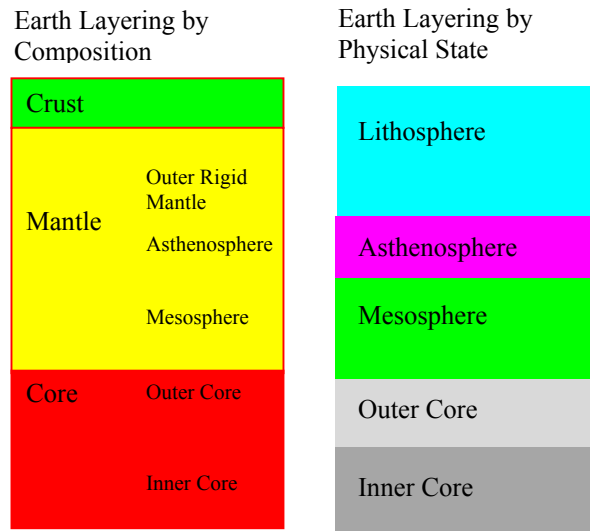


GEOLITHOSPHERE

Geolithosphere - the rocky portion of the Earth extending from Earth's rock surface to the center

- consists of a series of concentric rock layers which can be defined based upon rock composition or physical state (solid, plastic or liquid)



A. CRUST

- outermost shell, rigid, consisting of a great variety of rock types
- about 1% Earth's volume and .4% Earth's weight
- density and temperature gradually increase with depth
- base about 1000°C

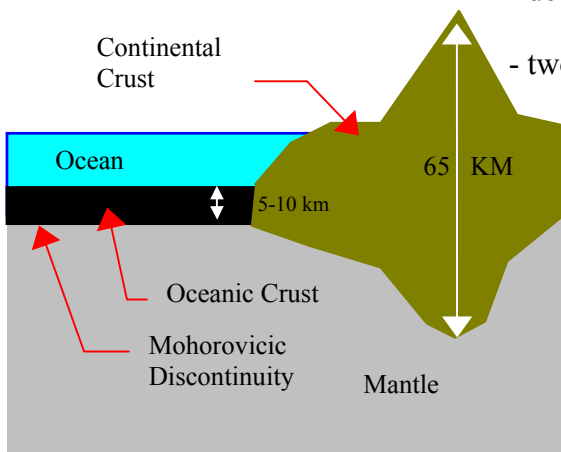
- two parts:

Continent (Continental Crust)

- averages 25 km thick, but reaches up to 65 km at mountains
- silica-rich rocks, main mineral is **quartz**
- average rock type is **granite**
- average density 2.7gm/cm^3

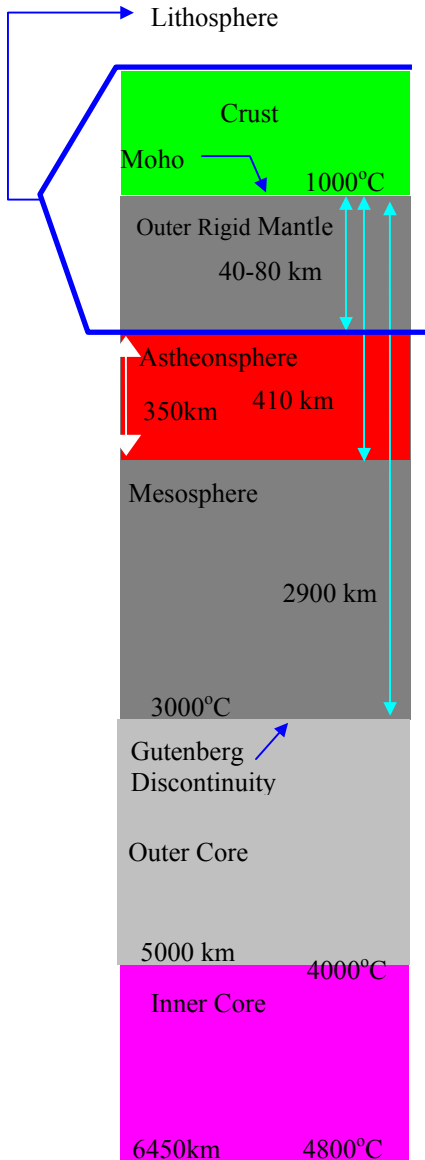
Ocean Floor (Oceanic Crust)

- 5-10 km thick
- iron-rich and magnesium-rich rocks, poor in silica
- average rock type is **basalt**
- average density 3.0gm/cm^3



B. Mohorovicic Discontinuity (Moho)

- boundary between crust and mantle
- represents a change in rock composition and rock density
-



C. Mantle

- base of crust to 2900 km (1800 mi)
- largest layer in volume (84%) and weight (66%) of the Earth
- rocks are super rich in iron and magnesium
- average density of upper part about 3.3gm/cm³
- density and temperature increase with depth
- divided into three parts:

1. Outer rigid mantle

- thin (80 km thick under oceans and 40km thick under continents)
- hard, rigid and fused to the base of the crust
- together with crust form a layer called the “**LITHOSPHERE**”
- *lithosphere = crust + outer rigid mantle*

2. Asthenosphere

- base of lithosphere to 350-700 km
- rocks in a plastic state, neither solid nor liquid
- rocks have the ability to deform and flow
- balance between temperature and pressure in the asthenosphere
 - increasing pressure favors more dense state because atoms are squeezed together changing gases to liquids and liquids to plastics and plastics to solids
 - increasing temperature favors less dense state because atoms have more energy and move farther apart changing solids to plastics, plastics to liquids, etc.
- temperature not enough to liquify the rock, only changing it to a plastic state at the pressure it is under

3. Mesosphere (inner rigid mantle)

- remainder of mantle
- rocks rigid because influence of pressure more significant than temperature
- temperature at base about 3000°C

D. Gutenberg Discontinuity

- represents change in composition and physical state: mantle is solid and outer portion of the core is liquid

E. Core

- mainly iron, nickel and cobalt
- 15% volume and 32% weight of Earth
- divided into two parts based on physical state:
 - **Outer Core**
 - base of mantle to a depth of 5000 km
 - molten, balance of temperature and pressure greatly favours melting
 - base of outer core about 4000°C

- Inner Core

- base of outer core to a depth of 6450 km
- solid, influence of pressure greatly exceeds temperature and rocks solidify
- center of Earth about 4800°C

How do we know Earth's interior composition

- little direct evidence:

- Deepest well, mines and caves only extend about 1.5 miles and Earth is about 6500 km in diameter
- Most knowledge of Earth's interior is inferred from indirect evidence such as meteorites, gravity and earthquakes

- meteorites

- represent original material from which the solar system was constructed and should tell about Earth's composition
- most meteorites are rich in iron, nickel and cobalt, in contrast the outer parts of the Earth are not
- the outer parts of the Earth are composed of lighter elements
- believed that early in Earth's history the planet may have been heated to a molten state and heavy material sank into the center and light material rose to the surface

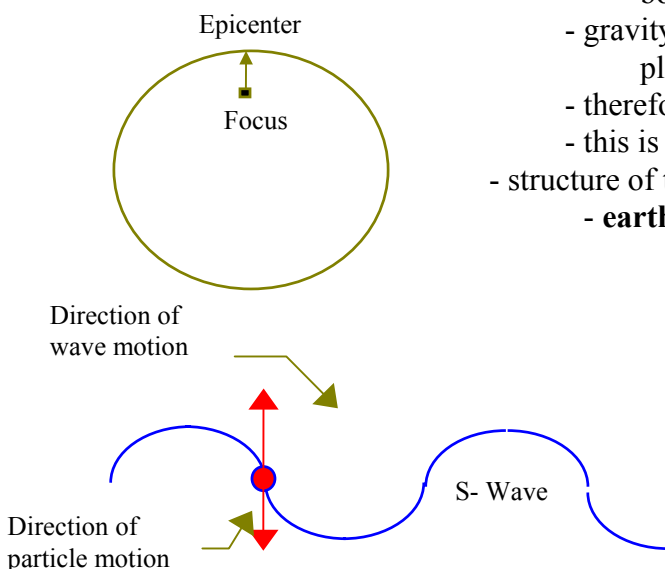
- gravity

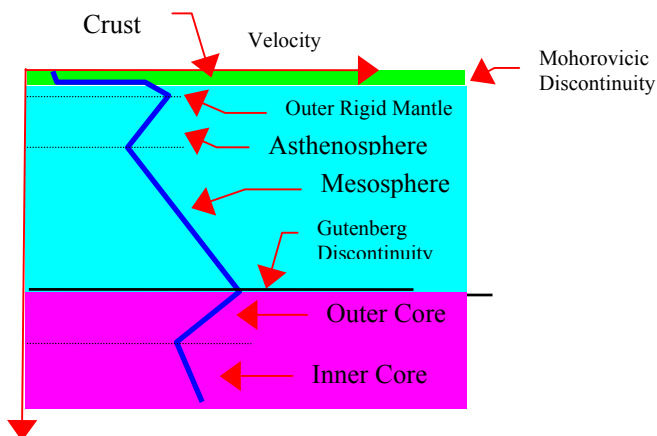
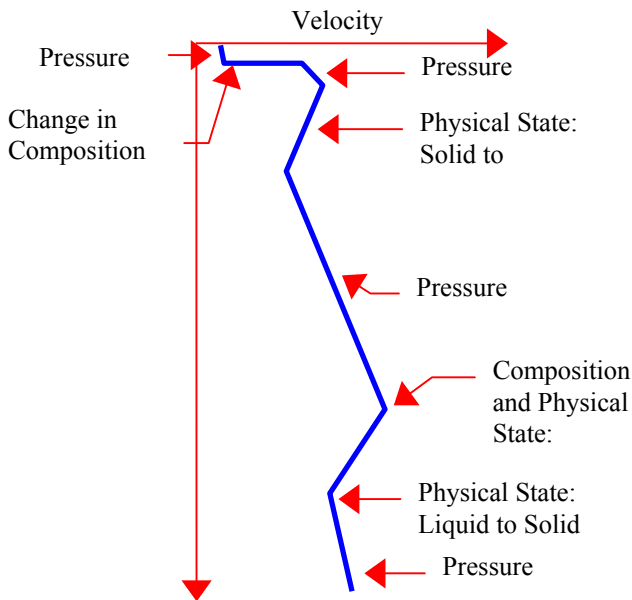
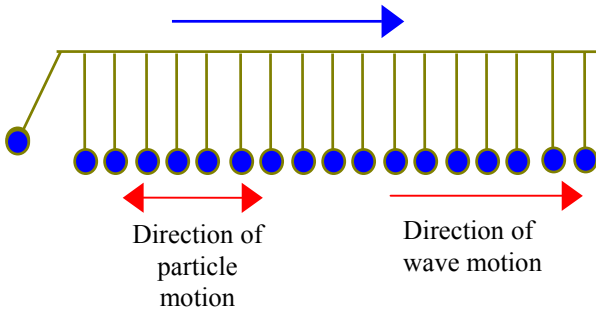
- attraction between two objects
- directly proportional to objects' masses (weight) and inversely proportional to the square of the distance between their centers
- $G \propto M_1M_2/D^2$ where M is the mass of objects 1 and 2 and D is the distance between their centers
- increases as mass increases and decreases as the distance between the bodies increase
- gravity exerted by the Earth suggests that the Earth is a very dense planet, much denser than the rocks at the surface would indicate
- therefore the interior of the Earth must be much denser
- this is where most of the iron, nickel and cobalt are located

- structure of the Earth

- earthquake waves

- earthquakes are vibrations generated when rocks within the Earth break
- vibrations (waves) travel outward in all directions from their origin (**focus**) and are altered by the type of material they pass through
- point on Earth's surface directly above the focus is the **epicenter**
- body waves can be divided into two types based upon the motion of the particles in the wave





- **S-wave (shear wave)** - particles vibrate perpendicularly to the direction the wave travels
 - can only pass through material where the particles are linked together such as in solids and plastics
- **P-wave (push-pull wave)** - particles vibrate parallel to the direction in which the wave travels
 - can pass through all phases of material
- earthquake wave speed is a function of the density of the material the wave is passing through
 - density is controlled by composition and physical state
 - as density increases speed increases
 - density increases from liquid to plastic to solid
 - waves travel fastest through solid and slowest through gas
 - by analyzing the changes in the wave speed can tell something about the construction of the Earth.
- changes in earthquake waves with depth and explanation for changes:
 1. from surface downward there is a gradual increase in S and P-wave speed to about 10 (seafloor) to 65 km (below continent) - increasing density with depth because of pressure
 2. sudden increase in S- and P-wave speed at 10 or 65 km - change in composition to more dense rock type
 3. decrease in wave speed at 70-80 km below ocean and 100 km under continents to 350-700 km is because of change in physical state from solid to plastic
 4. increase in speed from to 2900 km because rocks again solid and density increases with pressure
 5. at 2900 km, S-waves cease and P-waves abruptly slowed
 - major change in composition to much more dense material increases speed, but high temperature relative to pressure means material melts and this offsets the increase and waves are slowed
 - S-waves can not pass through liquid or gas and cease to exist
 - P-waves should accelerate because of denser composition, but because of change in physical state net result is a decrease in wave velocity
 6. from 2600 to 4600km velocity of P-waves gradually decreases because of relationship between pressure and temperature

7. at 4600 km, P-waves increase in speed because of change in physical state from liquid to solid as effect of pressure exceeds temperature
8. below 4600 km velocity gradually increases to Earth's center because of increasing pressure and density

Earth's Source of Internal Heat

- Heat in the interior of the Earth is generated by **fission**, the radioactive decay of large atoms, such as Uranium, into simpler atoms
- During Earth's early molten state, heavier atoms sank to the center and so radioactive material is much more abundant there than at the surface
- outer part of the Earth acts as an insulator and traps the heat inside the Earth, thereby allowing the temperature to increase to the high temperatures observed.

Earth's Magnetic Field (Magnetosphere)

- Earth's inner core is suspended in the outer core and unattached to the rest of the Earth
- Inner core is free to rotate at a different speed and even inclination than the remainder of the Earth
 - evidence indicated that the inner core rotates faster than the remainder of the geolithosphere and that its axial inclination is different
- at the very high temperature of the iron-rich outer core, some electrons become dissociated from their atoms and the mass behaves as a **plasma**, a super heated, electrically charged mass
- the fluid currents in the outer core, generated by the differential rotational speed between the inner core and the remainder of the geolithosphere, generate electrical currents around the iron-rich inner core
 - this is similar to the flow of electrons in a wire around a bar of iron in an electro-magnet and this generates Earth's magnetic field
 - because the inner core axis of rotation is different from that of the remainder of the Earth, the axis of the magnetosphere emerges at a different location than the rotational poles.
- magnetosphere protects the Earth from the solar wind by deflecting the high-energy, electrically charged particles which would otherwise bombard the Earth's surface and make life impossible.

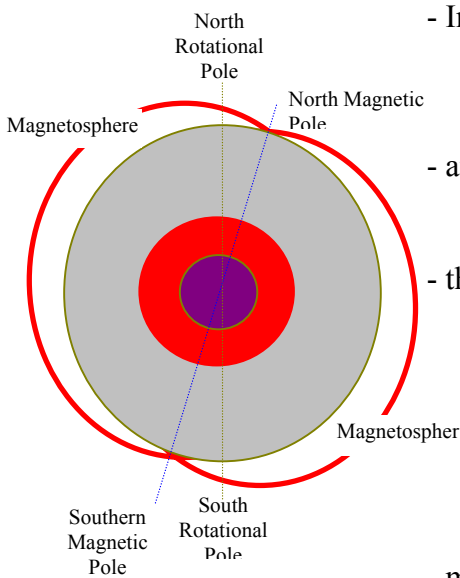
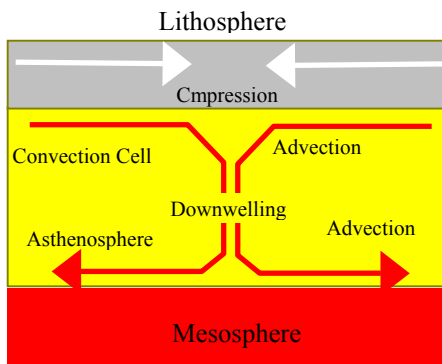
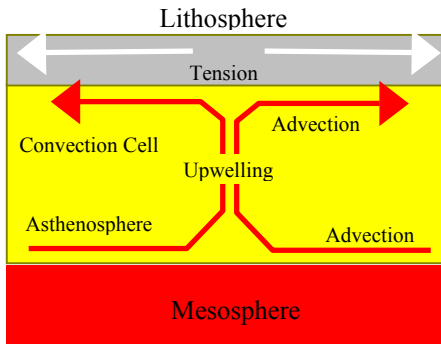


Plate Tectonics

- Earth's lithosphere is divided into a series of semi-rigid, mobile plates
- two types of plates:
 - **Continental** - contain continent and sea floor
 - **Oceanic** - consists of only sea floor
- plates vary greatly in size: 13 major plates and numerous smaller ones

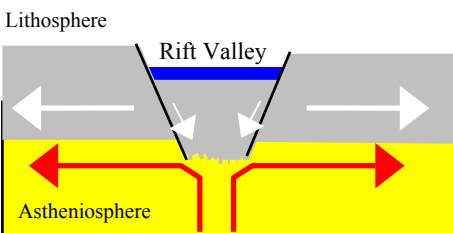
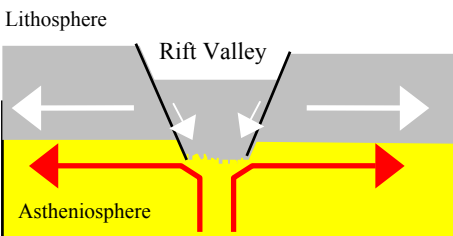
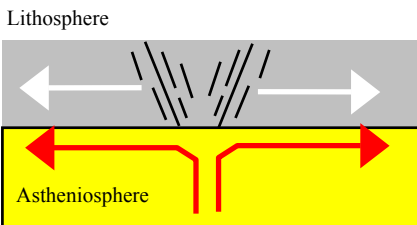


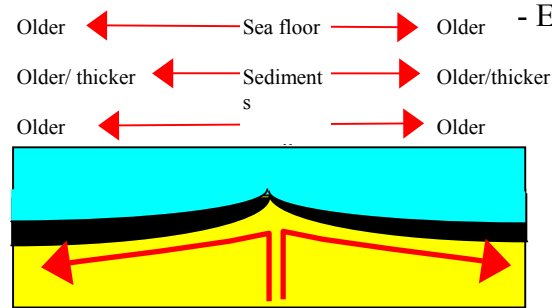
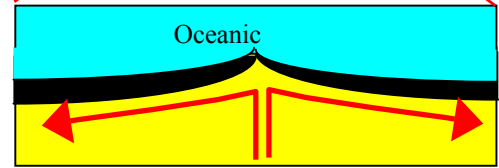
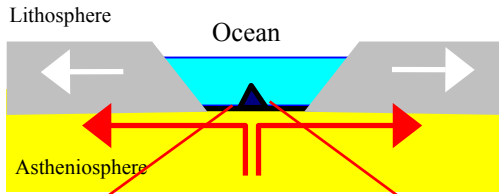
- size and shape of plates change over millions of years as plates fuse together and are later ripped apart as advection of rocks in the asthenosphere slowly moves the plates
- plate motion (**tectonics**)
 1. - rocks at the base of the asthenosphere are heated from below, expand, become less dense and in areas of **upwelling** rise (**convective flow**)
 2. - heated asthenospheric rock reaches the base of the lithosphere and flows laterally outward (**advection**), cools, becomes denser and sinks (**downwelling**, convective flow) to the bottom of the asthenosphere where they are re-heated and recycled
 3. - advection and convection form a series of **convection cells** within the asthenosphere
 4. - friction between the moving rocks in the asthenosphere and base of lithosphere drags the lithospheric plates along
 - creates tension above areas of upwelling and compression in areas of downwelling
 - speed of plate motion is only a few centimeters a year.
- movement of plates results in three types of relationships between plates:
 1. Divergent - moving apart
 2. Convergent - moving together
 3. Transform - sliding past each other

1. Divergent Boundaries

- located above areas of upwelling where advective motion is in opposite directions away from the area of upwelling
- areas of tension where plates split (**rift**) and move apart
 - as tension increases, two sets of cracks inclined downward from opposite direction toward the area of upwelling form and eventually merge splitting the plate into three parts
- the small central portion slides downward as plates move apart resulting in formation of a long, narrow **rift valley**

Example: Great Rift Valley in Africa; Death Valley,
- base of central portion melts as it sinks because of the concentrated heat in the zone of upwelling
- on a continent, the central area eventually sinks below sea level and floods forming a long, narrow sea
 - Example: Red Sea, Dead Sea (not fully flooded)
- gradually the two section of continent move so far apart that the gap becomes too large for the central section to fill and then molten (basaltic) material from below fills the gap and begins to form oceanic crust (sea floor)
- as gap continues to widen new oceanic crust is added to the central portion of sea floor
-

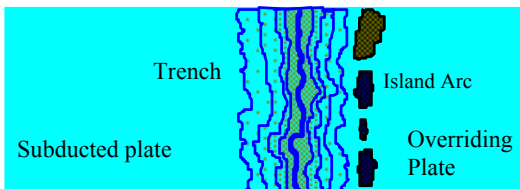




- oceanic section of plates are relatively thin and flexible compared to the continents
- when sea floor between the landmasses becomes very wide, the upwelling in the asthenosphere pushes the central portion upward into a seismically active (earthquake prone), volcanic **oceanic ridge** with a central rift valley
- **Oceanic Ridges**- extend for over 64,000 km around the world as a continuous system of submarine mountain chains
 - height of ridges result from accumulation of lava and bulging upward of the crust above the areas of upwelling
- as the rocks of the asthenosphere reach the continents they have cooled and begin to sink pulling the edge of the continent downward.
 - outer edge of the continent floods and is called the **continental shelf**

- Evidence for Divergence
 - can measure widening of rift valley in places such as Iceland
 - some continents, such as South America and Africa, North America and Africa, Australia and New Zealand appear to fit together
 - oldest parts of seafloor are directly adjacent to the continents and youngest parts are at the spreading ridges
 - sediments are thicker and older near the continents and progressively thinner and younger towards the ridge
 - older fossils are buried deeper and restricted to area near continents

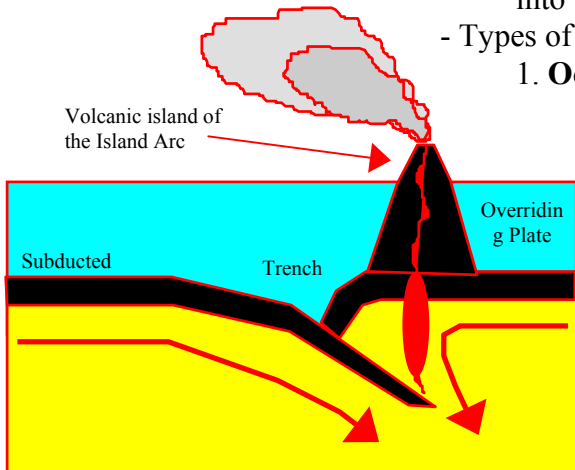
2. Convergent Boundaries



- area of compression where plates move towards each other
- located above areas where cooled rocks in the asthenosphere sink (downwelling)
- results in the formation of a **trench** (deep, elongate depression in the sea floor) and **subduction** (one plate riding over another as that plate sinks into the asthenosphere)
- Types of convergent boundaries:

1. Oceanic -Oceanic Crust Convergence

- results in deep trench
- **Subducted Plate** plunges down into the asthenosphere at about 45 to 60°
- plate begins to crack (generating earthquakes) as it is heated
- plate gradually melts producing magma which flows upward because it is less dense than the surrounding material



- **Over-riding Plate** is pushed upward

- magma from below melts through and produces a series of basaltic volcanic islands forming an **island arc** which parallels the trench

2. Oceanic-Continental Crust Convergence

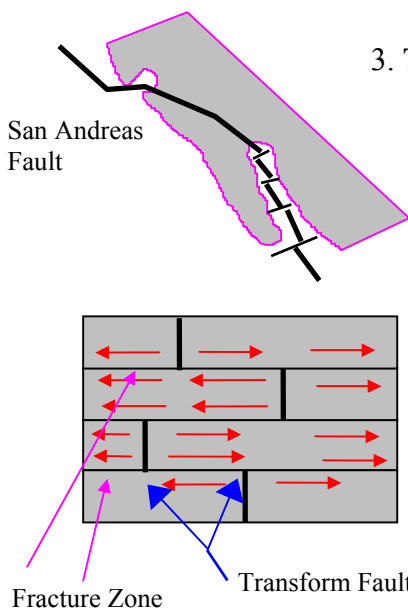
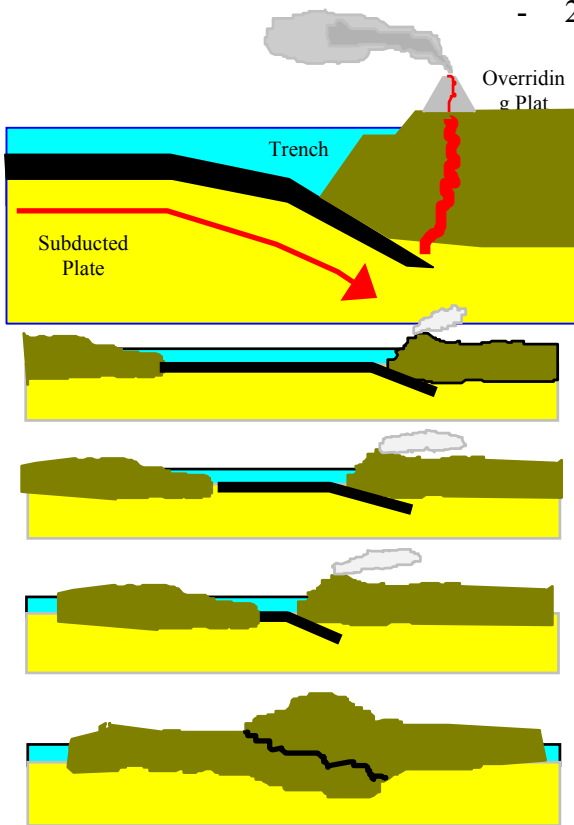
- Oceanic crust plunges into asthenosphere below continent because the oceanic plate is denser and thinner compared to the continental plate
- trench forms, but may fill with sediment eroded from the continent
- subducted plate cracks (earthquakes) and generates magma which melts through the continent and produces a **volcanic mountain chain** of intermediate composition (**andesite**) that parallels the trench on the continent (over-riding plate)
- andesite is produced by the mixing of the basalt and granite

Example: Andes Mountains of South America

3. Continental-Continental Crust Convergence

- one continent is subducted below the other, but does not plunge deep into the asthenosphere, only scrapes below base of the other lithospheric plate
- subjected to intense metamorphism
- over-riding plate is pushed upward into great, non-volcanic or **structural mountain chain**
- subducted plate acts as a buoyant base for the mountain such that as the mountain erode, isostasy keeps pushing it upwards for hundreds of millions of years
- reason why mountains exist for such a long time despite erosion

Example: Appalachians, Himalayas, Alps



3. Transform Boundary

- area of shear where plates slide past each other
- resulting in a **strike-slip** or **transform fault**
- faults may be hundreds of kilometers long
- Example: San Andreas
- earthquakes (large or small) generated each time the plates move
- most transform boundaries are associated with slight off-sets along the oceanic ridges where rocks slide past each other before joining other parts of the sea floor which are moving in the same direction
- transform fault is only located where plates slide past each other.
- **fracture zone** - scars left by the plates grinding past each other that extend beyond the transform fault
- in ocean basins the fracture zones extend from continent to continent but are usually buried under sediments away from the ridge

Evidence for Plate Tectonics

1. - fit of some of the continents
2. - alignment of mountain chains when continents are “reassembled”
3. - similarity of fossils and rock types on opposite sides of the ocean
4. - age of seafloor and sediments and thickness of sediment increase away from the ridge

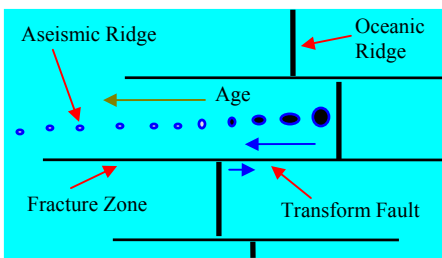
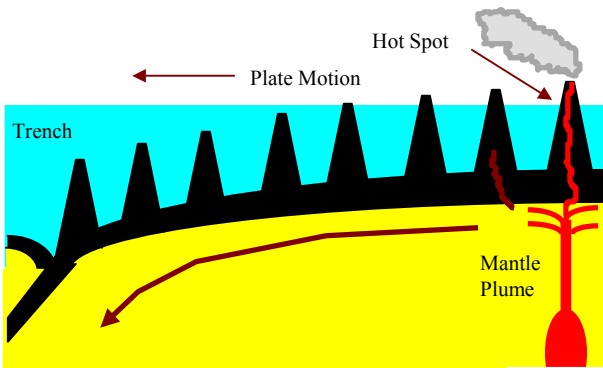
Other aspects of plate tectonics

1. Mantle Plumes and Hot Spots

- **Mantle Plume** - place in the Asthenosphere where a fountain of extra hot rock upwells
- not related to upwelling at the ridges, because has no great lateral extent and occurs in center of plate, not at edge
 - melts through plate and forms volcano
 - about 100 known

- **Hot Spot** - place on Earth’s surface directly above plume, usually marked by a periodically active volcano

- Over time the volcanic cone is carried away on the moving lithospheric plate
- when far enough away from source of magma, volcanoes cease to erupt because the magma cools and solidifies before it reaches the surface
- a new volcano forms at the hot spot
- over time a chain of volcanoes trail off from the hot spot toward a trench will form
 - oldest volcano near the trench and youngest at the hot spot
 - Example: Hawaiian Islands and Emperor Seamounts
- as volcanoes move towards the trench they submerge because of the slope of the sea floor and isostatic adjustment from the weight of the volcano
- changes in the linear trend of the volcanoes indicate past changes in direction of plate motion



2. Nemathat, Thread Ridge or Aseismic Ridge

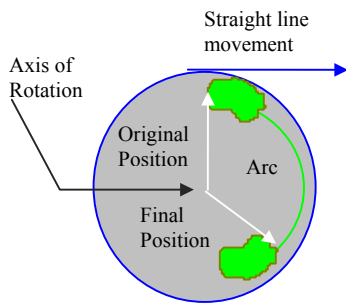
- chain of volcanoes aligned nearly perpendicular to an oceanic ridge and parallel to plate motion
- originates where there is a periodic, excess out-pouring of lava at a ridge
- youngest volcano in series is closest to ridge and oldest is farthest away
- changes in the linear trend of the volcanoes indicate past changes in direction of plate motion

Determining Direction of Plate Motion

- plates move:
 - away from rift valleys and the center of oceanic ridges
 - towards trenches

- parallel to transform faults
- parallel to the most recent series of volcanoes produced at a hot spot or a neomathat

3. Spreading Poles

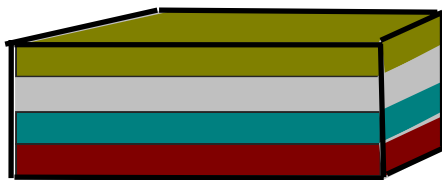


- it is impossible for objects moving across a spherical surface to travel in a straight line because that would require the object to leave the surface of the sphere
- Plates moving across a sphere inscribe an **arc**, a curved line that is part of a **great circle**
- the center of the circle of which the arc is part is called the **spreading pole** or **spreading axis** or **axis of rotation** for that plate and is a point on the Earth's surface about which the plate is rotating.
- every plate has its own spreading pole and the location of the spreading pole changes as the direction of plate motion changes.

Isostasy - maintenance of hydrostatic equilibrium in the crust

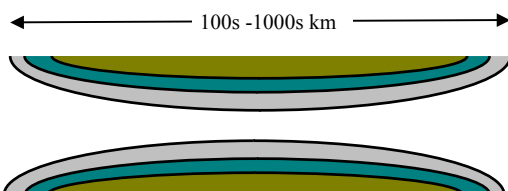
- if add weight on crust, crust responds by sinking; when removed crust rises
- imbalance can be caused by deposition of thick mass of sediment, buildup of a volcanic cone, accumulation of ice to form a glacier or even accumulation of water behind a large dam
- rising of the crust after weight removed is **isostatic rebound**

DIASTROPHISM



Horizontal Strata

- general term referring to the deformation of the Earth's crust caused by forces within the Earth
- implies that the material is deformed in the solid state, but movement of molten material may cause deformation
- most sedimentary layers when deposited are horizontal
- three major types of deformation:
 - Broad warping** - folding across a very large area
 - Folding** - tighter bending of strata
 - Faulting** - breaking and movement of the material along the break

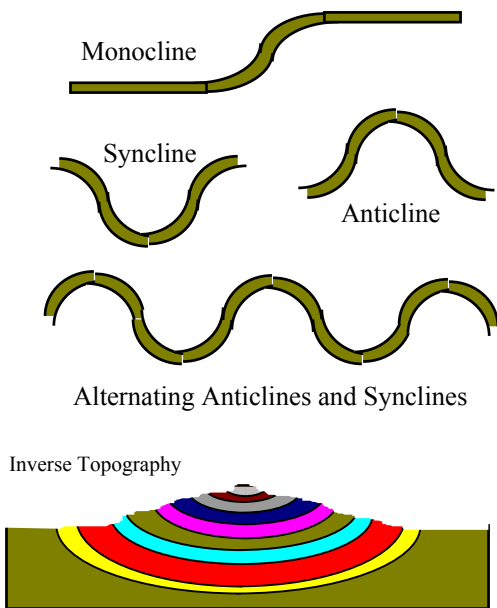


Broad Warping

- gentle deformation over a large area (100 to 1000s kilometers)
- can result in uplift or depression
- causes variable: isostasy, compression, large intrusions
- usually not easy to recognize because over such broad area, unless at sea coast and area either floods or emerges
- Example: Transcontinental Arch

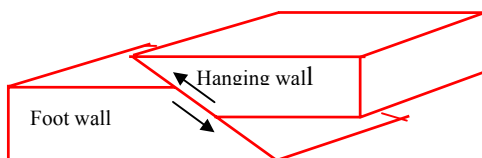
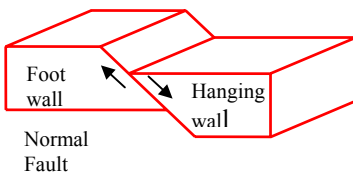
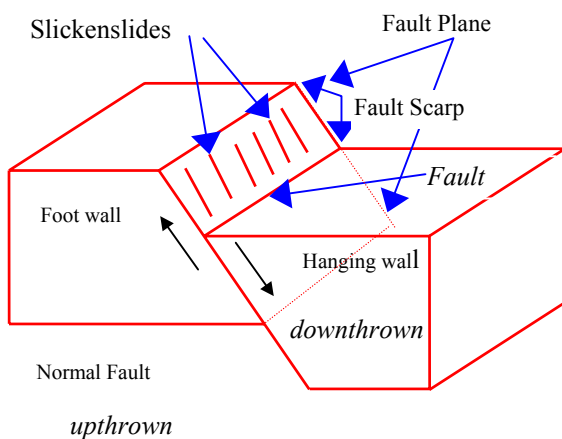
Folding

- deforming rock layers by bending them at a much smaller scale than broad warping



- mainly occurs underground where **lithostatic pressure** and heat make rocks more malleable
- **lithostatic pressure** - confining pressure of the rock being completely surrounded on all sides by other rocks
- scale highly variable from microscopic to mountains
- causes include compression or injection of magma or other materials
- types of folding:
 - **Monocline** - inclined beds connecting two horizontal areas at different elevations
 - **Anticline** - up-fold
 - **Syncline** - down-fold
- frequently occur in groups such that between two anticlines, a syncline is formed and same for two synclines producing an anticline
- if folding is near enough to surface can produce uplift or depression and a series of parallel ridges and valleys
- **Inverse topography** - if core of anticline weak it can erode to form a valley and if core of syncline is resistant, it can form a ridge

Faulting



Reverse Fault

- breaking of rock associated with subsequent vertical and/or horizontal movement
- can result from tension, compression or shearing
- generally occurs along zones of weakness in the crust (**Fault Zone**) and can continue periodically for millions of years
- movement can cause small to large earthquakes
- Parts of a fault:
 1. **Fault Plane** - surface of breakage across which rocks have moved
 2. **Fault** - where fault plane intersects surface, represented on maps by a line
 3. **Fault Scarp** - exposed portion of the fault plane in a fault associated with vertical movement
 4. **Foot Wall** - side below the fault plane
 5. **Hanging Wall** - side above fault plane
 6. **Relative motion** - usually not possible to tell which side of fault actually moved, so use relative terms:
 - a. **Up Thrown** - side that is higher after faulting
 - b. **Down Thrown** - side that is lower after faulting
 7. **Slickenslides** - scratches and grooves on the fault plane that indicate relative fault motion
- Types of faults:
 - Normal Fault** - results from tension
 - foot wall up thrown; hanging wall down thrown
- scarp usually prominent

Reverse Fault - results from compression

- foot wall down thrown; hanging wall up thrown

Strike-slip Fault

- movement horizontal with blocks sliding past each other
- causes offset of surface features where they cross the fault

Vertical Fault

- fault plane is vertical
- no hanging wall or foot wall

Translational Fault

- combines both vertical and horizontal motion

Special Types of Faults

Thrust faults - type of reverse fault in which the angle of the fault plane with the horizontal is very low resulting in great horizontal displacement with a small vertical displacement

- common in mountain building

Fault-block Mountains - block of rock severely faulted on one side with great vertical uplift, but other side broadly folds

- faulted side either normal fault or vertical fault

Horst - block of rock bounded on opposite sides by diverging downward normal faults and is the up thrown block for each

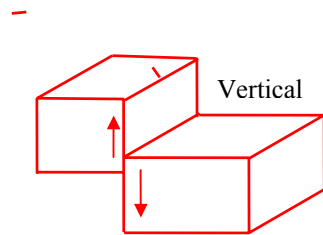
- block is uplifted as ridge

- **Graben** - block of rock bounded on opposite sides by converging downward normal faults and is the down thrown block for each

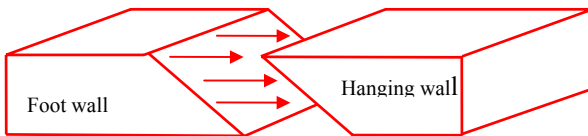
- rift valleys are grabens

Rotational Fault

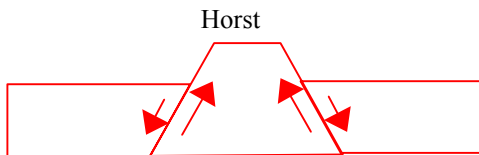
- movement along fault is rotation, pivoting about a point
- on one side of the pivotal point the fault is normal and on the other reverse
- Fault may also die-out at the pivot point and be only a normal or reverse fault that increases in displacement away from the pivot point



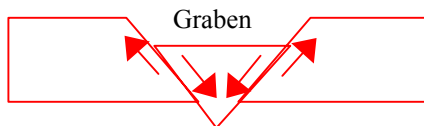
Transform Fault



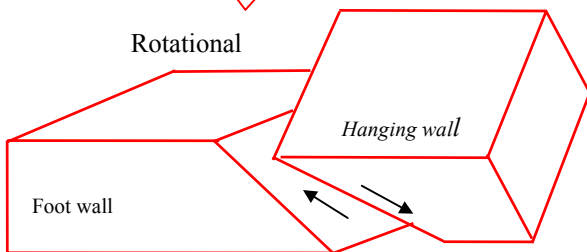
Translation Fault



Horst



Graben

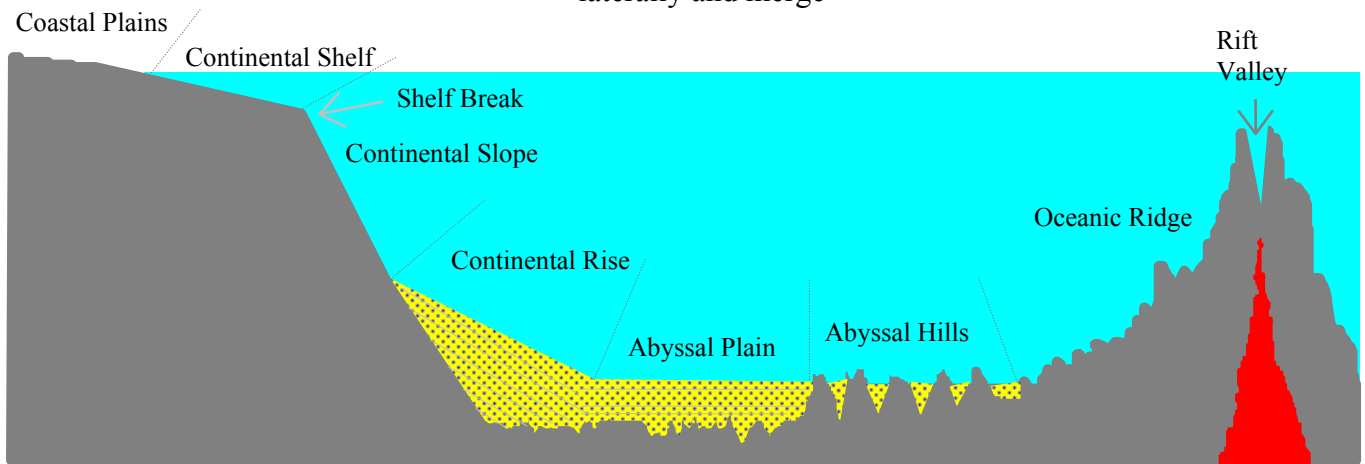


Rotational

Cross section of the Ocean Basin

- **Coastal Plains** - gently sloping area of land down to the sea shore
- **Continental Shelf** - submerged part of the coastal planes from the sea shore to a depth of 200 meters at the **shelf break**
- outer edge of the continent being pulled down by the subsidence of the cooling rocks within the asthenosphere

- surface of shelf is generally gently rolling to flat, but may be cut by deep **submarine canyons**
 - deep valleys eroded when sea level was lower and enlarged by **turbidity currents**- mobile masses of sediment-laden water that periodically flow cross the shelf, down the slope and onto the sea floor
- **Continental Slope** - gentle inclination of only a few degrees from the shelf break down to the sea floor
 - lower part is usually buried by thick deposits of sediments
 - in the Atlantic Ocean the slope represents the edges of the rift valley
- **Continental Rise** - massive accumulation of sediments that buries the contact between the slope and the oceanic crust
 - most of the sediments found here were transported from the shelf and down the slope as turbidity currents
 - consists of a series of **submarine fans** that eventually expand laterally and merge



- **Abyssal Plains** - extremely flat part of the sea floor formed where sediments have buried all of the volcanic irregularities of the oceanic crust
- **Abyssal Hills** - Where less sediments have been deposited and some of the oceanic crustal volcanic irregularities extend through the sediments
- **Oceanic Ridge** - Highly irregular volcanic mountain chain centered on the rift zone
- **Rift Valley** - depression in the center of the oceanic ridge where rifting occurs

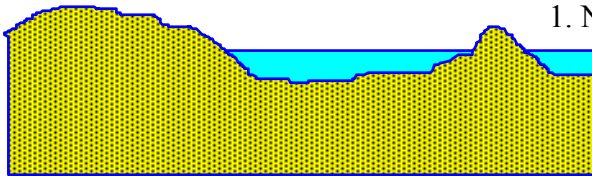
ISLANDS

- Island** - body of land that is smaller than a continent which is surrounded on all sides by water
- in one sense the continents are really just large islands
 - existence of islands is a function of the depth of the sea floor and height of the sea level

- over time as these change islands may appear and vanish either by being submerged or being reconnected to the mainland

- three major types of islands

1. Non-volcanic islands - island not formed by volcanic activity



i. rock islands - island composed of a solid rock core

a. emergent parts of the continental shelf isolated by higher sea level

Example: Baffin Island, Newfoundland, Falkland, Ireland, Britain, New Guinea, Sumatra, Borneo

b. fragments of continents partially separated by past rifting, but still attached to the continent

Example: Greenland

a and b - lowering of sea level just a few tens of meters would reconnect these to the continent

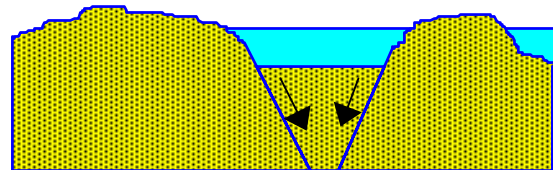
- generally isolated from the continent for only a few thousands to a few tens of thousands of years because of fluctuation in sea level

c. **microcontinents** - fragment of a continent totally separated by rifting and surrounded by deep ocean basin and oceanic crust

Examples: Greater Antilles (Cuba, Hispanola and Puerto Rico), Seychelles, New Zealand, Madagascar

- oceans would have to be drained before these would have a land connection to the continents

- island remains separated for tens to hundreds of millions of years

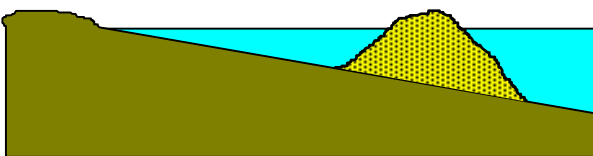


ii. sediment island - island mass made of loose sediment

a. wave-built islands - sediments piled-up by waves, usually in storms

- usually small, a few square kilometers

- most commonly formed in shallow waters of the shelf



2. Volcanic islands - composed of volcanic rock

a. **island arc** - series of islands that parallel a trench

Example: Antilles, Aleutians

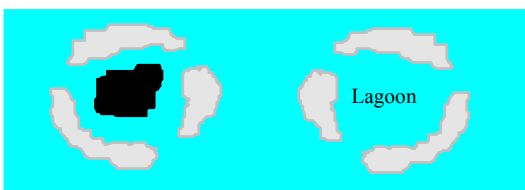
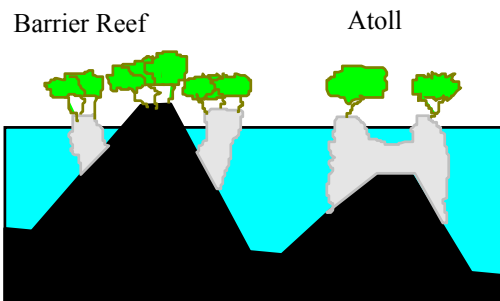
b. oceanic ridge islands - parts of the oceanic ridge that extend above the sea surface

Example: Iceland, Azores, Galapagos

c. **Hot Spots** island chains - series of islands that trend away from a hot spot toward a trench

- arranged perpendicularly to a trench

Example: Hawaiian chain



3. Coral Islands - islands constructed of coral debris usually raised above sea level by wave construction or becomes emergent as sea level is lowered

- in open ocean most are constructed atop extinct volcanoes, but near continents are generally constructed atop elevated submerged areas on the shelf
- only found in warm shallow seas
- includes:
 - a. **barrier reefs** - strings of low coral islands separated from a land area by a shallow lagoon
 - b. **atolls** - circular to irregular chain of low coral islands that surround a shallow lagoon which contains no land area
- generally develop from a barrier reef as the land area erodes away or is submerged

Geolithosphere is composed of rock in the solid, plastic or liquid state

- 3 basic rock types: igneous, sedimentary and metamorphic
- rich in about 90 elements which are usually bound together to form various chemical compounds called minerals
- **Mineral** - naturally occurring, inorganic solid, element or chemical compound with a specific composition and possessing a diagnostic crystalline structure
 - can be represented by a unique chemical formula
 - Example: quartz, gypsum, halite calcite, gold, copper
- **Rocks** - catch-all group for aggregates of two or more minerals and lithified accumulations of sediments, soil or organic material
 - 3 basic rock types:
 1. **Igneous Rocks** - crystalline rocks that form from the cooling of a molten **melt** (**Magma** when underground and **Lava** when at the surface)
 - divided into groups based upon crystal size and composition:
 1. Size of crystals tells about where cooled:
 - large crystals - underground where cools slowly because overlying rocks act as insulation
 - called **Intrusive** or **Plutonic Rocks**
 - form from magmas
 - small crystals - at the surface where heat is lost quickly and lava solidifies too rapidly for large crystals to grow
 - called **Extrusive** or **Volcanic Rocks**
 2. Composition - based upon minerals within the rock
 - **Felsic rocks** - rich in quartz and minerals containing aluminum; poor in iron and magnesium
 - Lighter in colour and lower in density
 - main rocks of continents
 - Example: **Granite, rhyolite, pumice**
 - **Mafic rocks** - rich in iron and magnesium, poor in silica and aluminum
 - dark in colour (black), and higher density

- main rocks of sea floor

Example: **Basalt**

- **Intermediate rocks** - midway in composition and characteristics between felsic and mafic

Example: **Andesite**

2. Sedimentary Rocks

- made of the remains of pre-existing rocks, through the growth of crystals and/or the accumulation of organic debris which have
- original rock destroyed by weathering
 - **physical weathering** - disintegration, breaking into smaller pieces with no change in composition
 - **chemical weathering** - decomposition, chemically altering composition of components of the rock
- rock debris which remains in place becomes regolith and possibly **soil**
- debris which is transported by wind, water or ice is called **Sediments**
- after deposition of sediments, formation of soil or accumulation of organic debris, pressure (**compaction**), water loss and **cementation** (growth of crystals) can **lithify** (turn into rock - **lithification**) material into sedimentary rock
- sedimentary rocks typically occur as layers (**stratification; strata**)
 - generally subdivided into three types based on origin and composition
 - a. **Clastic Rocks** - made mainly of fragments of pre-existing rocks
 - Example: conglomerate, sandstone, siltstone, shale
 - b. **Chemical Rocks** - crystals that grew in place; as in the evaporation of sea water leaving deposits of salt behind or the accumulation of organism-produced debris
 - Example: limestones, peat, some chert, salt, gypsum

3. Metamorphic Rocks

- pre-existing rocks which have been subjected to extreme heat, pressure and/or chemically active solutions which change the **texture** (how the grains are arranged within the rock), composition or structure of the original rock - some develop **foliation** (layering of crystals) or segregation of minerals into colour bands
- rocks divided into **grades** (severity) of **metamorphism** depending upon how much they have been altered
 - **Low Grade** - slight change (low temperature and pressure)
 - **High Grade** - major change (high temperature and pressure)

Example:

Original Rock	Low Grade	High Grade
Limestone	-----Marble-----	Marble
Sandstone	-----Quartzite-----	Quartzite

Shale -----Slate-----Schist
 Granite -----Gneiss

- Frequency of rock types:

- Sedimentary rocks cover about 75% of the continents and sediments cover most of the sea floor
 - only about 2.4 km at thickest and represent 5% of crust in volume
- Igneous - Metamorphic rocks grade one into the other
 - form the bulk of the crust

Rock Cycle - recycling of the various rock types from one to the other

