Glaciers
Most of the world's fresh water (about 75%) is in the form of glaciers
➔Called the Cryosphere, a subsystem of the hydrosphere

Glacier – large, long lasting mass of ice, formed on land, that moves under its own weight.

There are two types of glaciated terrain:
1) Alpine Glaciation – found in mountainous regions (*high altitudes*)
2) Continental Glaciation – exists where a large part of a continent is covered by glacial ice. (*high latitude*)

Theory of Glacial Ages – states that at times in the past, colder climates prevailed during which much more of the land surface of the earth was glaciated then at present.
➔ Hypotheses began in 1800's
➔ First not believed, then Agassiz bought into it
➔ Last glaciation was at its peak 18K years ago
➔ Many of our national parks were made by glacial action

Types of Glaciers
1) Mountain Glaciers – confined to a valley and flows from a higher to a lower elevation.
➔ Corresponding to alpine terrains (*higher altitudes*)
  a) Valley Glaciers: confined to a valley
  b) Piedmont Glaciers: form where valley glaciers coalesce and spread out over flatter land at the base of a mountainous region.
  c) Cirque Glaciers: found in amphitheatre-like hollows at the head of a glacial valley.
2) Ice sheet – mass of ice that is not restricted to a valley, but covers a large area of land (over 50,000 km^2) – Associated with continental glaciation (*therefore high latitudes*)

Ice Caps – similar to ice sheet but smaller, and can exist in high altitudes or high latitudes
➔ Arctic coast – Canada, Russia, Scandinavia

<u>Formation and Growth of Glaciers</u>
Snow converts to glacier ice in somewhat the same way as sediment turns to sedimentary and later into metamorphic rock.

Snow→Granular Snow→Firn→ Glacier Ice
Peat→ Bituminous Coal→Anthracite
Sand→ Quarts sandstone→Quartzite

As ice moves to lower elevations, it will eventually be ablated (or lost).
Types of Ablation:
1) Melting
2) Sublimation
3) Calving – forms icebergs

Glacial Budgets
Positive – Accumulation > Ablation – Advancing Glaciers
Negative – Ablation > Accumulation – Receding or Retreating Glaciers
Balanced → Accumulation = Ablation
Fig. 12.6

EQ Line = 0° Isotherm = Snow line
Zone of Accumulation – perennial snow cover
Zone of Ablation – melting zone – zone of ice loss
Terminus – lower edge of the glacier

Advancing or receding glaciers are significant and sensitive indicators of climate change
→ Advancing does mean more precipitation, not necessarily a cold trend.
→ Global warming has diminished glacier size (in both South America and Glacier National Park)

Movement of Valley Glaciers
→ Move down slope due to gravity
→ Range – a few mm to 15m a day
→ Glaciers in temperate areas tend to move faster than ones in colder regions

Velocity also varies within the glacier itself (FIG. 12.8)

<u>Types of Movement</u>

1) Basal sliding – glacier moves as a single unit over the underlying rock

→Can have freeze-on of boulders, rock at the base, which can then move with the glacier in the basal sliding process
→ Due to pressure of the Glacier, a thin film of meltwater at its base aids in the movement

2) Plastic Flow – movement that occurs within the glacier due to the plastic or deformable nature of ice itself. (FIG. 12.8)

➔ Easier flows at depth due to the pressure
➔ Near the surface of the ice, the glacier is more rigid (hence the Rigid Zone) (Lithosphere VS. Asthenosphere of the earth)
Rigid Zone – grains of ice do not move separately due to pressure, as a result, the ice cracks.
Crevasses – open fissures that exist in the ice due to stress.
➔ Crevasses can close in areas of compression (FIG. 12.9)
Icefall – where glaciers flow over steep slopes.

Movements of ice sheets
An ice sheet/cap moves similarly to a valley glacier, except that it moves downward and outward from a central high area toward the edges of the glacier.

Where the ice reaches the sea, it can form an:
1) Ice Shelve, which actually floats on the ocean.
2) Outlet Glaciers, which typically calves into the ocean (icebergs), sometimes in a narrow, but deep valley (fjord)

Antarctica (FIG. 12.10)
➔ Two ice sheets separated by the trans Antarctic mountains
➔ East (largest), west sheets
➔ South Pole – ice is 2700m thick
➔ Thickest part = east sheet – 4776 meters
➔ Lake Vostok 200 km long, 50 km wide (size of Lake Ontario) – 510 m deep

Glacial Erosion
At the base of the glacier:
From freezing/thawing
Plucking – pieces of rock are broken loose and frozen into the moving glacier
Faceting – pebbles or boulders which are dragged along and given a flat surface due to abrasion
Polishing – by fine particles over the bedrock
Striations – scratching on bedrock done by plucked grains
Rock flour – grinding of rock across rock produces this powder (silt/clay sized particles)

Not all glacier-associated erosion is caused directly by glaciers. Frost wedging – rockfalls, snow avalanching, debris flows

Erosional Landscapes Associated with Alpine Glaciation
Glacial Valleys – U-shaped compared to a V-shaped river-crowded valley

Primary valleys erode faster and deeper, which produce *hanging valleys*, which are high above the main valley
➔ Waterfall of Yosemite

Truncated Spurs – process of carving the sides of a river valley.

➔ produces triangular facets where carving takes place

Rock – Basin lakes (or tarns)
➔ form due to variable resistance to erosion
➔ freeze/thaw weakens fractured bedrock
➔ can also form at the base of a cirque
➔ a series of these lakes → *pater-noster lakes*

Roche Moutonneés – rounded knobs of rock
➔ resemble grasing sheep

Cirque – steep-sided, half bowl shaped recess carved into a mountain at the head of a valley by a glacier
➔ usually north or east-facing

Horn – sharp peak created by the merging of several cirques

Arêtè – sharp ridge between 2 glacial valleys

Erosional landscapes associated with continental glaciation
➔ tend to round everything off

Glacial Depositional Features
Till – unsorted and unlayered rock debris carried or deposited by a glacier.

Erratic – ice-transported boulders from a different area, usually of unlike composition.

Moraines – glacial deposits

1) Lateral – elongate, low mounds of till that form along the sides of a valley glacier
2) Medial – created by the merging of two lateral moraines from tributary valleys
3) End – deposit at the edge of the glacial ice (usually the temporary terminus)
4) Recessional – end moraine built as the glacier was receding
5) Ground – material deposited on the underside of the glacier – usually thin
6) Terminal – the end moraine marking the farthest advance of the glacier.

Glacial Depositional Features Associated with Continental Glaciers

Drumlin – streamlined hills of till that were formed under a glacier.

Flute – elongated drumlin

Outwash – melt-water that runs in front of the glacier that can come from anywhere on the glacier.
➔ can be stratified because of its genesis

Esker – long sinuous feature of stratified and sorted sediment that formed within or under the glacier, where meltwater landed with sediment flows under and out of the ice.

At the terminus of the glacier, mounds of sediment buildup on top of the ice. As the glacier recedes, pieces of ice fall off the edge of the glacier and can get buried by the tons of sediment.
➔ the ice chunks (if they are of size) can form *kettles* once they melt (a glacier lake)
➔ the mounds of sediment can form *kames* (a type of glacial sediment)

They are frequently found together and form *kame and kettle topography*.

Varves – two layers of sediment representing one year's deposition in a lake.
➔ low energy environment

<u>Effects of Past Glaciations</u>

The Glacial Ages
➔The most recent ended 10K years ago.

Evidence of earlier glaciations can be erased:
1) Weathering and erosion that occur during warmer interglacial periods
2) Later ice sheets and valley glaciers over-rode and destroyed many of the features of earlier glaciations.

We know more about glaciations past from the marine sediment record: 18O/16O
18O-heavier isotope 16O-lighter
Colder water typically has more 18O
Water utilized by critters-16O

Where: Forams (CaCO3 shell)-oxygen in their shells has the same ratio as seawater.

Glaciations can occur due to any of the following:
1) Extraterrestrial: Milankovitch Cycles
    a) Eccentricity
    b) Obliquity
    c) Preseccion
2) Changes in Atmospheric Composition-Carbon Dioxide fluctuations
3) Changes in the Position of the continents
4) Changes in the circulation of seawater

Direct Effects of Past Glaciations
Figure 12.33-maximum glaciation of North America
➔know direction from grooving/striations
➔Ground Moraine-northern states
➔Terminal Moraines: MASS, NY, Kansas, WI, MN
➔Rock Flour-wind blown loess
➔MN-land of 10,000 lakes-most of which are kettles
➔Finger Lakes of NY-damned by moraines

Indirect Effects of Past Glaciations
Pluvial Lakes-formed in periods of higher humidity
➔Lake Manly-Death Valley
➔Scablands-created by a huge flood after an ice dam broke

Lowering of Sea Level
➔Fiords-coastal inlet that is a drowned glacially carved valley-AK, NZ, Norway (very deep, carved when sealevel was lower

Crustal Rebound
➔weight of ice sheets depresses the continents

Evidence For Older Glaciation
Tillite-lithified till
➔oldest-2.3BYA
➔Snowball Earth-ancient ice age, some or all of the surface of the ocean was frozen
    Evidence: tillites at the equator
    Reason: absence of greenhouse gases, and a weaker sun
➔Paleozoic Glaciation: helped in the Theory of Plate Tectonics