Outwash)** - drift transported by glacier but deposited by streams. Tend to be well sorted, layered deposits.

Till Landforms

- **Erratics**
  - Large boulders transported by glacier and deposited some distance from original outcrop.

- **Moraines** (figs. 12.26, 12.29)
  - **End or terminal moraines** - deposited at terminus.
  - **Lateral or medial moraines** - deposited along sides.
  - **Ground or recessional moraines** - deposited at base during melting/retreat.

- **Drumlin** (fig. 12.30)
  - Elongate hill formed when flows over and reshapes a mound of previously deposited drift.

Stratified Drift Landforms

- **Outwash** (fig. 12.32)
  - sediment deposited by streams beyond terminus of glacier.
  - **Outwash plain** - Broad level surface composed of outwash.

- **Kame**
  - small mound or ridge of sediment layers deposited by stream at glacier margin.

- **Esker** (fig. 12.31)
  - long ridge formed by stream that flowed within, on, or beneath glacier.

- **Kettle**
  - depression in outwash created by melting large chunk of ice left buried in drift.
  - **Kettle lake** - kettle filled with water.
Other Glacial Deposits

- Lake Deposits
  - Varves - paired light and dark layers deposited annually in a glacial lake (fig. 12.33).
- Loess deposits
  - Wind blown glacial rock flour. In U.S., deposits range from 1.5 to 30 m thick and form some of the most fertile soils in Midwest (fig. 13.19).

Effect of Glaciers on North America

- Much of Canada scoured.
- Formed Great Lakes & Finger Lakes.
- Deposited till and flattened much of Midwest (especially Wood County).
- Extensive alpine glaciers shaped mountains (especially Rocky Mountains).

What Causes Glacial Ages?

1. Astronomical factors
2. Atmospheric factors
3. Tectonic factors
Astronomical Factors

- Milankovitch Theory
- Idea that glacial ages are relate to decreases in amount of solar radiation received by the Earth due to cyclical orbital variations.
  - Orbital Essentricity (100,000 year cycle)
  - Tilt of axis (41,000 year cycle)
  - Precession of axis (23,000 year cycle)

Atmospheric Factors

- Glacial ages are due to decreases in the amount of solar radiation that reaches the Earth’s surface.
- Decreases in solar radiation reaching the Earth’s surface may be due to increases in:
  - CO₂ in atmosphere
  - Volcanic ash
  - Dust and ash from meteorite impact

Tectonic Factors

- Glaciation is related to latitude, altitude, and moisture budget.
- Hence, glacial ages may correspond to changes in:
  - Position (latitude) of continents through time.
  - Mountain building and erosion.
  - Presence and magnitude of deep ocean currents.
Effects of Glaciation

- Sea level changes
  - Lower during glacial ages
- Crustal deformation
  - Isostatic rebound
- Stream drainage diversion
  - Ice dams
- Changes in pattern of precipitation
  - Pluvial lakes

Information from Ice Cores

- Provide time-correlated:
  - Sampling of air (gases and dust/ash) trapped at the time of snowfall.
  - Information on changes in precipitation patterns.
  - Information on temperature and rates of temperature change.