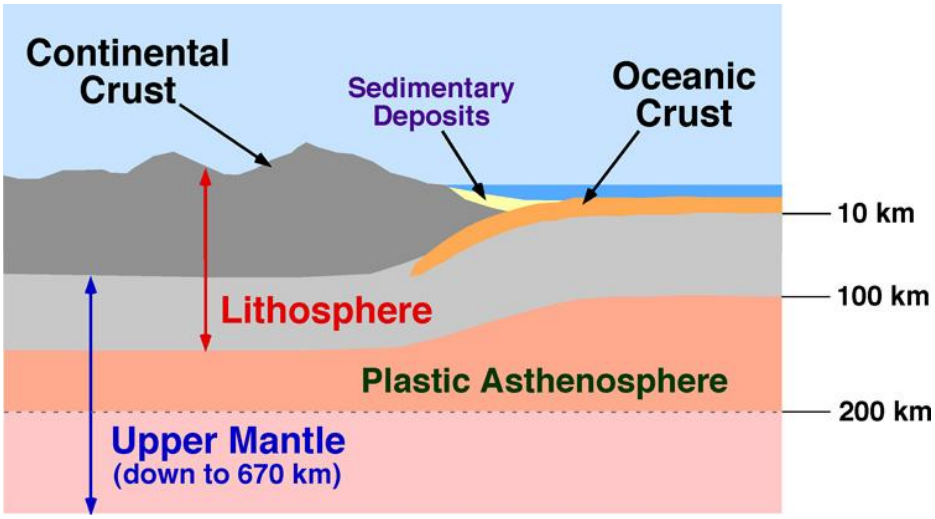
Introduction to Earth Sciences

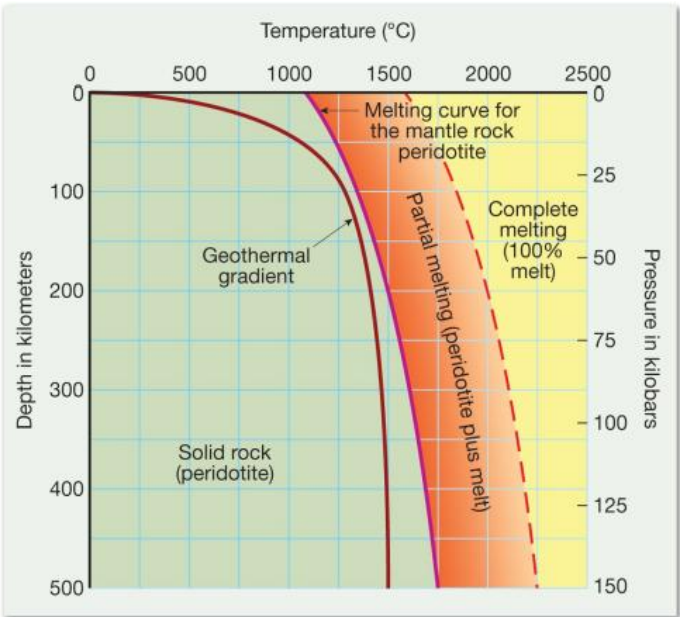
1. Introduction

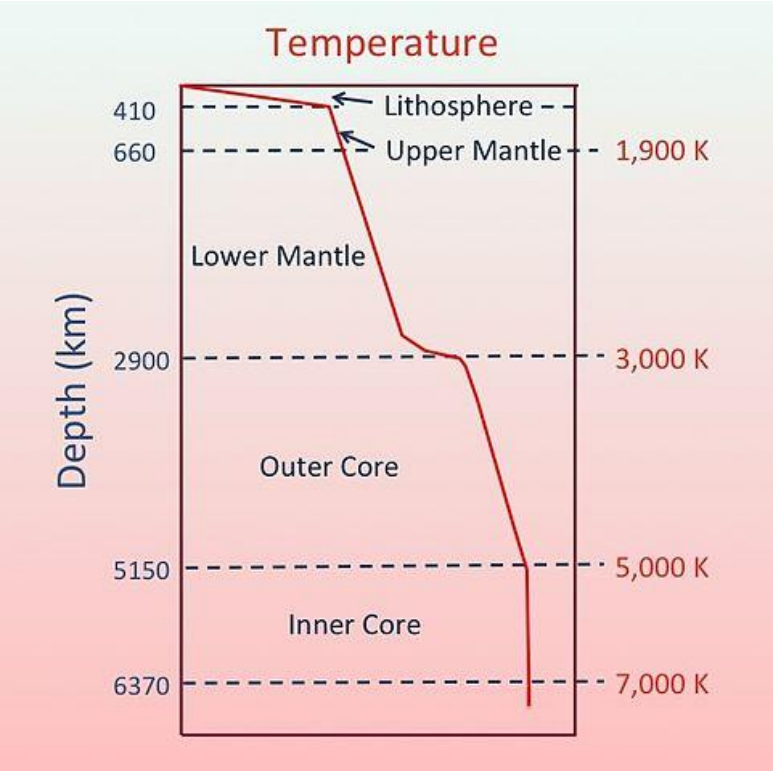
Earth's Composition

- The Mesosphere: From core-mantle boundary to ~350 km depth, a region of high temperature and high strength
- The Asthenosphere: From depth of 350 km to between 100 and 200 km, a region where rocks have little strength and are easily deformed. Compositionally, mesosphere and athenosphere appear to be the same, however their physical properties differ
- The Lithosphere: Above the asthenosphere and encompassing the crust. Made of cool, strong rocks. Note that the lithosphere contains material of different composition – i.e. crust and mantle – but similar/same physical properties



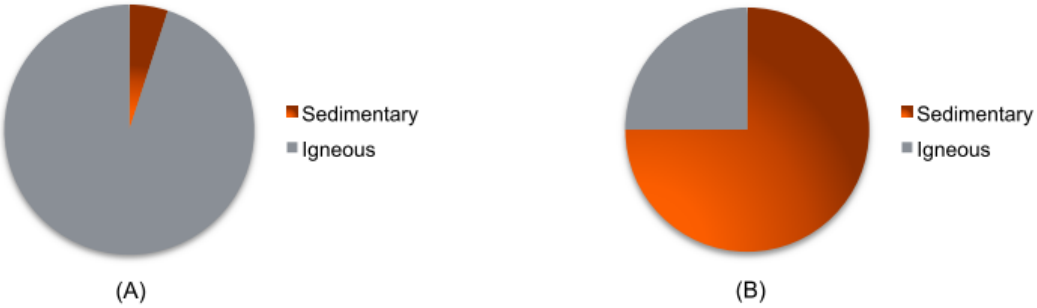
Geothermal Gradient



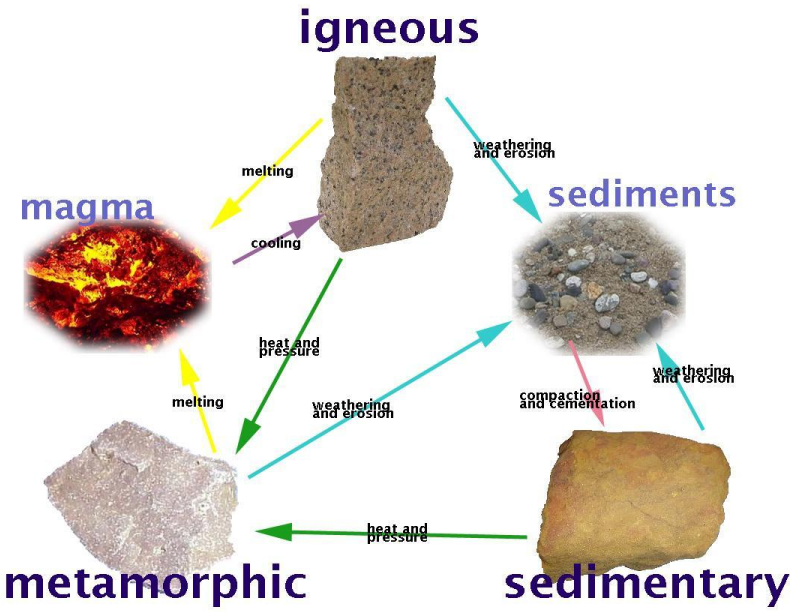


The Rock Cycle

- Igneous: formed by cooling and consolidation of magma
- Sedimentary: formed by (chemical) precipitation or by cementation of sediment
- Metamorphic: formed by metamorphosis of original rock due to temperature and pressure

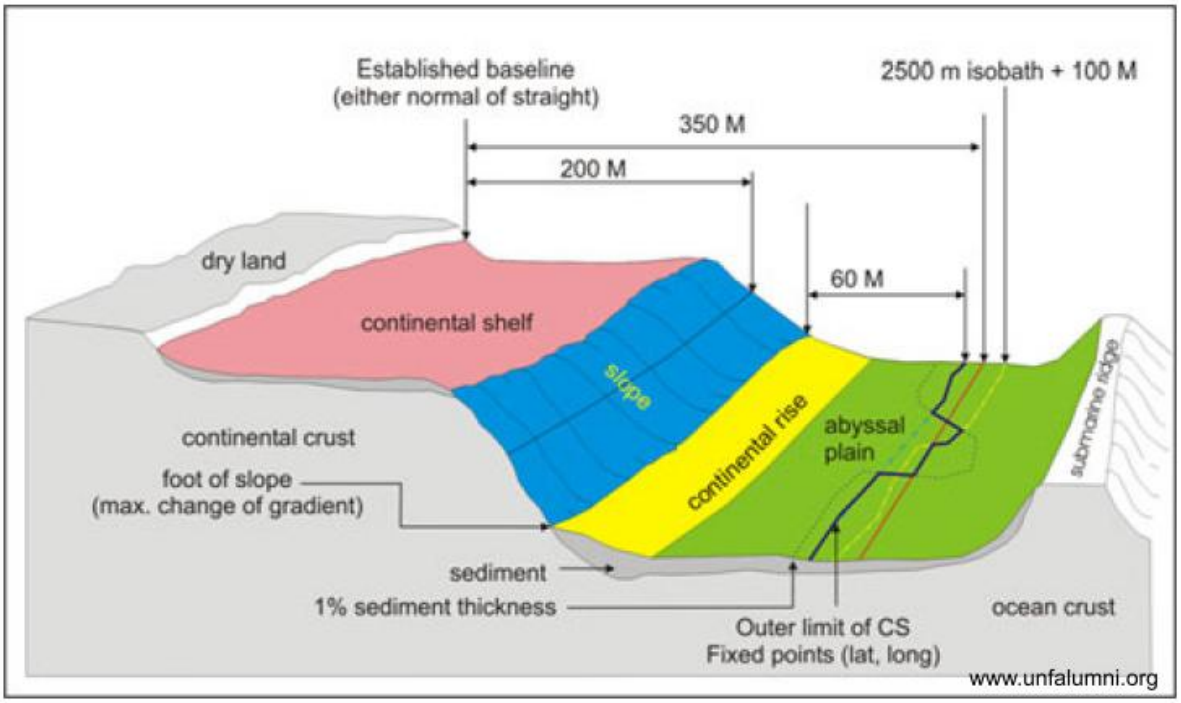


Relative amounts of sedimentary and igneous rock in the crust (A) and on the surface (B) of Earth



Ocean Basins

- Shorelines do not coincide exactly with boundaries between continental and oceanic crust - ocean water spills out onto the continental crust
- Continental shelf: flooded margins of continental crust
- Continental slope: slope beyond the seaward margin of the continental shelf
- Continental rise: at the base of the continental slope where floor of ocean basin meets margin of continent. Covered by erosion debris.
- Abyssal plains: lie adjacent to continental rise, and found at depths of 3 to 6 km below sea level. Form as a result of mud (from rivers entering the ocean) settling through ocean water and forming a 'blanket' over original seafloor topography



2. Time and Geology

Key Concepts

- absolute age: the process of determining an age on a specified time scale in archaeology and geology. Some scientists prefer the terms *chronometric*
- angular unconformity: marked by an angular discontinuity between older and younger strata; suggests that older strata were deformed and truncated by erosion before younger layers were deposited across them
- correlation of strata: determination of equivalence in rock or time-stratigraphic units of the succession of strata found in two or more different areas
- disconformity: an irregular surface of erosion between parallel strata; suggests cessation of sedimentation in addition to erosion but no tilting (i.e., no deformation)
- **formation**: a recognisable unit that can be used for mapping over a large area. Readily distinguishable from other units, thick and easily 'seen'. May consist of rocks of different ages, but same material characteristics
- Geological Time Scale: a system of chronological measurement that relates stratigraphy to time, and is used by geologists, paleontologists, and other Earth scientists to describe the timing and relationships between events that have occurred throughout Earth's history
- hiatus: a discontinuity in the age of strata
- index fossil: a fossil that may be used to identify and date a stratum in which it is found. Ideally will have common occurrence, wide geographic distribution and a narrow age range
- **key bed**: a thin, widespread sedimentary bed with very distinctive characteristics allowing it to be very easily recognised – e.g.ash layers in volcanic regions magnetic field polarity reversal
- magnetic striping: a zebra-like pattern of magnetic variation on the ocean floor, with one stripe with normal polarity and the adjoining stripe with reversed polarity
- magnetic isochron: a common technique of radiometric dating and is applied to date certain events, such as crystallization, metamorphism, shock events, and differentiation of precursor melts
- nonconformity: strata overly igneous or metamorphic rocks
- original horizontality: layers of sediment are originally deposited horizontally under the action of gravity
- polarity reversal time scale: dating method using patters of magnetic striping, particularly useful for igneous and metamorphic rocks
- radiometric dating: a technique used to date materials such as rocks or carbon, usually based on a comparison between the observed abundance of a naturally occurring radioactive isotope and its decay products, using known decay rates
- relative age: determining ordinal age without numbers of years
- rock: a naturally occurring solid aggregate of minerals or mineraloids
- rock-stratigraphic unit: distinctive bodies/layers of rocks that differ from the rocks above and below in the general characteristics
- strata: a layer of sedimentary rock or soil with internally consistent characteristics that distinguish it from other layers
- stratigraphic superposition: in undeformed stratigraphic sequences, the oldest strata will be at the bottom of the sequence. This is important to stratigraphic dating,

which assumes that the law of superposition holds true and that an object cannot be older than the materials of which it is composed

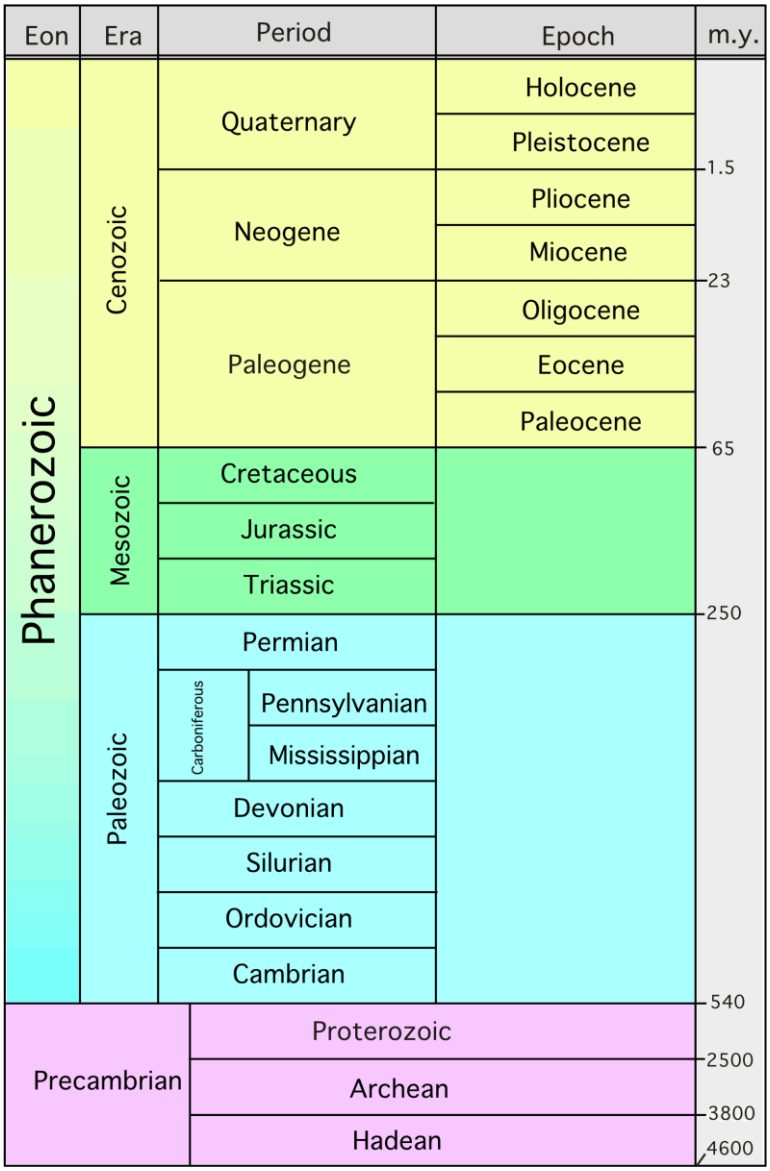
- stratigraphy: a branch of geology which studies rock layers (strata) and layering (stratification). It is primarily used for sedimentary and layered volcanic rocks
- thermo-remanent magnetism: When an igneous rock cools, it acquires a thermoremanent magnetization (TRM) from the Earth's field
- **time-stratigraphic unit**: represents all the rocks formed during a specific interval of geologic time. Rocks may have different compositions, but all same age
- unconformity: a buried erosional or non-depositional surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous

Relative Dating Techniques

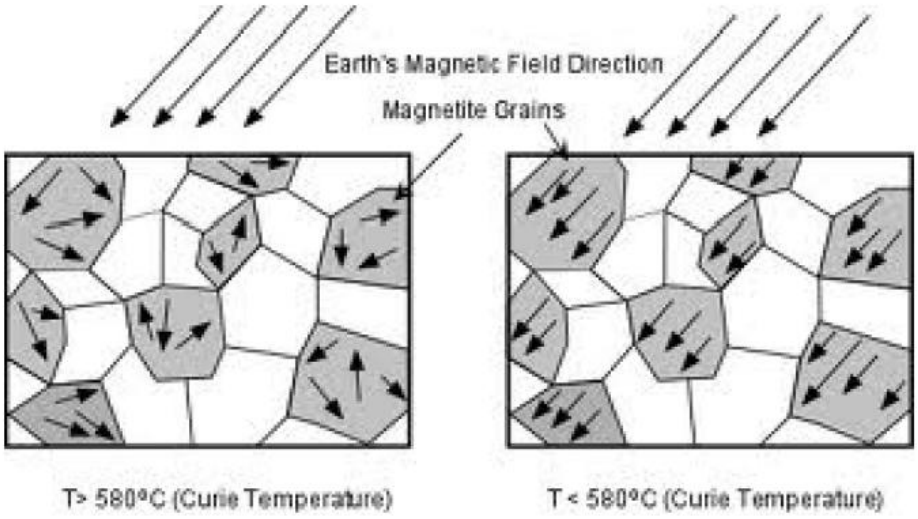
Geologic Time Scale

Four eons
• Phanerozoic ("visible life") – the most recent eon
• Proterozoic – evidence for multicellular organisms
• Archean – contans microscopic life forms
• Hadean – the oldest eon, no rock record on earth as rock cycle has recycled rock from this eon; present on other planets and moons

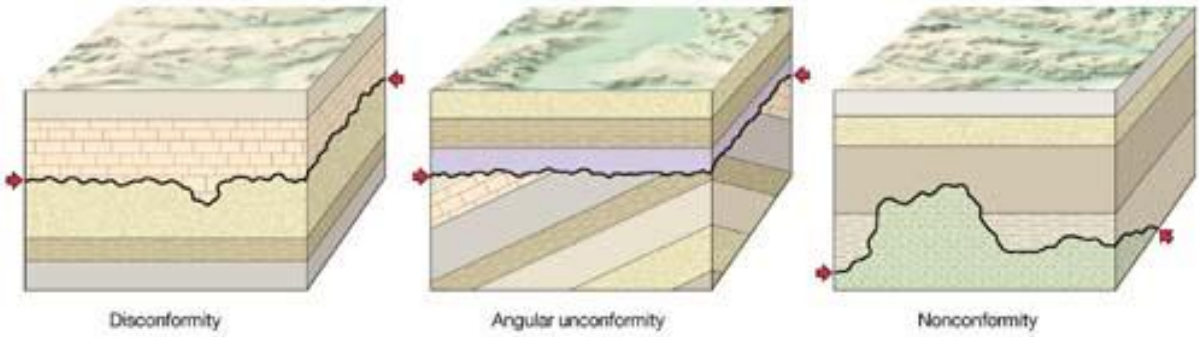
Can old senators demand more political power than junior congressmen?



Magnetic Striping



Unconformities



Radiocarbon Dating

- Based on ^{14}C
- Half-life of only 5730 years
- Carbon-14 produced in upper atmosphere
  - Levels of ^{14}C remain (for dating purposes) constant in the atmosphere
  - Incorporated into carbon dioxide
  - Absorbed by living matter
- Time since death can be determined through drop-off of ^{14}C levels
- Useful tool for anthropologists, archeologists, historians, and geologists who study recent Earth history

3. Minerals

Key Concepts

- **cleavage**: the tendency of a mineral to break along planar surfaces
- crystal: a solid material whose constituents, such as atoms, molecules or ions, are arranged in a highly ordered microscopic structure
- **form**: a set of crystal faces that are related to each other by symmetry
- **habit**: crystal habit is the characteristic external shape of an individual crystal or groups of crystals
- hardness: resistance of a mineral to scratching
- lustre: the intensity and quality of light reflected from a mineral (metallic, vitreous, resinous, pearly, greasy)
- mineral: A naturally formed, inorganic, solid chemical having a specific (constant) composition and a characteristic crystal structure
- mineraloids: Have some (but not all) of the characteristics of minerals
- mineral group: a series of minerals displaying extensive substitution
- Moh's hardness scale: qualitative ordinal scale that characterizes the scratch resistance of various minerals through the ability of a harder material to scratch a softer material
- petrology: the branch of geology that studies the origin, composition, distribution and structure of rocks

- polymorphs: compounds that occur in more than one crystal structure. e.g. diamond and graphite (both C), calcite and aragonite (both CaCO3)
- specific gravity: ratio of the mass of a substance to the mass of an equal volume of pure water
- streak: prepared by rubbing the specimen on a non-glazed porcelain plate. More reliable than colour - both sapphire and ruby are Corundum
- **texture**: overall appearance of a rock due to size, shape and arrangement of constituent mineral grains e.g. platy

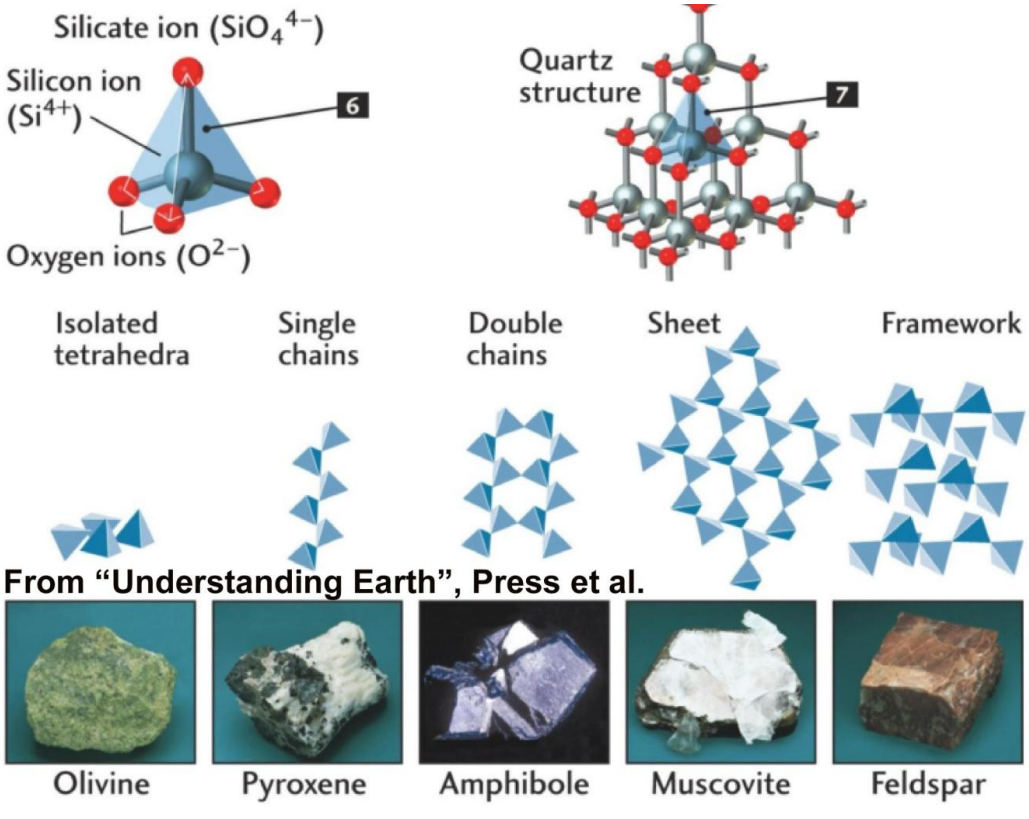
Mineral Classes

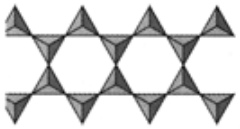
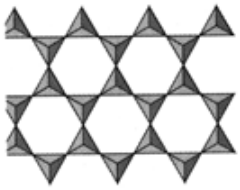
- sulfate mineral
- sulfide mineral
- oxide mineral
- halide mineral
- hydroxide mineral
- ferromagnesian mineral
- carbonate mineral
- phosphate mineral
- native element mineral

Ionic Substitution

- Substitution requires same charge and similar atomic radius so as to avoid disrupting lattice and maintain bonding
- Fe2+ may substitute for Mg2+ in magnesium-bearing minerals, and vice versa
- Alkali Feldspars: $KAlSi_3O_8$ (orthoclase) and $NaAlSi_3O_8$, (albite) K+1 can substitute for Na+1

Silicate Minerals

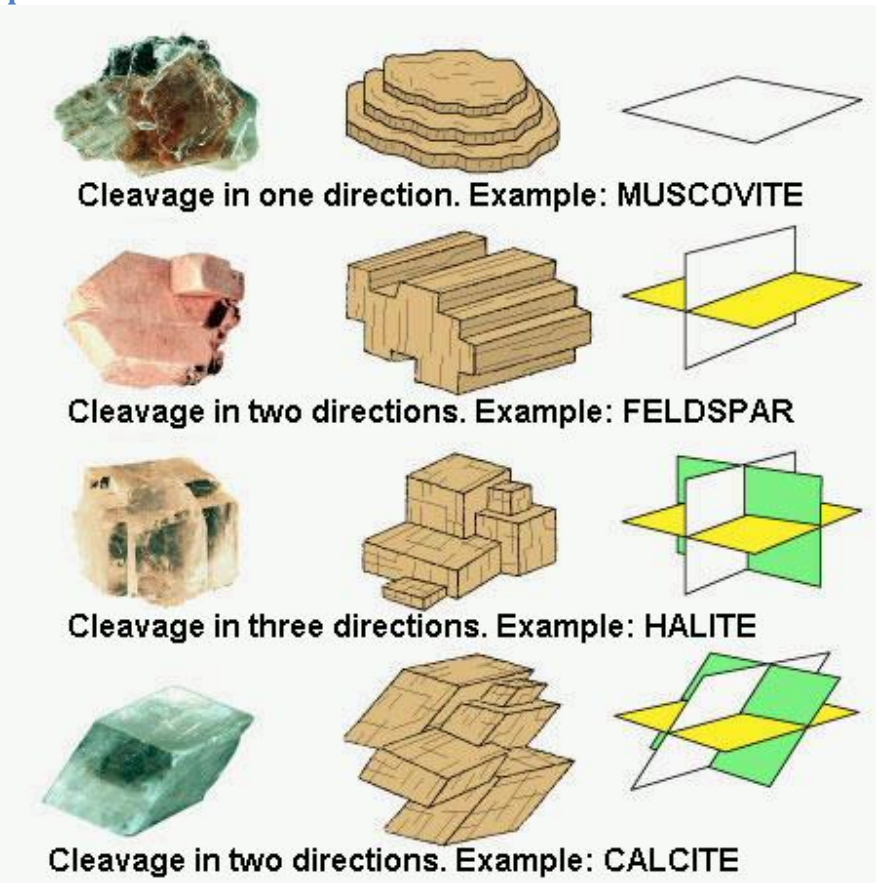


GEOMETRY OF LINKAGE OF SiO_4 TETRAHEDRA		EXAMPLE MINERAL	CHEMICAL COMPOSITION
Isolated tetrahedra: No sharing of oxygens between tetrahedra; individual tetrahedra linked to each other by bonding to cation between them		Olivine	Magnesium-iron silicate
Rings of tetrahedra: Joined by shared oxygens in three-, four-, or six-membered rings		Cordierite	Magnesium-iron-aluminum silicate
Single chains: Each tetrahedron linked to two others by shared oxygens; chains bonded by cations		Pyroxene	Magnesium-iron silicate
Double chains: Two parallel chains joined by shared oxygens between every other pair of tetrahedra; the other pairs of tetrahedra bond to cations that lie between the chains		Amphibole	Calcium-magnesium-iron silicate
Sheets: Each tetrahedron linked to three others by shared oxygens; sheets bonded by cations		Kaolinite Mica (muscovite)	Aluminum silicate Potassium-aluminum silicate
Frameworks: Each tetrahedron shares all its oxygens with other SiO_4 tetrahedra (in quartz) or AlO_4 tetrahedra		Feldspar (orthoclase) Quartz	Potassium-aluminum silicate Silicon dioxide

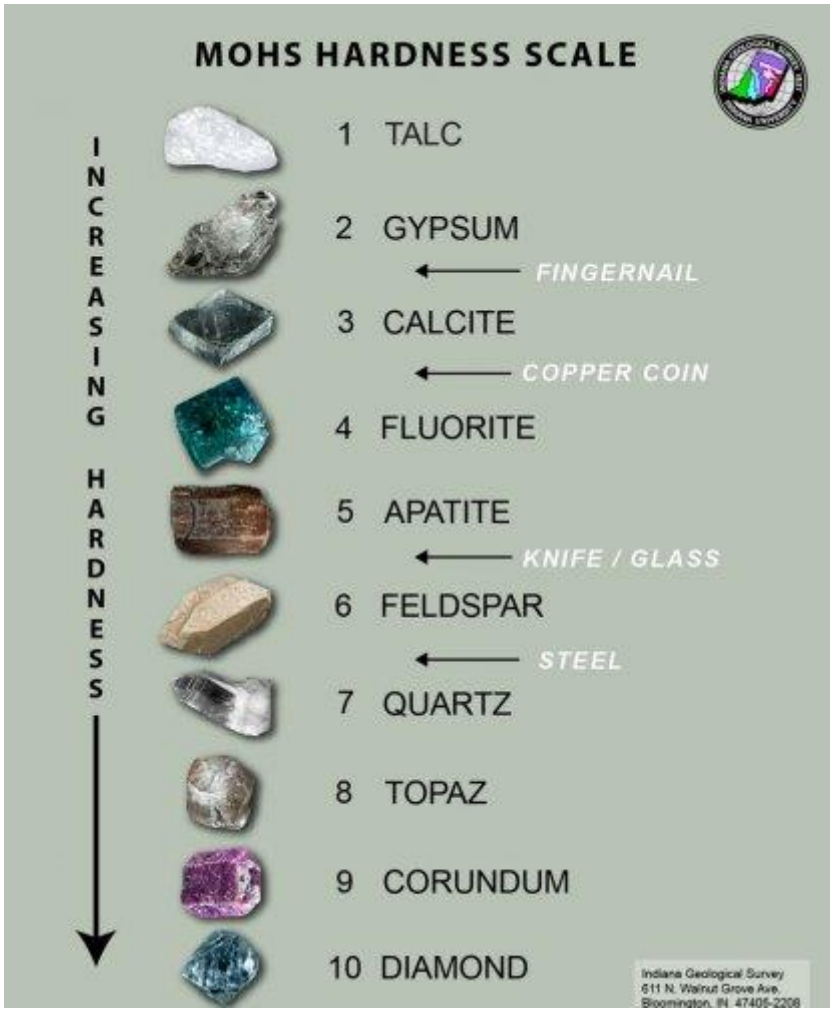
Type of Silicate Structure	Formula	Si:O Ratio
Independent Tetrahedra	SiO_4	0.25
Double Tetrahedra	Si_2O_7	0.29
Ring Silicates	Si_6O_{18}	0.33
Single Chains	SiO_3	0.33
Double Chains	Si_4O_{11}	0.36
Sheet Silicates	Si_2O_5	0.40
Framework Silicates	SiO_2	0.50

Mineral		Idealized Formula	Cleavage	Silicate Structure
Olivine		$(Mg, Fe)_2SiO_4$	None	Single tetrahedron
Pyroxene group (Augite)		$(Mg,Fe)SiO_3$	Two planes at right angles	Single chains
Amphibole group (Hornblende)		$Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains
Micas	Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	One plane	Sheets
	Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$		
Feld-spars	Orthoclase	$KAlSi_3O_8$	Two planes at 90°	Three-dimensional networks
	Plagioclase	$(Ca,Na)AlSi_3O_8$		
Quartz		SiO_2	None	(Expanded view)

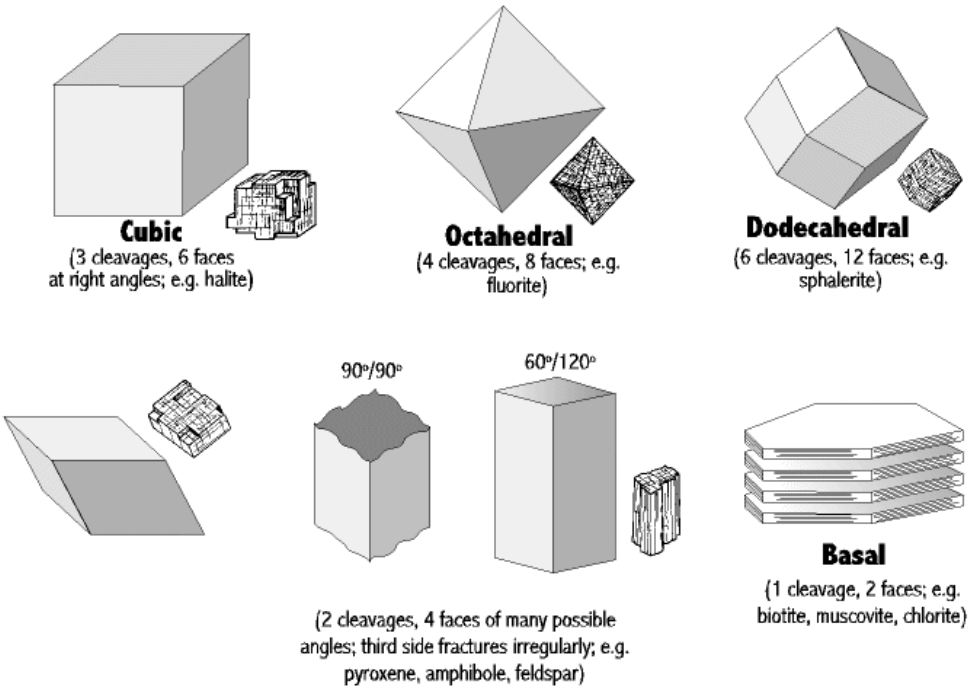
Mineral Properties



Texas Girls Can Flirt And Fight Quite Thoroughly



Mineral Cleavage and Crystal Form



Chemical Formulae for Major Minerals

Mineral Group	Major Minerals	Chemical Formula
Carbonates	Calcite Dolomite	$CaCO_3$ $Ca\ Mg\ (CO_3)_2$
Silicates	Quartz Potassium Feldspar Biotite Pyroxene Amphibole Olivine	SiO_2 $KalSi_3O_8$ $K(MgFe)_3AlSi_3O_{10}\ (OH_2)$ $(Mg, Fe)_2Si_2O_6$ Variable $(Mg, Fe)_2\ SiO_4$
Sulfides	Galena Pyrite Sphalerite	PbS FeS_2 ZnS
Oxides	Hematite Magnetite Corundum	Fe_2O_3 Fe_3O_4 Al_2O_3
Sulfates	Gypsum Anhydrite	$CaSO_4 \cdot H_2O$ $CaSO_4$
Halides	Halite Fluorite	NaCl CaF_2
Native Elements	Silver Gold Graphite/Diamond	S Au Ag

Metal	Mineral	Formula
Gold	Native Gold	Au
Silver	Argentite (in Galena)	Ag_2S
Copper	Malachite	$Cu_2CO_3(OH)_2$
	Azurite	$Cu_3(CO_3)_2(OH)_2$
	Chalcopyrite	$CuFeS_2$
Mercury	Cinnabar	HgS
Iron	Hematite	Fe_2O_3
	Magnetite	Fe_3O_4
	Pyrite	FeS_2
Tin	Cassiterite	SnO_2
Lead	Galena	PbS

Both calcite and aragonite have the formula CaCO3. Calcite and aragonite are polymorphs (i.e., same formula, different mineral structure).

Apatite is the most important phosphate mineral Ca5(PO4)3(F,OH)

4. Igneous Rocks

Key Concepts

- aa lava flow: basaltic lava characterized by a rough or rubbly surface composed of broken lava blocks called clinker
- **agglomerate**: coarse accumulations of large blocks of volcanic material that contain at least 75% bombs
- Andesite Line: line surrounding the Pacific Ocean that separates andesitic volcanoes from those that erupt basaltic magma
- batholith: a large emplacement of igneous intrusive (also called plutonic) rock that forms from cooled magma deep in the Earth's crust. Batholiths are almost always made mostly of felsic or intermediate rock-types
- caldera: a cauldron-like volcanic feature usually formed by the collapse of land, following a volcanic eruption
- cinder cone: build around the vent of rhyolitic and andesitic volcanoes, which tend to eject large quantities of tephra. Tend to be small and sloped at 30 degrees
- **columnar jointing**: a geological structure where sets of intersecting closely spaced fractures, referred to as joints, result in the formation of a regular array of polygonal prisms, or columns
- dyke: a sheet of rock that formed in a fracture in a pre-existing rock body
- extrusion: magma crystallising on the surface
- **fissure eruption**: a linear volcanic vent through which lava erupts, usually without any explosive activity. The vent is often a few meters wide and may be many kilometers long
- flood basalt: the result of a giant volcanic eruption or series of eruptions that coats large stretches of land or the ocean floor with basalt lava
- **fumarole**: an opening in a planet's crust, often in the neighborhood of volcanoes, which emits steam and gases such as carbon dioxide, sulfur dioxide, hydrogen chloride, and hydrogen sulfide
- geyser: a spring characterized by intermittent discharge of water ejected turbulently and accompanied by steam
- **groundmass**: the matrix or groundmass of rock is the finer grained mass of material in which larger grains, crystals or clasts are embedded
- hot spot: volcanic regions thought to be fed by underlying mantle that is anomalously hot compared with the surrounding mantle. They may be on, near to, or far from tectonic plate boundaries. Currently, there are two hypotheses that attempt to explain their origins. One suggests that they are due to hot mantle plumes that rise as thermal diapirs from the core-mantle boundary
- ignimbrite (welded tuff): poorly sorted deposit resulting from a pyroclastic flow
- intrusive/intrusion: magma that crystallises underground
- lava: magma that reaches the earth's surface as a result of magma being less dense than rock
- lava dome: a roughly circular mound-shaped protrusion resulting from the slow extrusion of viscous lava from a volcano
- magma: molten rock + mineral grains + dissolved gases. Forms when temperatures rise sufficiently high in crust or mantle to cause melting
- magmatic differentiation: processes by which magmas undergo bulk chemical change during the partial melting process, cooling, emplacement, or eruption

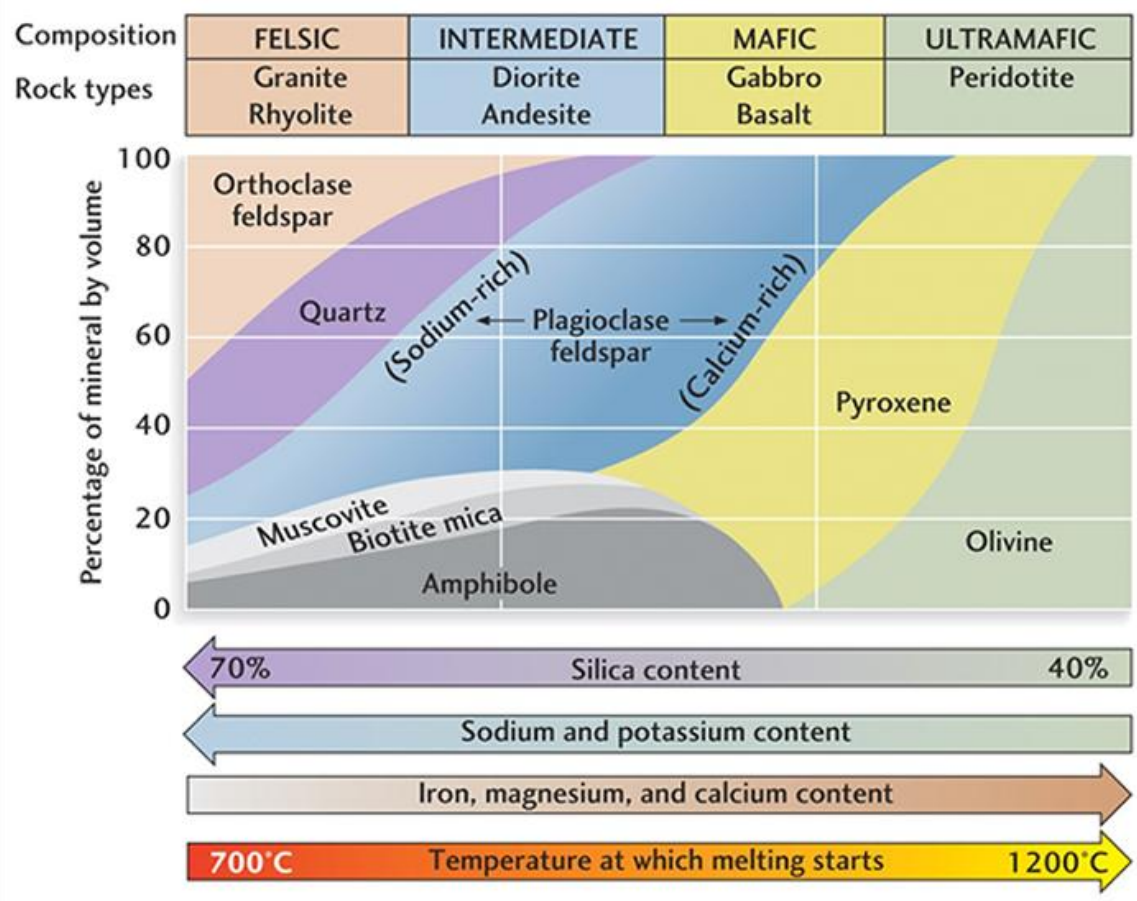
- magmatic segregation: any process by which one or more minerals become locally concentrated (segregated) during the cooling and crystallization of a magma
- pahoehoe lava flow: basaltic lava that has a smooth, billowy, undulating, or ropy surface. These surface features are due to the movement of very fluid lava under a congealing surface crust
- phenocryst: particularly large cystals
- pillow lava: the lava structure typically formed when lava emerges from an underwater volcanic vent or subglacial volcano or a lava flow enters the ocean
- pluton: magma that cools at depth form bodies of rocks called intrusive bodies or plutonic bodies
- **porphyritic**: a mixed texture, often with larger and smaller cystals mixed
- pumice: rock formed by the explosion of rising gas in a rhyolitic magma to form many tiny glass-walled bubbles. Floats on water
- pyroclast: fragment of rock ejected during a volcanic eruption. Form rocks that are intermediate between igneous and sedimentary
- pyroclastic flow: a fast-moving current of hot gas and rock (collectively known as tephra), which reaches speeds moving away from a volcano of up to 700 km/h
- shield volcano: formed from very fluid (normally basaltic) lava. A broad, dome-shaped mountain with an average surface slope of only a few degrees.
- sill: a tabular sheet intrusion that has intruded between older layers of sedimentary rock, beds of volcanic lava or tuff, or even along the direction of foliation in metamorphic rock
- spatter cone: a low, steep-sided hill or mound that consists of welded lava fragments, called *spatter,* which has formed around a lava fountain issuing from a central vent. Typically, spatter cones are about 3–5 meters
- stratovolcano: emit tephra and viscous lava and build up steep conical mounds. Often very large. Possess lava flows that cinders don't, which facilitates consolidation of tephra and reduces its rapid erosion
- **tephra**: any type of airbone pyroclast
- tuff: type of rock made of volcanic ash ejected from a vent during a volcanic eruption. Following ejection and deposition, the ash is compacted into a solid rock in a process called consolidation
- vesicle: trapped bubbles of gas formed when magma crystalises. May be later filled with secondary minerals to form amygdules
- volcanic neck and pipe
- volcano: a rupture on the crust of Earth that allows hot lava, volcanic ash, and gases to escape from a magma chamber below the surface
- welded tuff (ignimbrite)
- xenolith: a rock fragment which becomes enveloped in a larger rock during the latter's development and hardening

Types of Igneous Rocks

- amygdaloidal basalt
- amygdule (amygdale)
- andesite
- basalt
- breccia
- scoria
- diorite

- obsidian
- dolerite (diabase)
- granite
- rhyolite
- pegmatite
- peridotlte

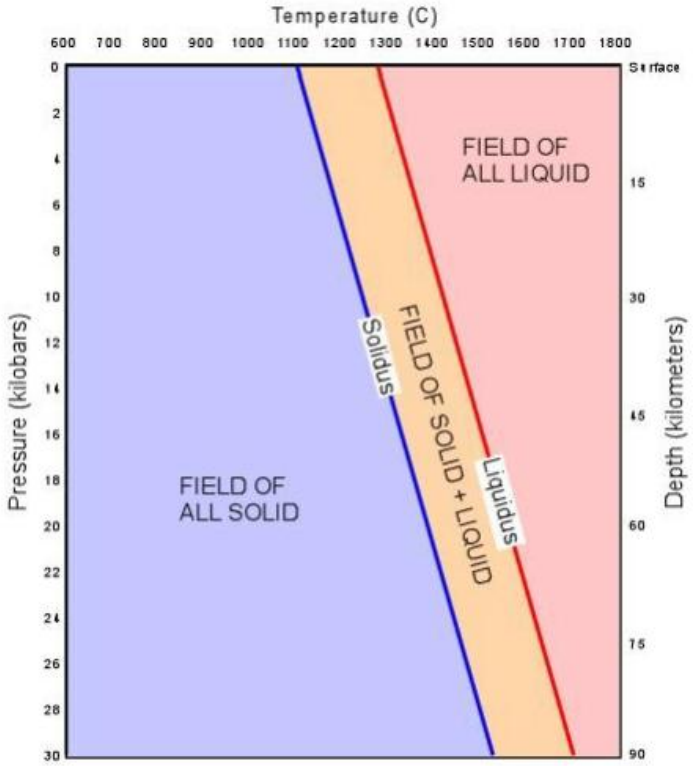
Igneous Rock Classification

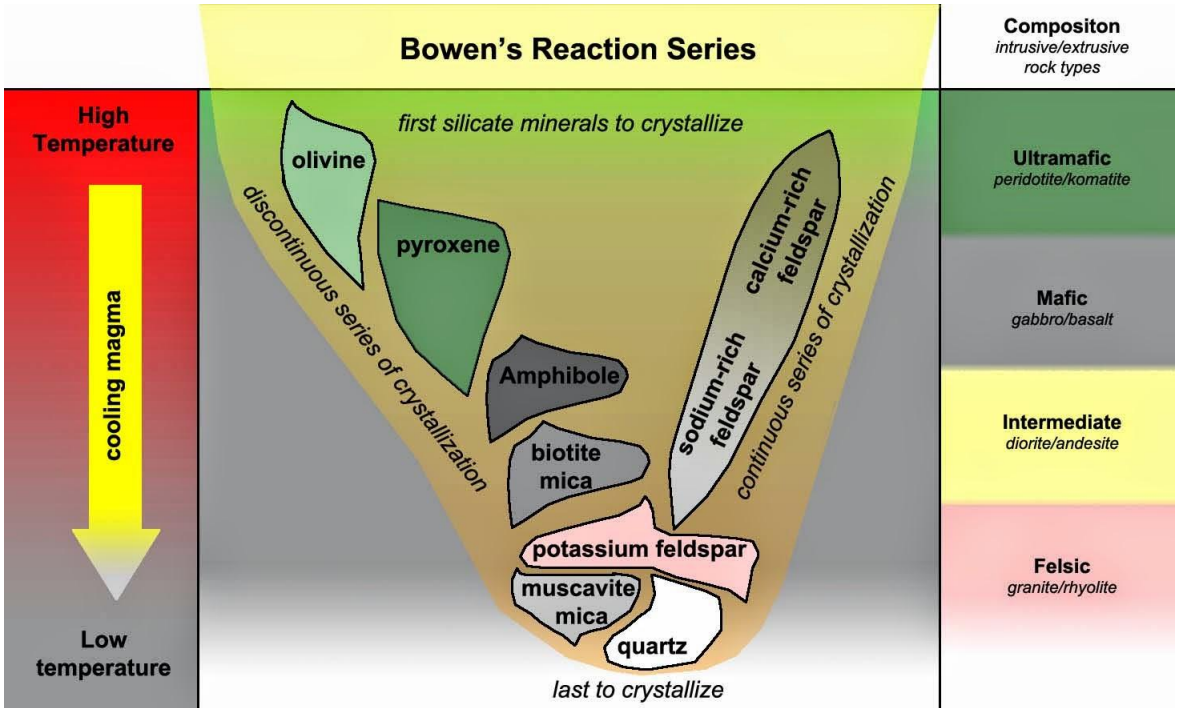


Bowen's Reaction Series

Rock has two melting points: a lower temperature, which marks the onset of melting, and a higher temperature, which marks the conclusion of melting. The lower temperature is called the solidus and the higher temperature is called the liquidus. At temperatures between the liquidus and solidus a mixture of liquid and solid occurs, and the liquid is called a partial melt

A wet mineral will melt at a lower temperature than a dry mineral. The effect of water is enhanced at greater pressures, i.e. temperature of melting decreases even further in the presence of water at great depths.





Origin of Different of Magmas

Basaltic magma

- The minerals found in basalt (olivine, pyroxene, plagioclase) are dry.
- Suggests that basaltic magma is dry (or close to dry), and forms from a dry partial-melting process.

- Basaltic magma forms by dry partial melting of rocks in the upper mantle (specifically, olivine-rich rocks called garnet peridotites).

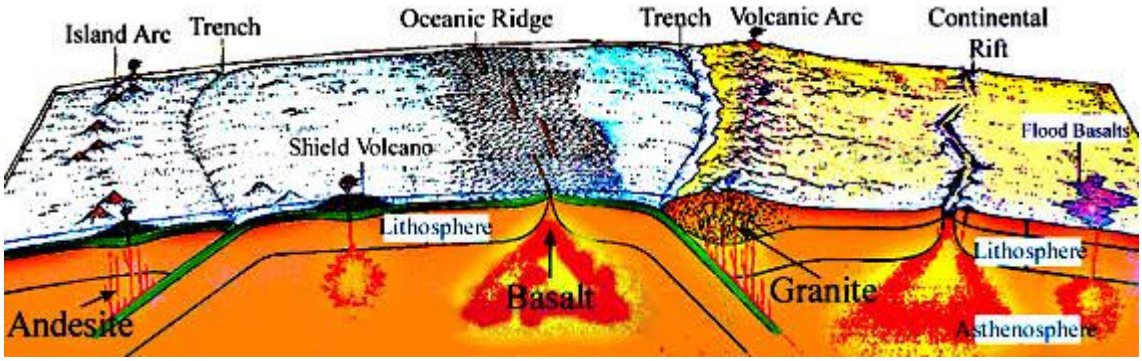
Andesitic magma

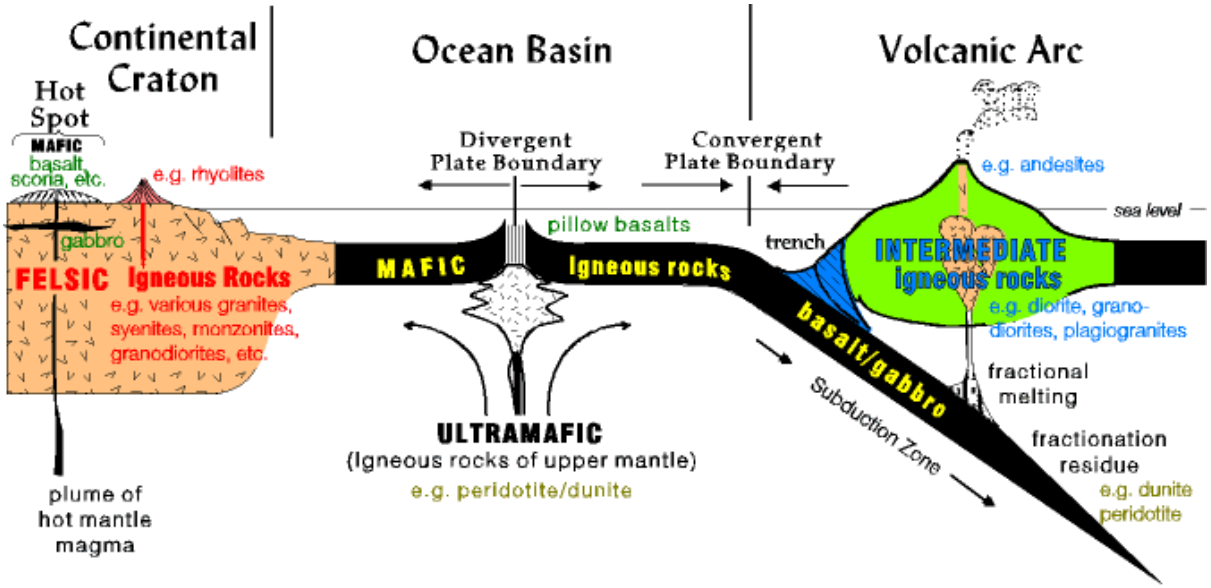
- Partial melting of wet oceanic crust under high pressure yields a magma of andesitic composition
- Consider a moving lithosphere plunging back into the asthenosphere; it carries with it a slab of oceanic crust saturated by seawater.
- The Andesite line corresponds with plate subduction boundaries.

Rhyolitic magma

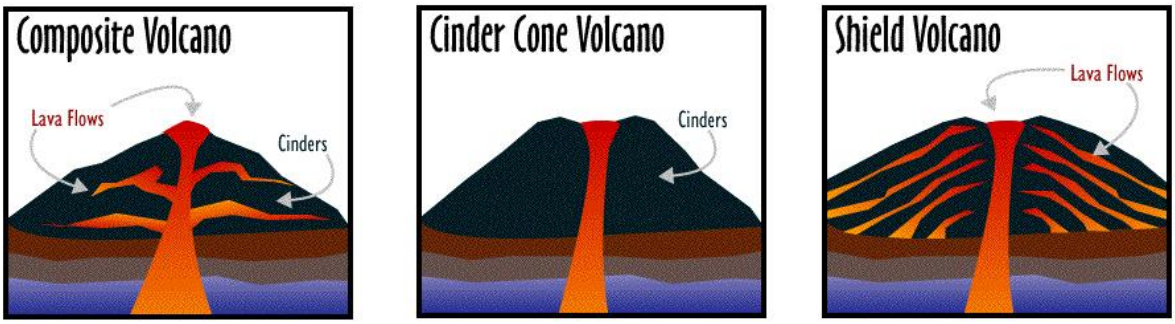
- Origin seems to be wet partial melting of rock with a composition similar to that of the continental crust.
- Because of the melting and viscous properties of rhyolitic magma, most of it solidifies (as intrusive magma) underground to form granitic batholiths rather than making it to the surface as lava.

vii. Describe the various locations where magma is generated, the physical conditions of these settings and the sources of heat involved.





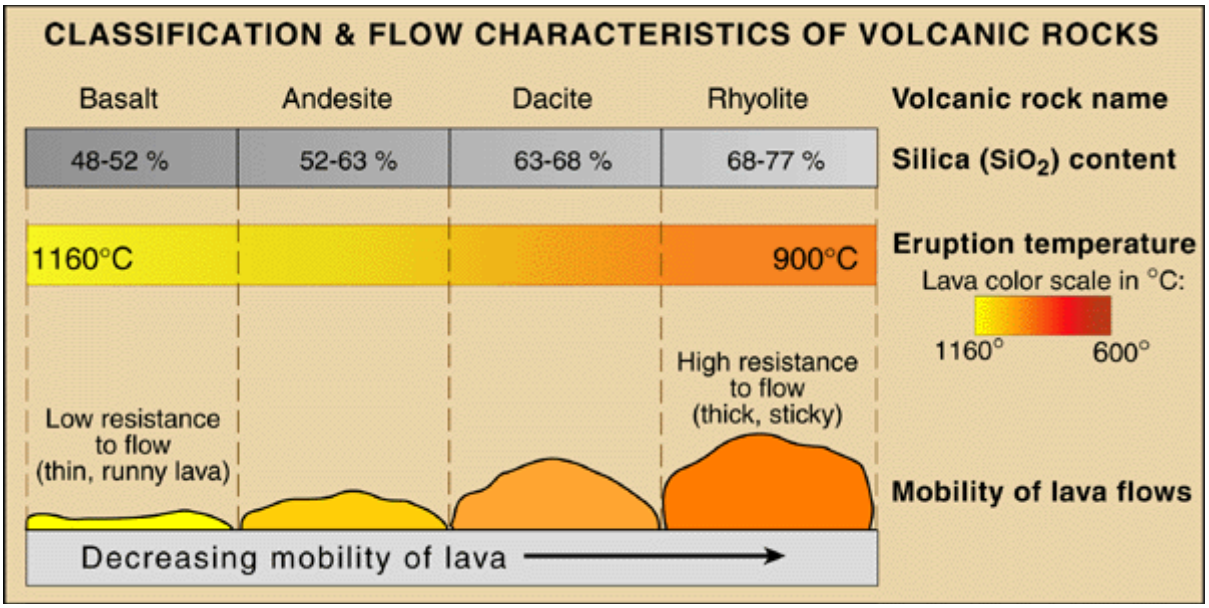
Types of Volcanoes



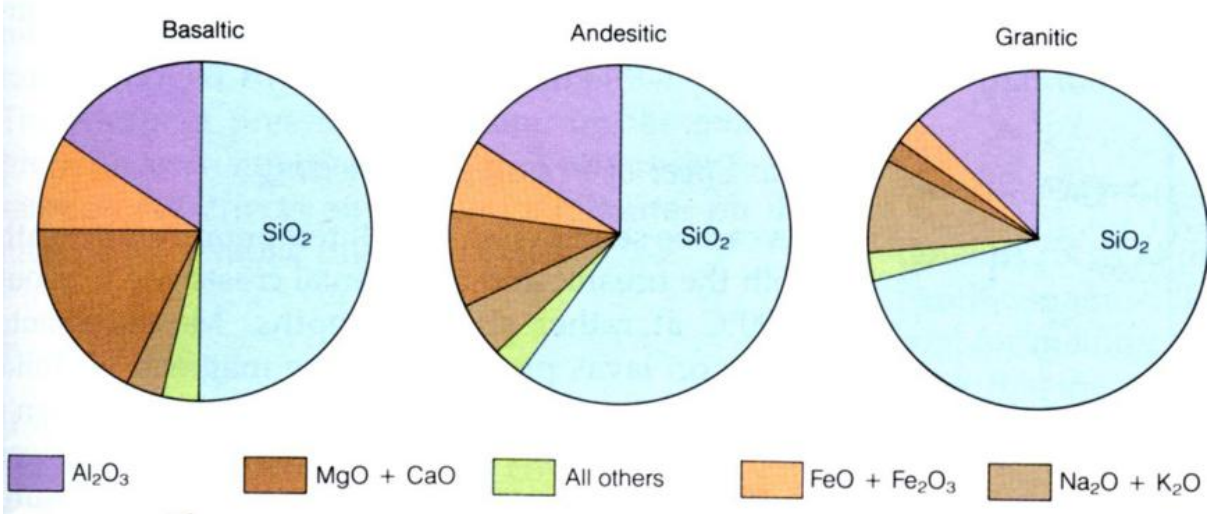
Explosiveness of a volcanic eruption is a function of magma viscosity and gas content

- Explosive: high viscosity, high gas content
- Non-explosive: low viscosity, low gas content

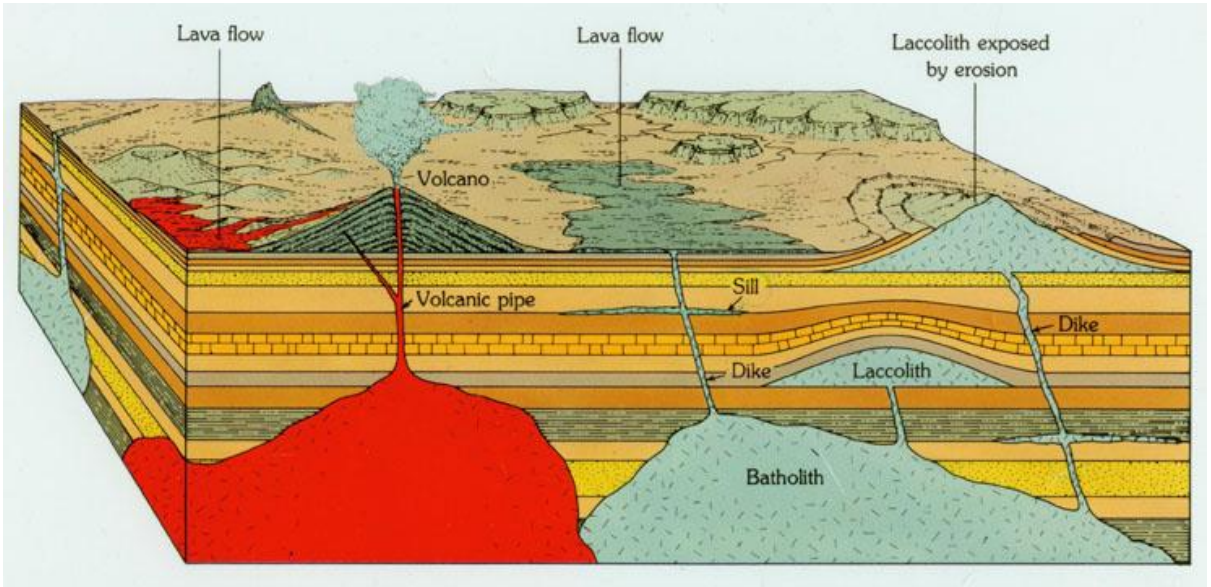
Particle Diameter (mm)	Tephra	Pyroclastic Rock
> 64	Bombs	Agglomerate
2 - 64	Lapilli	Lapilli tuff
< 2	Ash	Ash tuff



Summary Table for Distribution of Volcanoes								
Magma Type	**Volcanic Rock**	**Plutonic Rock**	**Chemical Composition**			**Temperature degrees/ C**	**Viscosity**	**Gas Content Volatile**
			SiO_2 %	Fe, Mg, Ca amount	K, Na amount			
Basaltic or Mafic	Basalt	Gabbro	50	High	Low	1000 – 1200	Low	Low
Andesitic	Andesite	Diorite	60	Intermediate	Intermediate	800 – 1000	Intermediate	Intermediate
Rhyolitic or Felsic	Rhyolite	Granite	70	Low	High	650-800	High	High



Igneous Intrusions



5. Sedimentary Rocks

- alluvium: loose, unconsolidated (not cemented together into a solid rock) soil or sediments, which has been eroded, reshaped by water in some form, and redeposited in a non-marine setting
- bedding: refers to the layered arrangement of strata
- bioclastic sediment: sediment consisting largely of biogenic clasts (broken fossils)
- calcareous ooze: a form of calcium carbonate derived from planktonic organisms that accumulates on the sea floor. This can only occur if the ocean is shallower than the carbonate compensation depth (CCD). Below this depth, calcium carbonate begins to dissolve in the ocean, and only non-calcareous sediments are stable
- carbonate shelf: sedimentary body which possesses topographic relief, and is composed of autochthonous calcareous deposits, such as a reef
- cementation: involves ions carried in groundwater chemically precipitating to form new crystalline material between sedimentary grains
- chemical sediment: formed from the precipiation of minerals from solution, resulting from changes in temperature, evaporation, changed pH, ionic saturation
- clastic sediment: loose, fragmental debris produced by the mechanical breakdown of older rocks
- compaction: part of the process of lithification involving mechanical dewatering of a sediment by progressive loading under several km of geomaterial
- cross bedding: beds that are inclined with respect to a thicker stratum in which they occur
- deep-sea fans: underwater geological structures associated with large-scale sediment deposition and formed by turbidity currents
- **diagenesis**: the change of sediments or existing sedimentary rocks into a different sedimentary rock during and after rock formation (lithification), at temperatures and pressures less than that required for the formation of metamorphic rocks. It is any chemical, physical, or biological change undergone by a sediment after its initial deposition, after its lithification
- evaporite: water-soluble mineral sediment that results from concentration and crystallization by evaporation from an aqueous solution
- fossils: the preserved remains or traces of animals, plants, and other organisms from the remote past
- graded bedding: graded bed is one characterized by a systematic change in grain or clast size from the base of the bed to the top. Most commonly this takes the form of normal grading, with coarser sediments at the base, which grade upward into progressively finer ones. Normally graded beds generally represent depositional environments which decrease in transport energy as time passes, but also form during rapid depositional events
- lithification: the process in which sediments compact under pressure, expel connate fluids, and gradually become solid rock
- mud cracks: sedimentary structures formed as muddy sediment dries and contracts. Crack formation also occurs in clayey soils as a result of a reduction in water content
- offshore sediments: fine-grained sediment reaching the outer continental shelf
- ripple marks: sedimentary structures that indicate agitation by water (current or waves) or wind

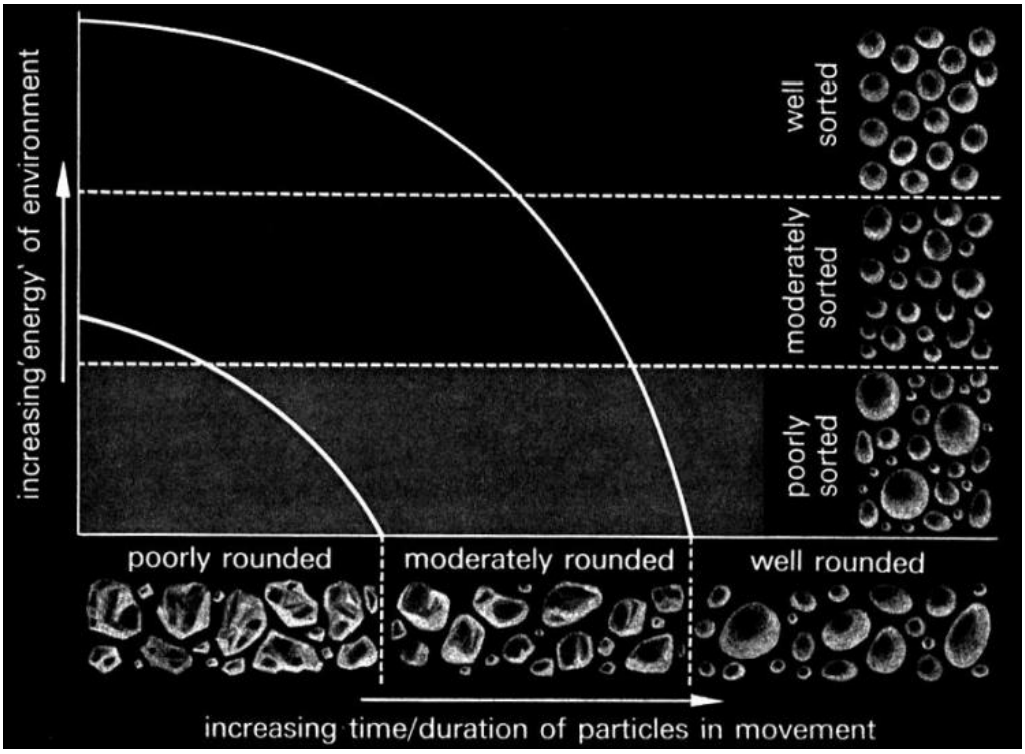
- sediment: naturally occurring eroded material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice, and/or by the force of gravity acting on the particles
- **sedimentary facies**: bodies of sediment recognizably different from adjacent sediment deposited in a different depositional environment. Generally, facies are distinguished by what aspect of the rock or sediment is being studied. Different facies accumulate/d in different depositional environments
- sedimentary rock: types of rock that are formed by the deposition of material at the Earth's surface and within bodies of water. Sedimentation is the collective name for processes that cause mineral and/or organic particles (detritus) to settle and accumulate or minerals to precipitate from a solution
- siliceous ooze: a siliceous pelagic sediment (fine settled particles) that covers large areas of the deep ocean floor. Siliceous oozes consist predominantly of the remains of microscopic sea creatures, mostly those of diatoms and radiolarians.
- sorting: a measure of the range of sediment particle sizes in a given sample. A well-sorted sediment has a small range of particle sizes, while a poorly sorted sediment has a wide range of particle sizes
- stratification: the arrangement of sediment in distinct layers
- **texture**: the relationship between the materials of which a rock is composed. The broadest textural classes are crystalline (in which the components are intergrown and interlocking crystals), fragmental (in which there is an accumulation of fragments by some physical process), aphanitic (in which crystals are not visible to the unaided eye), and glassy (in which the particles are too small to be seen and amorphously arranged)
- **till**/tillite: a non-sorted sediment of glacial origin
- turbidite: the geologic deposit of a turbidity current
- turbidity currents: a current of rapidly moving, sediment-laden water moving down a slope through water, or another fluid. Turbidity currents are an example of density or gravity currents, which include: oceanic fronts, avalanches, lahars, pyroclastic flows and lava flows
- **varve**: an annual layer of sediment or sedimentary rock

Types of Sedimentary Rocks

- sandstone
- siltstone
- shale
- mudstone
- limestone
- coal
- breccia
- conglomerate
- claystone
- coquina
- peat: partial decay product of plants found in water saturated environments
- petroleum: the decay product of organic matter from plankton and bacteria on the ocean floor; often found in marine sedimentary rocks
- coal: diagenic changes to peat over time cause it to form into lignite and then coal

Sediment Sizes

Name of Particle	Diameter Range (mm)	Name of Loose Sediment	Name of Consolidated Rock
Boulder	> 256	Boulder gravel	Boulder conglomerate
Cobble	64 to 256	Cobble gravel	Cobble conglomerate
Pebble	2 to 64	Pebble gravel	Pebble conglomerate
Sand	1/16 to 2	Sand	Sandstone
Silt	1/256 to 1/16	Silt	Siltstone
Clay	< 1/256	Clay	Mudstone and shale



Clastic and Chemical Sediments

Clastic sedimentary rocks: Note that rock texture is a clue as to whether a rock is igneous or sedimentary. Igneous rock has mineral grains interlocked and irregular, while sedimentary rock has fragments commonly rounded or show other signs of weathering and abrasion. Sedimentary rocks also contain cement and possibly fossils

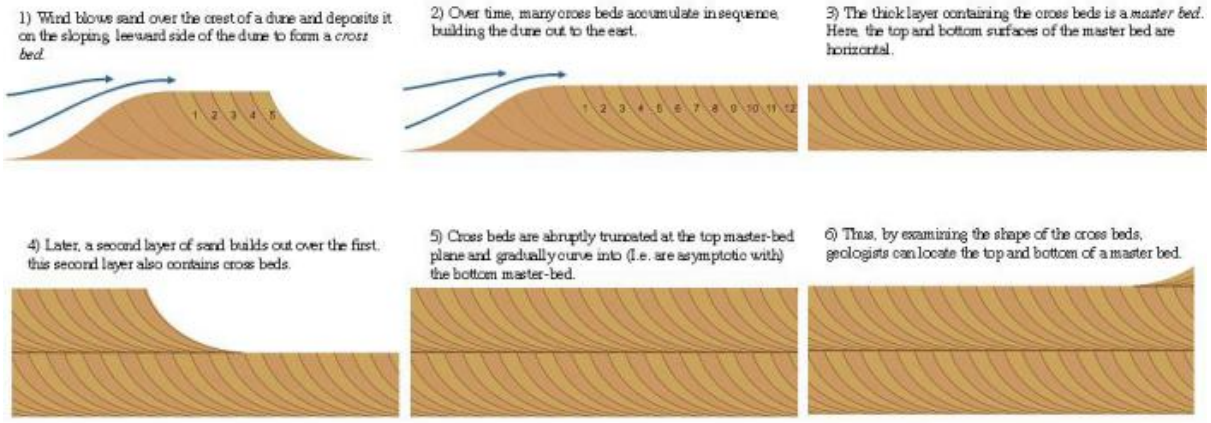
Chemical sedimentary rocks: formed from lithification of chemical precipitates
A single mineral normally predominates

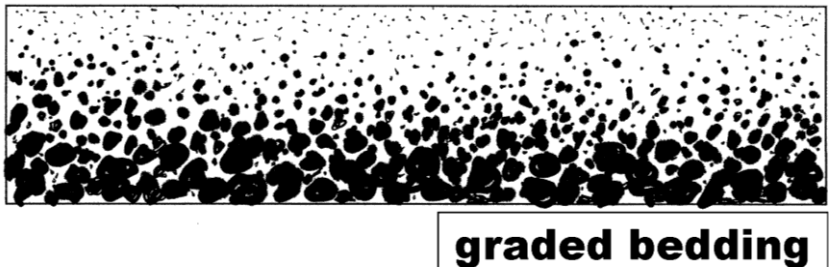
Biogenic sedimentary rocks: results from lithification of biogenic sediment and/or

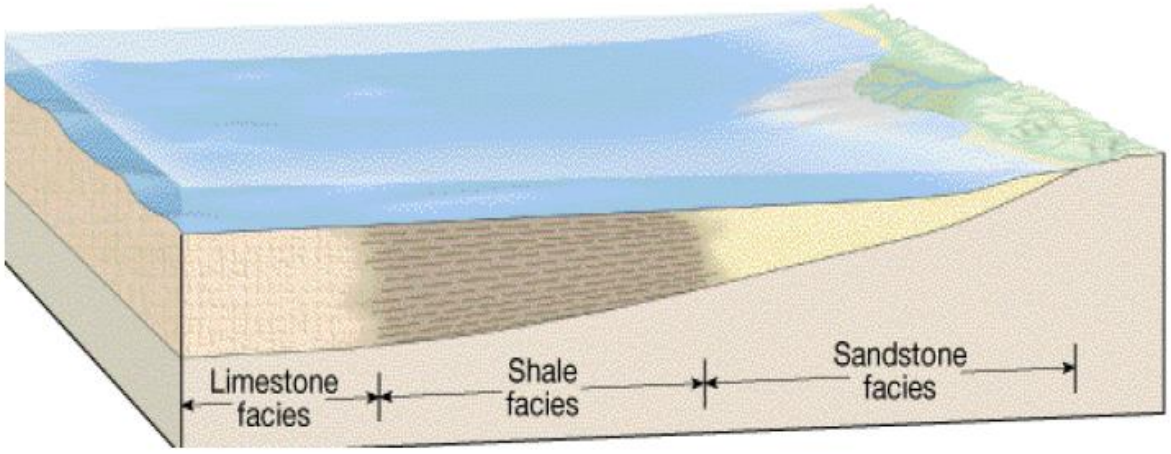
sediment with a high organic component. Limestone accounts for a large proportion of CO2 stored in Earth's crust. Note that both limestone and dolostone may be clastic or chemical in nature. Bioclastic limestones consist of lithified shells and other calcareous matter

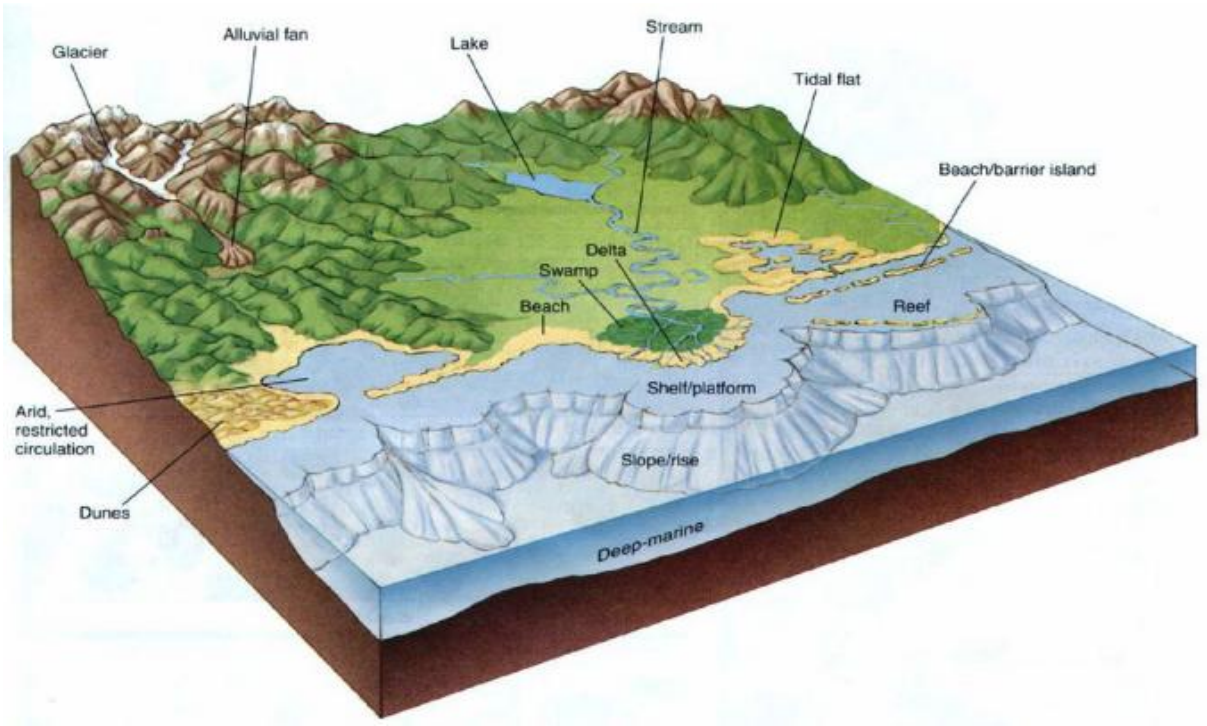
Sedimentary Environments

- High-energy environments such as steep river channels usually deposit coarse arkosic sandstones or conglomerates. Beaches and barrier islands consist of well-rounded quartz sandstone
- Lower-energy environments like lake beds, deltas, lagoons, and the deep ocean can be identified by the finer-grained rocks such as shale and siltstone
- Marine basins with restricted water circulation in warm environments will evaporate, leading to precipitation and formation of marine evaporite deposits
- Limestones usually identify marine reef environments

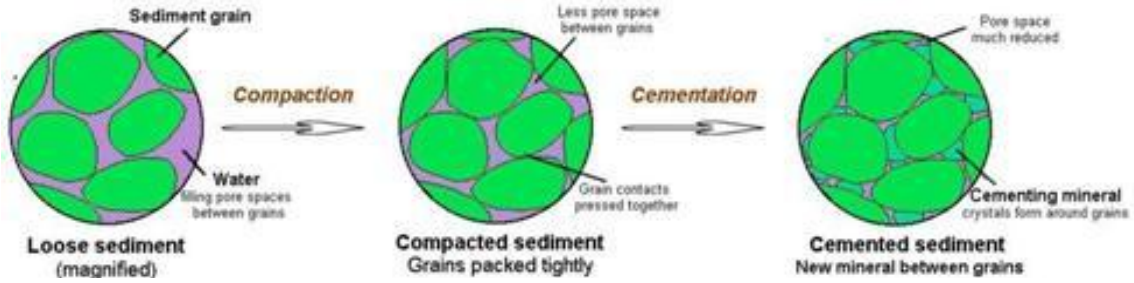


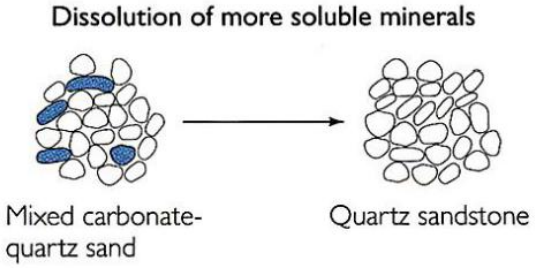


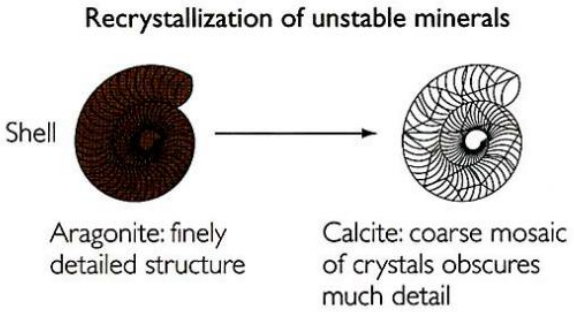




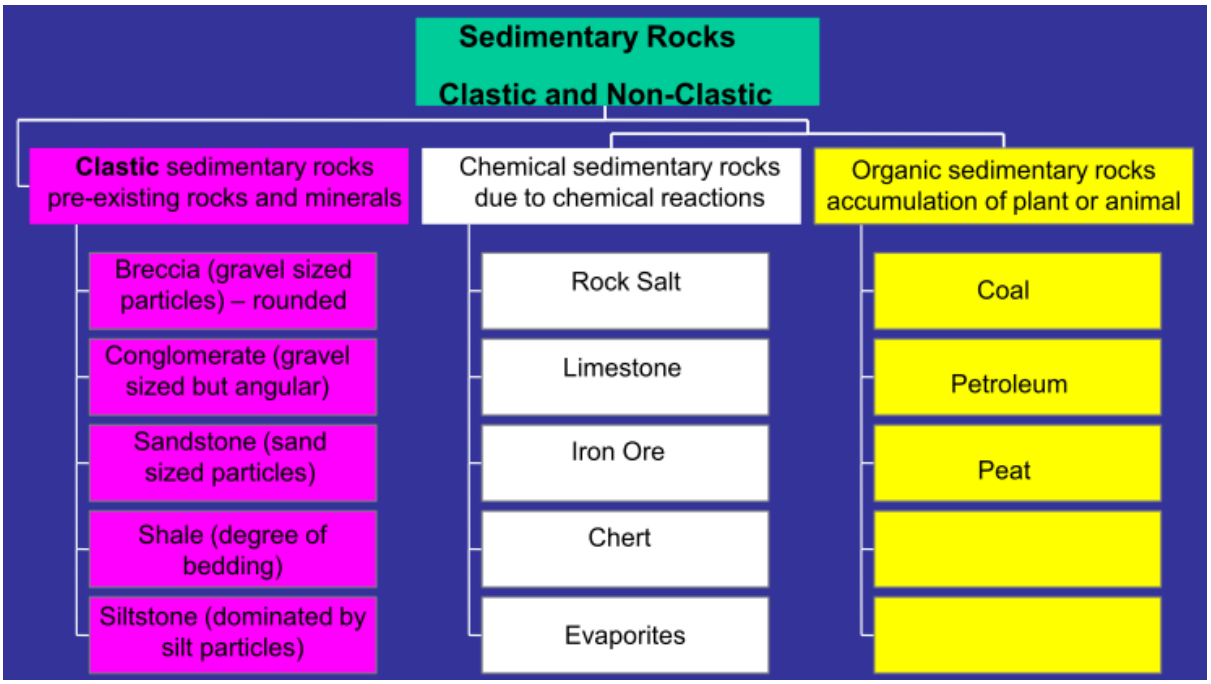
Sedimentation Processes







Classification of Sedimentary Rocks

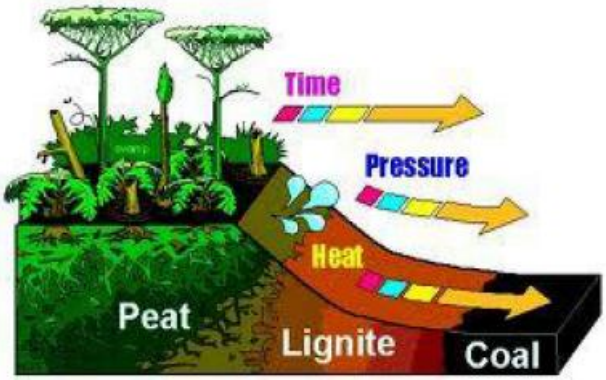


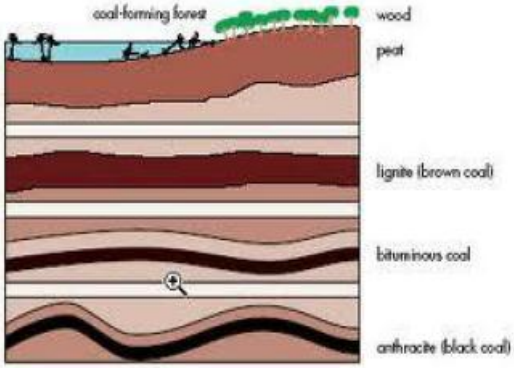
Classification of sedimentary rocks -

Chemical sediments

Group	Composition	Rock name	Formation
Inorganic	$CaCO_3$ $CaMg(CO_3)_2$	Travertine Oolites Limestone Calcrete Dolostone (Dolomite)	Cave deposits Concretions; ppt in sea water Can be biogenic Ppt in soils Alteration of limestone by Mg-rich solution.
	SiO_2	Chalcedony Sinter Jasper (with Fe) Flint	Microcrystalline silica deposited from colloidal silica in groundwaters, hot springs.
	Fe oxides and silica	Banded Iron Formation (BIF)	Layered Fe oxide and silica rocks formed by alternating chemical precipitation.
	Evaporation minerals	Halite rock Gypsum rock	Evaporation of sea water and saline lakes.

Coal Formation





6. Metamorphic Rocks

Key Concepts

- burial metamorphism: When sedimentary rocks are buried to depths of several hundred meters, temperatures greater than 300 o C may develop in the absence of differential stress. New minerals grow, but the rock does not appear to be metamorphosed. The main minerals produced are the **Zeolites**
- **cataclastic metamorphism**: occurs as a result of mechanical deformation, like when two bodies of rock slide past one another along a fault zone. Heat is generated by the friction of sliding along such a shear zone, and the rocks tend to be mechanically deformed, being crushed and pulverized, due to the shearing
- contact aureole: the zone surrounding an intrusion of magma
- contact metamorphlsm: changes that take place when magma is injected into the surrounding solid rock (country rock)
- foliation: repetitive layering in metamorphic rocks
- **hydrothermal metamorphism**: the result of the interaction of a rock with a high-temperature fluid of variable composition. Contrasts with metamorphism in that significant alterations to overall chemical composition. Much more water present than for metamorphism
- **index mineral**: used in geology to determine the degree of metamorphism a rock has experienced. When an index mineral is found in a metamorphosed rock, it indicates the minimum pressure and temperature the protolith must have achieved in order for that mineral to form
- **intergranular fluid**: during metamorphic processes, some ions in the I.G. fluid will form new minerals, while some ions from already existing minerals will move to the fluid. It thus serves as a transporting medium that accelerates metamorphic processes. Where little fluid is present, metamorphic processes are slow
- isochemical metamorphism: recrystallization of previously present elements into new species of minerals
- **isograd**: a plane of constant metamorphic grade in the field; it separates metamorphic zones of different metamorphic index minerals
- metamorphic aureole: a region in which country rocks surrounding an igneous intrusion have been recrystallized in response to the heat
- metamorphic facies: a set of metamorphic mineral assemblages that were formed under similar pressures and temperatures. The assemblage is typical of what is formed in conditions corresponding to an area on the two dimensional graph of

temperature vs. pressure. That does not mean these minerals will necessarily be visible with the naked eye, or even exist in the rock

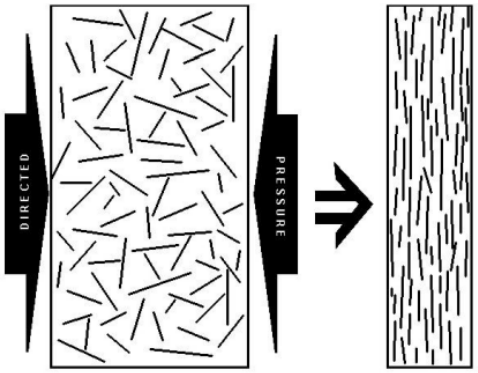
- metamorphic grade: an informal indication of the amount or degree of metamorphism. A more complete indication of this intensity or degree is provided with the concept of metamorphic facies
- metamorphic zone: an area where, as a result of metamorphism, the same combination of minerals occurs in the bed rocks
- metamorphism: the change of minerals or geologic texture (distinct arrangement of minerals) in pre-existing rocks (protoliths), without the rock melting into liquid magma
- **metasomatism**: the chemical alteration of a rock by hydrothermal and other fluids
- recrystallisation: a metamorphic process that occurs under situations of intense temperature and pressure where grains, atoms or molecules of a rock or mineral are packed closer together, creating a new crystal structure
- regional metamorphism: changes in great masses of rock over a wide area. Rocks can be metamorphosed simply by being at great depths below the Earth's surface
- schistosity: geological foliation (metamorphic arrangement in layers) with medium to large grained flakes in a preferred sheetlike orientation is called schistosity
- slaty cleavage: cleavage is defined as having 0.01 mm or less of space occurring between layers
- **stoping**: the mechanical disintegration of the surrounding country/host rock, typically through fracturing due to pressure increases associated with thermal expansion of the host rock in proximity of the interface with the melt
- thermal metamorphism: same as contact metamorphism

Types of Metamorphic Rocks

- phyllite
- porphyroblast/porphyroblastlc
- quartzite
- marble
- schist
- slate
- gneiss
- granulite
- granulite facies
- greenschist
- greenschist facies
- hornfels
- hornfels facles
- amphibolite
- amphibolite facles
- Eclogite facies

Metamorphic Grades

Metamorphism occurs because some minerals are stable only under certain conditions of pressure and temperature. When pressure and temperature change, chemical reactions occur to cause the minerals in the rock to change to an assemblage that is stable at the new pressure and temperature conditions.



Minerals that crystallize or grow in the differential stress field can have a preferred orientation.

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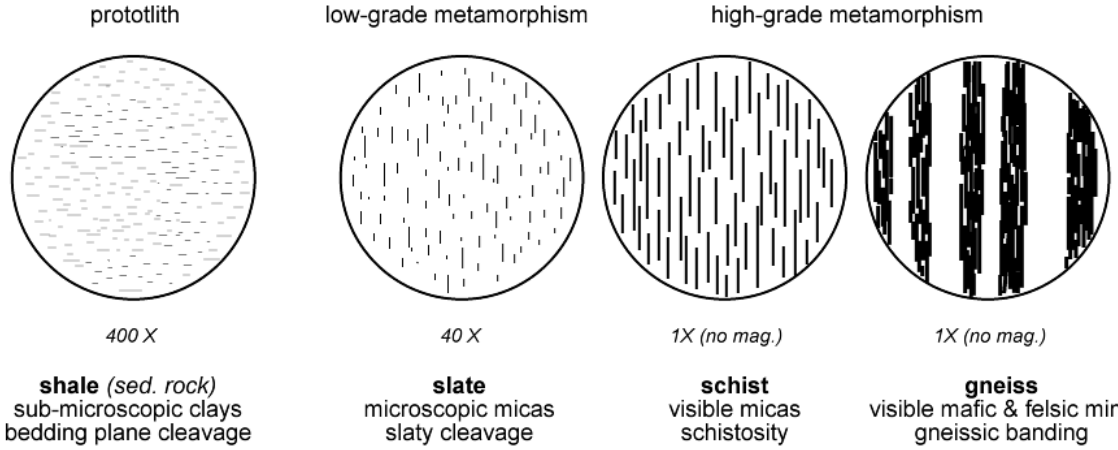
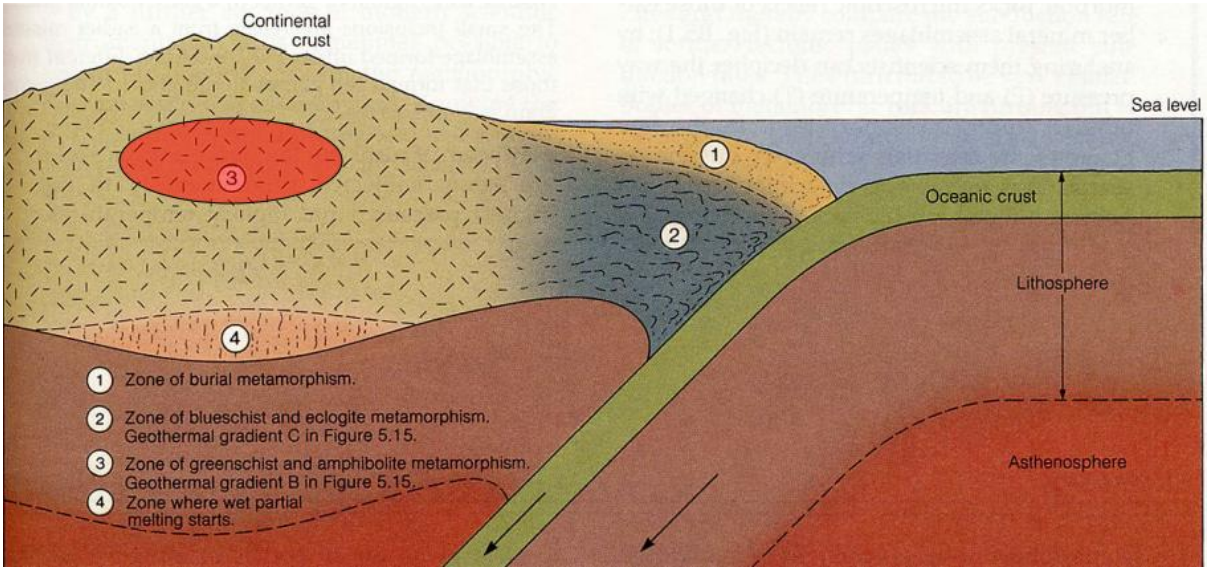
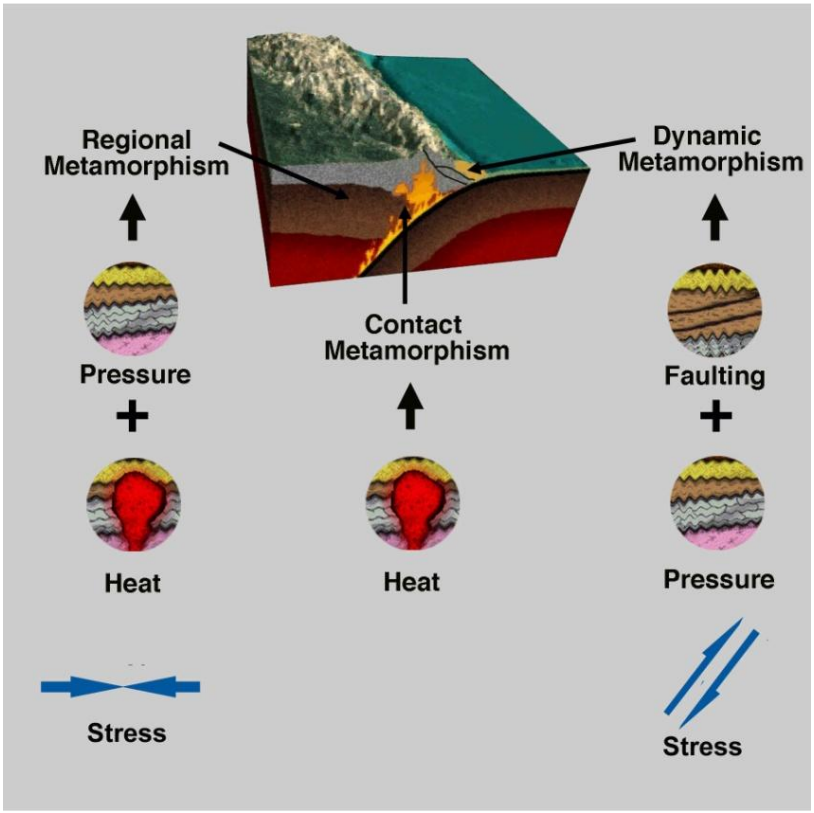


Clastic, Burial and Contact Metamorphism

- Typically occurs at 300-800 degree celsius, 5-30 km depth
- Low grade - temperatures between about 200 to 320C
- High grade - temperatures above 550C

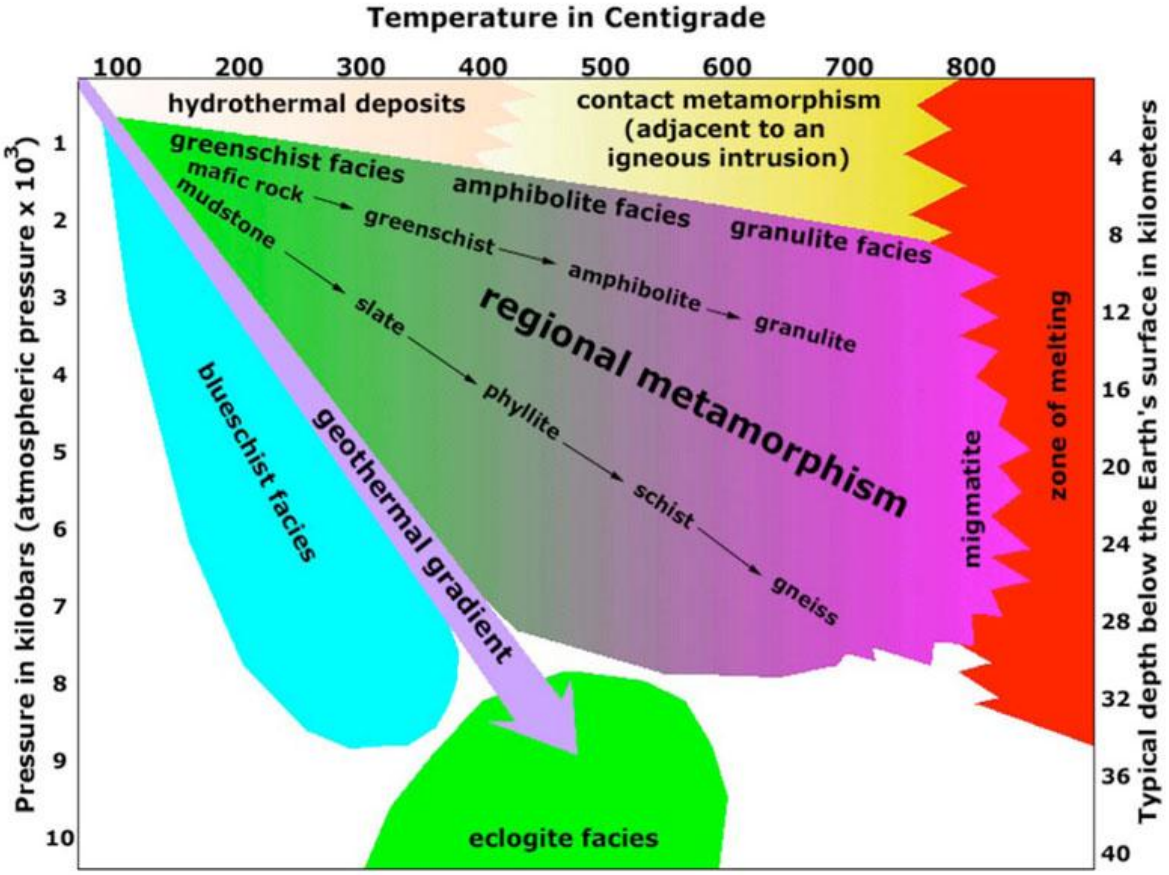




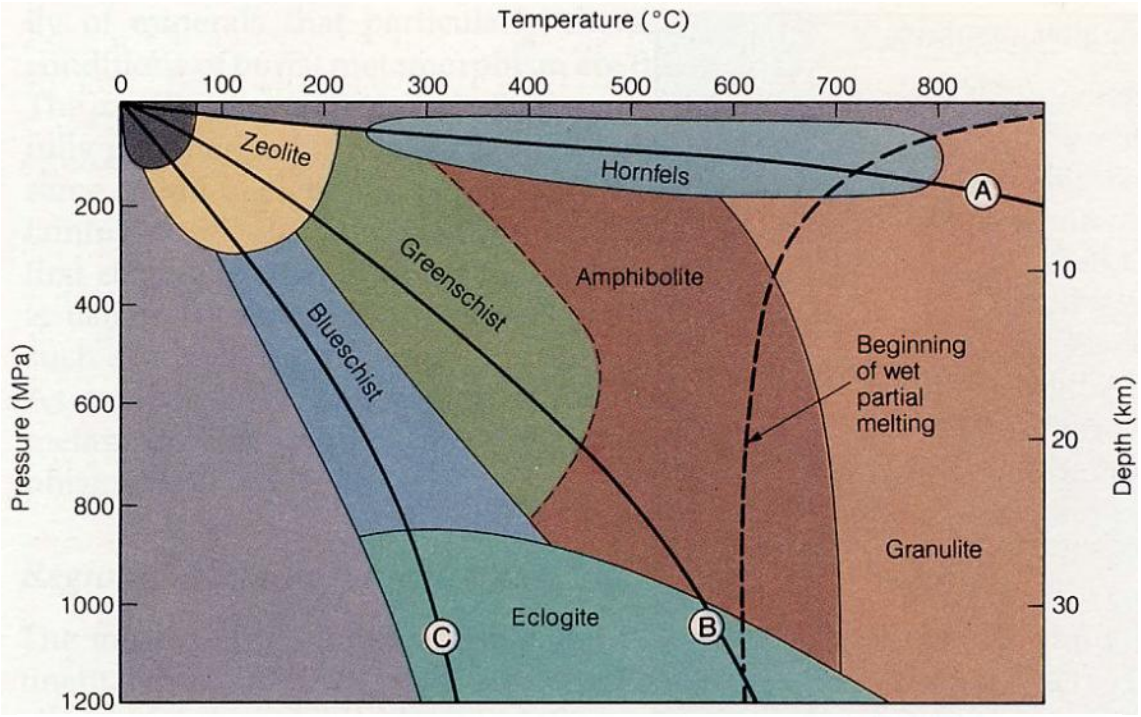
Metamorphic Reactions

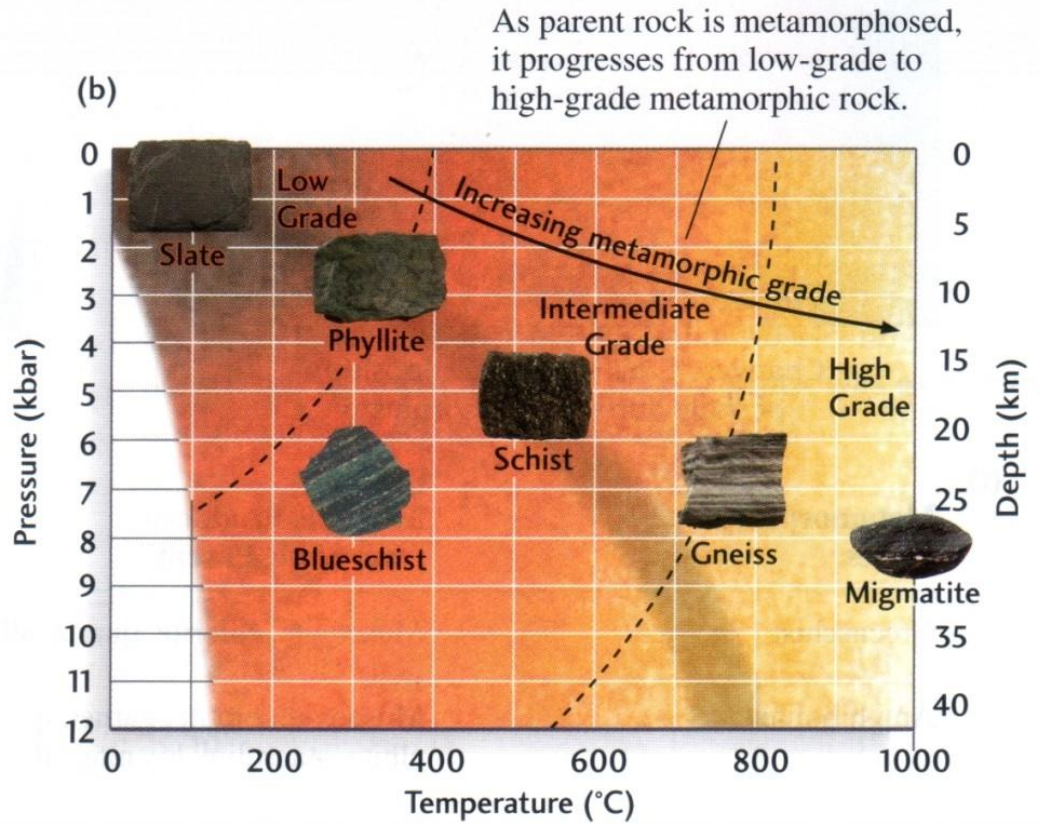
METAMORPHIC REACTIONS		
Dehydration Reactions (Water is Given Off)		
Muscovite + quartz	→	sillimanite + potassic feldspar + water
$KAl_2(AlSi_3O_{10})(OH)_2 + SiO_2$	→	$Al_2SiO_5 + KAlSi_3O_8 + H_2O$
Kaolinite	→	andalusite + quartz + water
$Al_2Si_2O_5(OH)_4$	→	$Al_2SiO_5 + SiO_2 + 2H_2O$
Decarbonation Reactions (Carbon Dioxide is Given Off)		
Calcite + quartz	→	wollastonite + carbon dioxide
$CaCO_3 + SiO_2$	→	$CaSiO_3 + CO_2$
Dolomite + quartz	→	diopside + carbon dioxide
$CaMg(CO_3)_2 + 2SiO_2$	→	$CaMg\ Si_2O_6 + 2CO_2$

P-T Chart

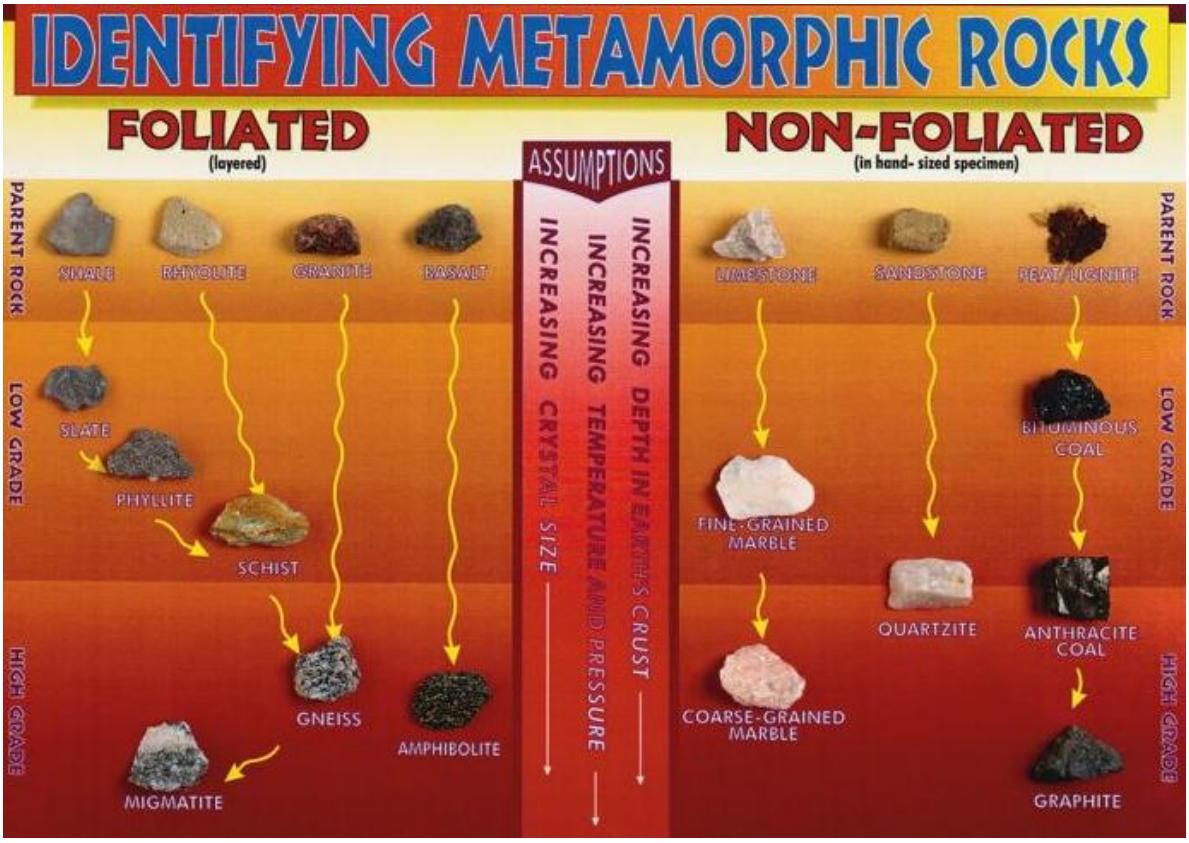


Metamorphic Facies





Classification of Metamorphic Rocks



Simplified summary classification of metamorphic rocks:

Original rock type	changed by low grade metamorphism into:	changed by medium grade metamorphism into:	changed by high grade metamorphism into:	changed by contact metamorphism into:
quartz sandstone	*quartz schist*	*quartzite*	*quartzite*	*quartzite*
greywacke	*schist*	*schist*	*gneiss / granulite*	*hornfels*
pure limestone	*marble*	*marble*	*marble*	*marble*
impure limestone	*calc. schist*	*calc. silicate*	*gneiss*	*calc. hornfels*
shale / mudstone	*phyllite / slate*	*schist*	*gneiss*	*hornfels*
basalt	*greenschist*	*amphibolite*	*amphibolite*	*basic hornfels*

7. Weathering and Soils

- adsorption: the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface
- bedrock: consolidated rock underlying the surface of a terrestrial planet, usually the Earth. Above the bedrock is usually an area of broken and weathered unconsolidated rock in the basal subsoil
- Carbonation: the process of dissolving carbon dioxide in a liquid
- chemical weathering: the direct effect of atmospheric chemicals or biologically produced chemicals also known as biological weathering in the breakdown of rocks, soils and minerals

- clay minerals: hydrous aluminium phyllosilicates (sheet), sometimes with variable amounts of iron, magnesium, and other cations found on or near some planetary surfaces. Clay minerals form in the presence of water and have been important to life, and many theories of abiogenesis involve them
- differential weathering: the difference in degree of discoloration, disintegration, etc., of rocks of different kinds exposed to the same environment
- erosion: the action of exogenic processes (such as water flow or wind) which remove soil and rock from one location on the Earth's crust, then transport it to another location where it is deposited
- exfoliation: surface-parallel fracture systems in rock often leading to erosion of concentric slabs
- **flocculation**: a process wherein colloids come out of suspension
- humus: the fraction of soil organic matter that is amorphous and without the cellular structure characteristic of plants, micro-organisms or animals. It is difficult to define humus precisely; it is a highly complex substance, which is still not fully understood
- Hydration: an inorganic chemical reaction where water is added to the crystal structure of a mineral, usually creating a new mineral, usually called a *hydrate*
- kaolinite laterite
- leaching: the loss of mineral and organic solutes due to percolation
- mechanical weathering: the breakdown of rocks and soils through direct contact with atmospheric conditions, such as heat, water, ice and pressure
- precipitation: any product of the condensation of atmospheric water vapour that falls under gravity
- regolith: a layer of loose, heterogeneous superficial material covering solid rock. It includes dust, soil, broken rock, and other related materials
- soil: the mixture of minerals, organic matter, gases, liquids, and the countless organisms that together support life on earth
- **soil horizons (A, B, C):** a layer generally parallel to the soil surface, whose physical characteristics differ from the layers above and beneath. Each soil type usually has three or four horizons. Horizons are defined in most cases by obvious physical features, chiefly colour and texture
- soil profile: the collection of soil horizons
- spheroidal weathering: a form of chemical weathering that affects jointed bedrock and results in the formation of concentric or spherical layers of highly decayed rock within weathered bedrock that is known as saprolite
- translocation: Removal of things from one place to another; displacement; substitution of one thing for another
- weathering: the breaking down of rocks, soil and minerals as well as artificial materials through contact with the Earth's atmosphere, biota and waters

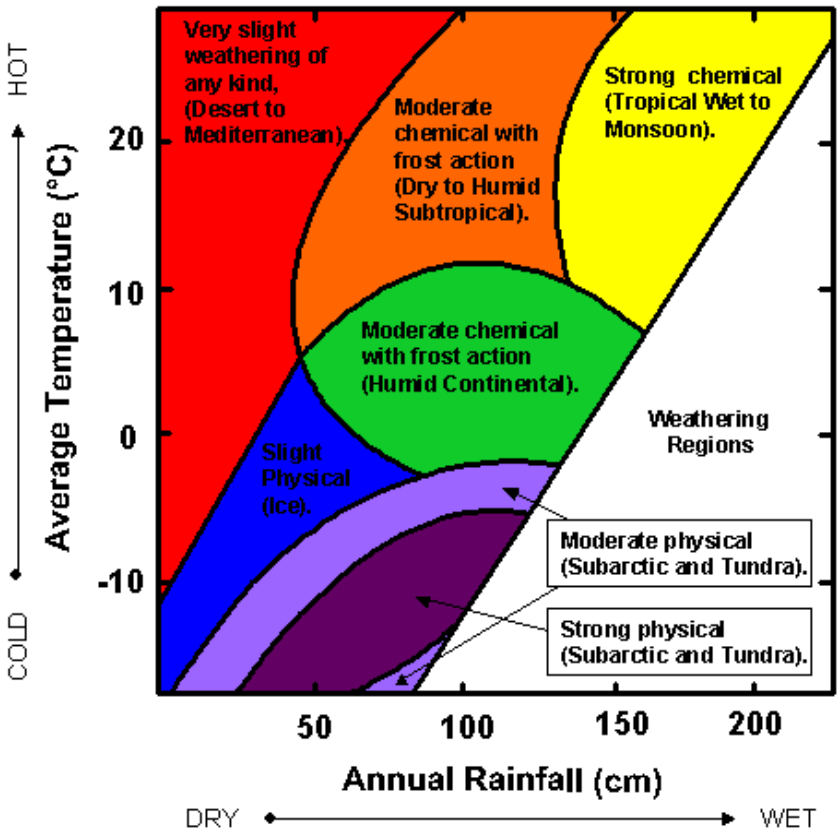
Soils and Minerals

- limonite
- goethite
- hematite
- duricrust
- bauxite

Difference between Soil and Regolith

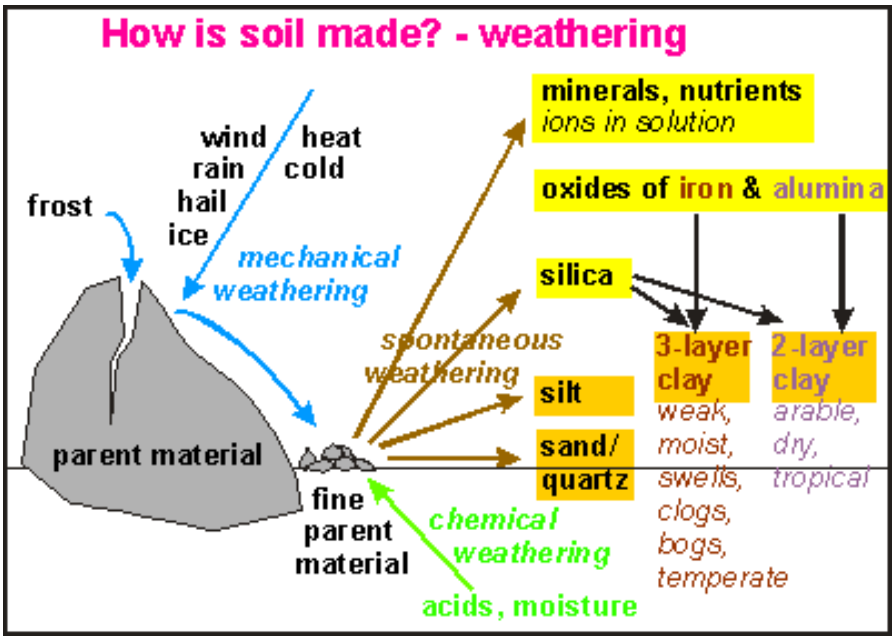
- Regolith: a layer of loose, heterogeneous superficial material covering solid rock. It includes dust, soil, broken rock, and other related materials and is present on Earth
- Soil: the mixture of minerals, organic matter, gases, liquids, and the countless organisms that together support life on earth
- Sediment: a naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice, and/or by the force of gravity acting on the particles

Rates of Chemical Weathering

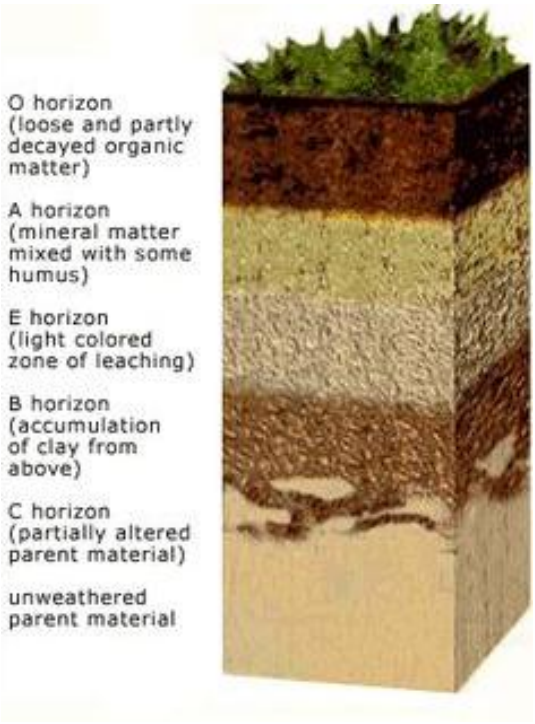


Mechanical Weathering

Soil Formation



Soil Horizons



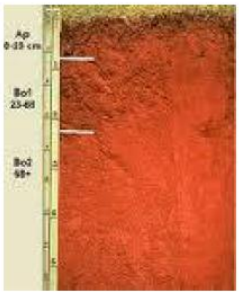
Soil Climactic Types

Tropical soils

- Often are characterised by oxisols.
- Features include
  - extensive change in the chemical nature of the parent material. A horizon is well oxidised.
  - Intensive weathering
  - Infertility

Why?

Warmth and water – chemical reactions are faster and nutrients are leached away.



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Desert soils

- The dry desert climates develop aridosols:
  - Low moisture leads to lack of leaching allowing carbonates to build in the soil profile which can result in a $CaCO_3$ layer
  - Alkaline soils
  - Low vegetative/organic content

Temperate-latitude soils

- Sloping ground in cool climates have entisols
  - Little development of soil profile – A horizon only (or possibly very slight B horizon as well)

- Grasslands and prairies usually have mollisols:
  - Nutrient rich A horizon, dark coloured

Polar soils

- Where would you expect to find them?
  - High-latitude deserts eg. Greenland, Antarctica
- Features:
  - Dry
  - Lack well-developed horizon
  - Weakly oxidised parent material (why weakly oxidised?) underlay courser stones
- Where high-latitude regions are wetter tundra may overlay water logged soils rich in organic matter (histosol).

Tundra

8. Structural Geology

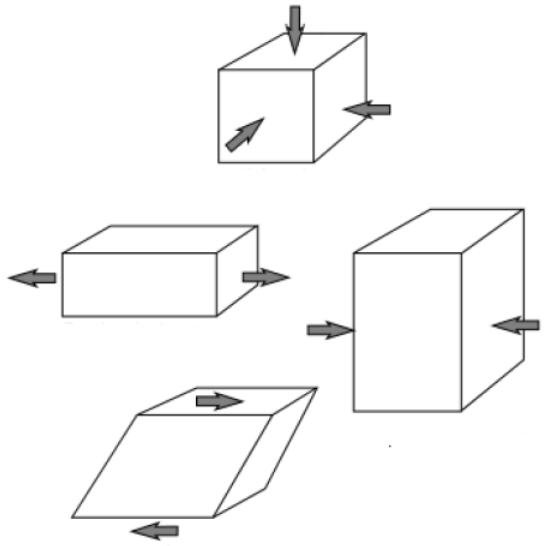
Key Concepts

- anticline: a fold that is convex up and has its oldest beds at its core
- asymmetrical fold: the axial plane is inclined relative to the vertical
- brittle fracture: for a brittle substance, the elastic limit and fracture point are close to each other, while they are further apart for a ductile substance
- differential stress: the main stress that deforms rocks, as opposed to uniform stress
- dip-slip fault: offset is predominately vertical and/or perpendicular to the fault trace
- dome: feature in structural geology consisting of symmetrical anticlines that intersect each other at their respective apices
- ductile deformation: irreversible change in shape and/or volume of a rock that has been stressed beyond the elastic limit
- elastic deformation: non-permanent change (rock returns to original size and shape when stress is removed), obeys Hooke's law
- fault: planar rock fractures which show evidence of relative movement
- fault breccia: breccia (rock composed of broken fragments of minerals or rock cemented together by a fine-grained matrix) formed primarily by tectonic movement along a localized zone of brittle deformation (a fault zone) in a rock formation
- fold: occurs when one or a stack of originally flat and planar surfaces, such as sedimentary strata, are bent or curved as a result of permanent deformation
- fold axis: the closest approximation to a straight line that when moved parallel to itself, generates the form of the fold
- fracture: a 'break' in rock at Earth's surface along which here has been movement
- graben: a depressed block of land bordered by parallel faults. *Graben* is German for *ditch* or *trench*
- horst: the raised fault block bounded by normal faults or graben
- **joint**: a 'break' in rock at Earth's surface along which there has not been any movement
- limb (of fold): the sides of a fold
- overturned fold: the axial plane inclined to such an extent that the strata on one limb are overturned
- **plunging fold**: fold with an inclined axis
- strain rate: terms of change of volume per unit volume per second. The lower the strain rate the greater the tendency for ductile deformation to occur. Water generally reduces brittleness
- strike and dip: refer to the orientation or *attitude* of a geologic feature. The *strike line* of a bed, fault, or other planar feature, is a line representing the intersection of that feature with a horizontal plane. The *dip* gives the steepest angle of descent of a tilted bed or feature relative to a horizontal plane
- strike-slip fault: the offset is predominately horizontal, parallel to the fault trace; arise from shear stresses
- structural geology: the study of the three-dimensional distribution of rock units with respect to their deformational histories
- syncline: a fold with younger layers closer to the center of the structure
- thrust fault: rocks of lower stratigraphic position are pushed up and over higher strata. They are often recognized because they place older rocks above younger. Thrust faults are the result of compressional forces

- transform fault: a special class of strike-slip faults is the transform fault, where such faults form a plate boundary. Transform faults are also referred to as conservative plate boundaries, as lithosphere is neither created nor destroyed

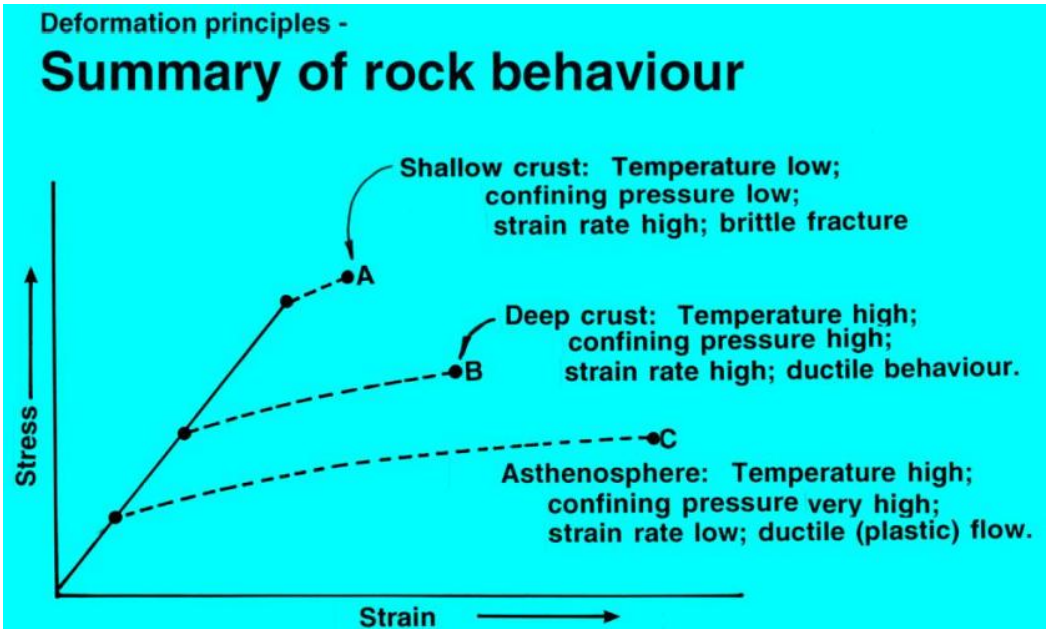
Rock Deformation

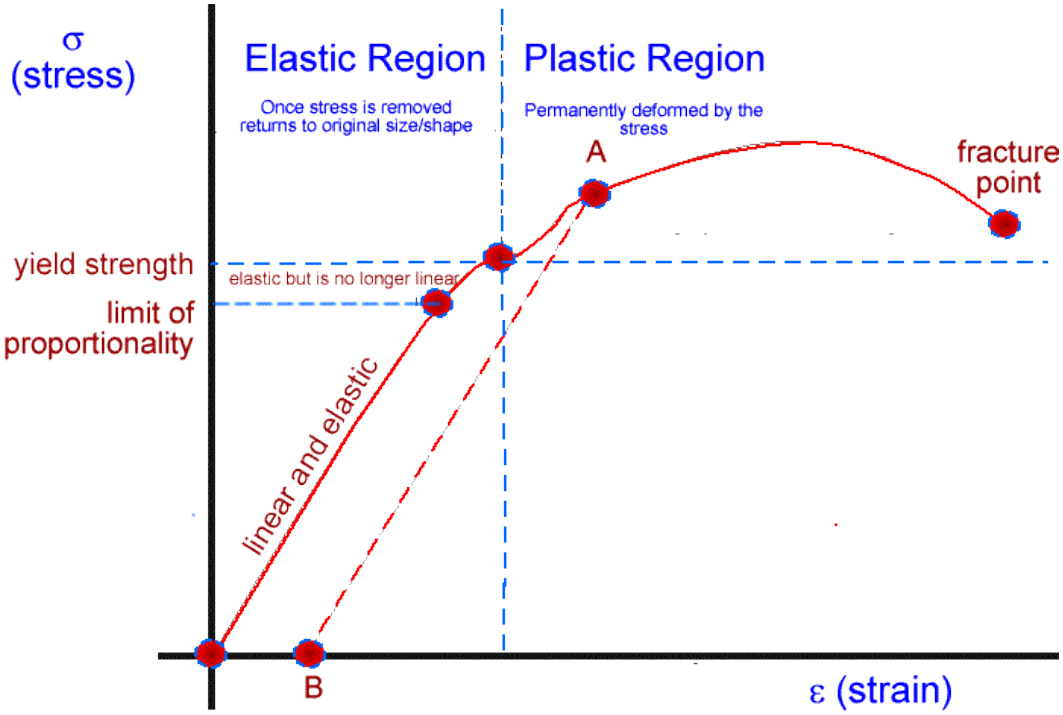
- Temperature: a solid becomes less brittle and more ductile as temperature increases
- Rocks become more ductile with depth (as temperature increases)
- **Confining stress**: reduces brittle properties as it inhibits the formation of fractures
- Time and strain rate: A solid under gradually increasing stress/strain for a sustained period of time will have a tendency to undergo ductile deformation
- Strain rate: the term used to describe time-dependent deformation of rock – i.e. the rate at which a rock is forced to change its shape or volume

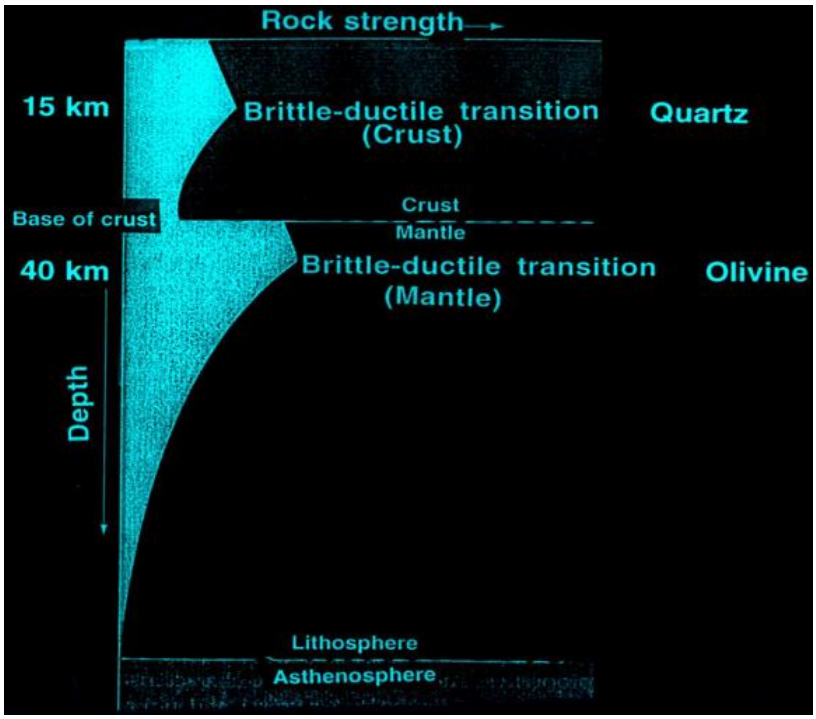


Three types of differential stress:

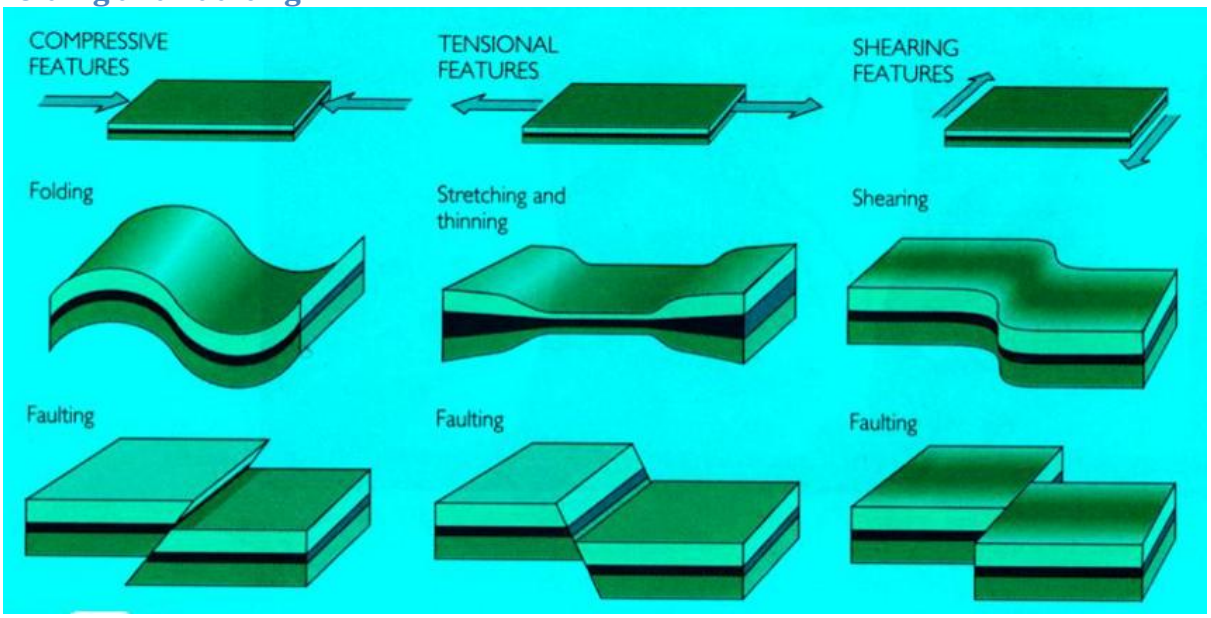
i. Tensional stress
ii. Compressional stress
iii. Shear stress




σ
(stress)
Elastic Region
Plastic Region
Once stress is removed returns to original size/shape
Permanently deformed by the stress
A
fracture point
yield strength
limit of proportionality
elastic but is no longer linear
linear and elastic
B
ε (strain)

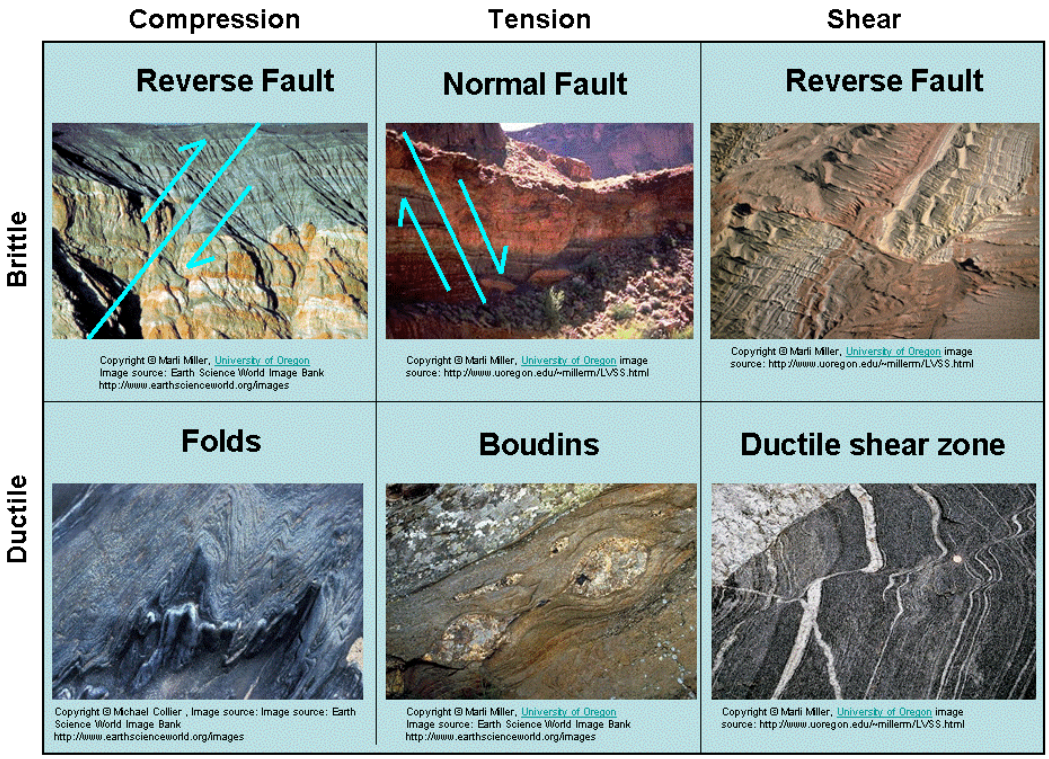

Rock strength
15 km
Brittle-ductile transition (Crust)
Quartz
Base of crust
Crust
Mantle
40 km
Brittle-ductile transition (Mantle)
Olivine
Depth
Lithosphere
Asthenosphere

Folding and Faulting

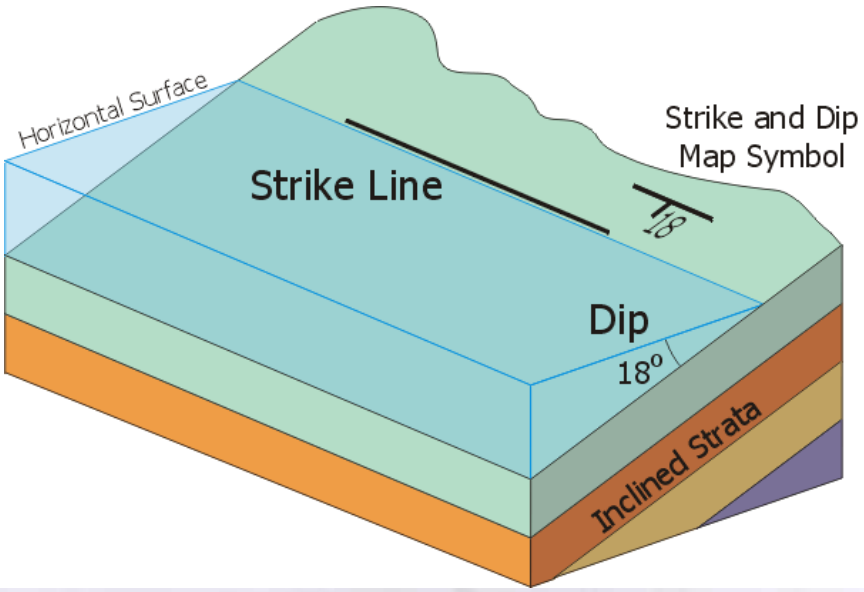


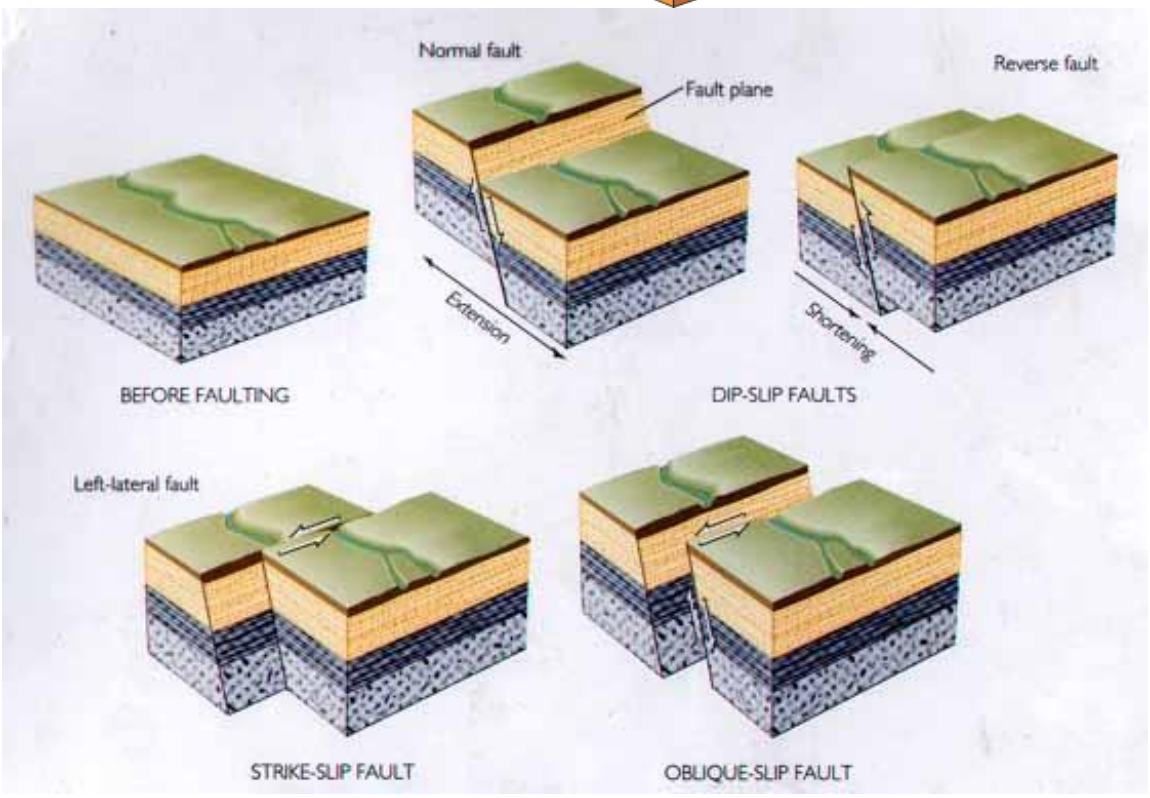
Brittle deformation

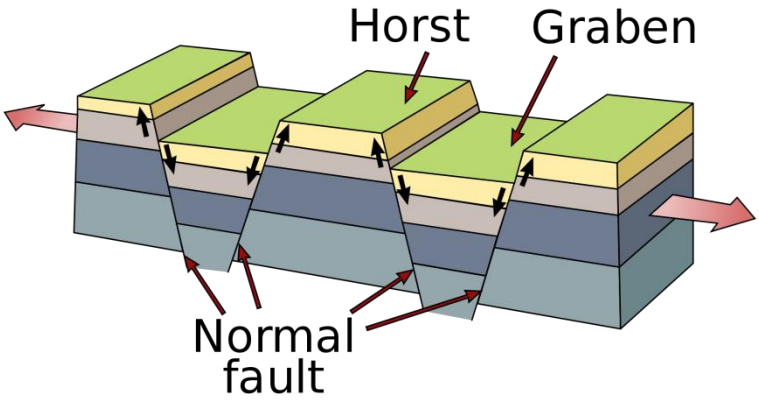
Ductile deformation



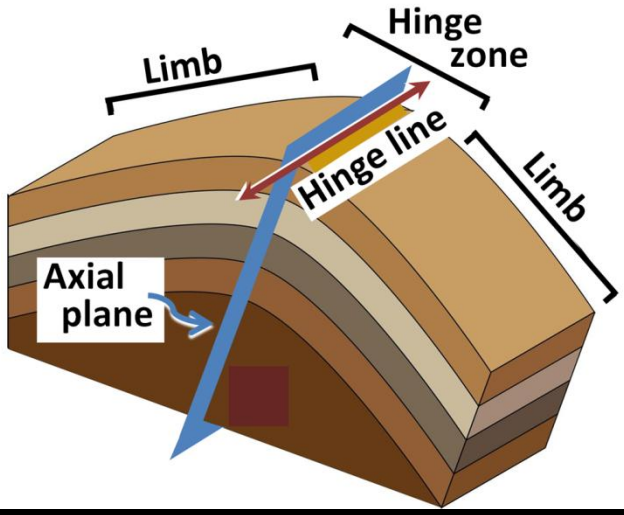
Types of Faults

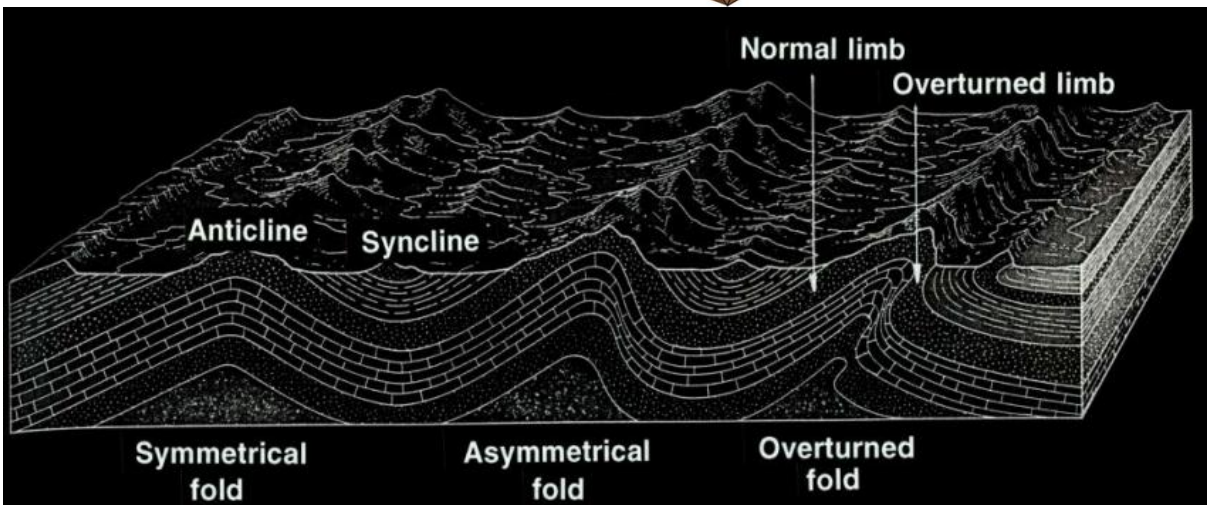


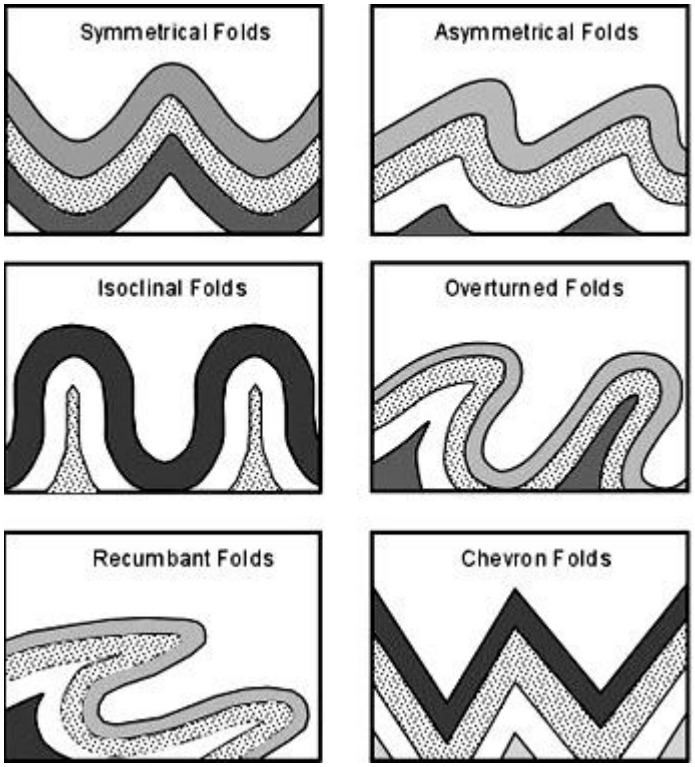




Types of Folds







9. Earthquakes

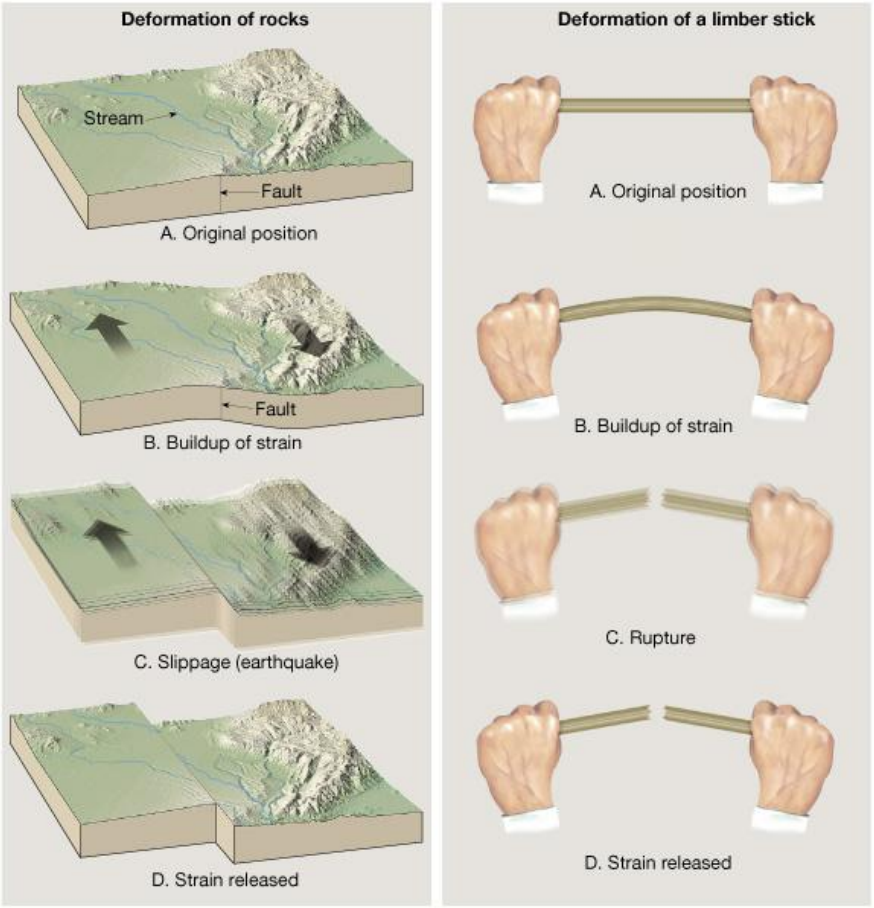
Key Concepts

- Benioff zone: a planar zone of seismicity corresponding with the down-going slab in a subduction zone. Form magmatic arcs and stratovolcanoes over land
- body waves: travel through the interior of the Earth.
- earthquake: the perceptible shaking of the surface of the Earth, which can be violent enough to destroy major buildings and kill thousands of people
- earthquake first motion: on a seismogram, the first motion is the direction of ground motion as the P wave arrives at the seismometer
- epicentre: the point on the Earth's surface that is directly above the hypocentre or focus, the point where an earthquake or underground explosion originates
- fault: a planar fracture or discontinuity in a volume of rock, across which there has been significant displacement as a result of rock mass movement
- isostasy: the state of gravitational equilibrium between Earth's crust and mantle such that the crust "floats" at an elevation that depends on its thickness and density
- **low velocity zone**: occurs close to the boundary between the lithosphere and the asthenosphere in the upper mantle. It is present between about 80 and 300 km depth. The LVZ has been interpreted to indicate the presence of a significant degree of partial melting, and alternatively as a natural consequence of a thermal boundary layer and the effects of pressure and temperature on the elastic wave velocity of mantle components in the solid state
- Mercallli Intensity Scale: a seismic scale used for measuring the intensity of an earthquake. It measures the effects of an earthquake, not based on first physical principles, but is, instead, empirically based on observed effects
- **Mohorovicic discontinuity:** the boundary between the Earth's crust and the mantle
- moment magnitude: used by seismologists to measure the size of earthquakes in terms of the energy released. The magnitude is based on the seismic moment of the earthquake, which is equal to the rigidity of the Earth multiplied by the average amount of slip on the fault and the size of the area that slipped
- P waves: Primary waves (P-waves) are compressional waves that are longitudinal in nature. P waves are pressure waves that travel faster than other waves through the earth to arrive at seismograph stations first, hence the name "Primary". These waves can travel through any type of material, including fluids, and can travel at nearly twice the speed of S waves. In air, they take the form of sound waves, hence they travel at the speed of sound
- Rayleigh waves: surface waves that travel as ripples with motions that are similar to those of waves on the surface of water
- Richter magnitude scale: Richter scale, developed in the 1930s, is a base-10 logarithmic scale, which defines magnitude as the logarithm of the ratio of the amplitude of the seismic waves to an arbitrary, minor amplitude
- S waves: Secondary waves (S-waves) are shear waves that are transverse in nature. Following an earthquake event, S-waves arrive at seismograph stations after the faster-moving P-waves and displace the ground perpendicular to the direction of propagation
- seismic belt: area of frequent earthquake shocks

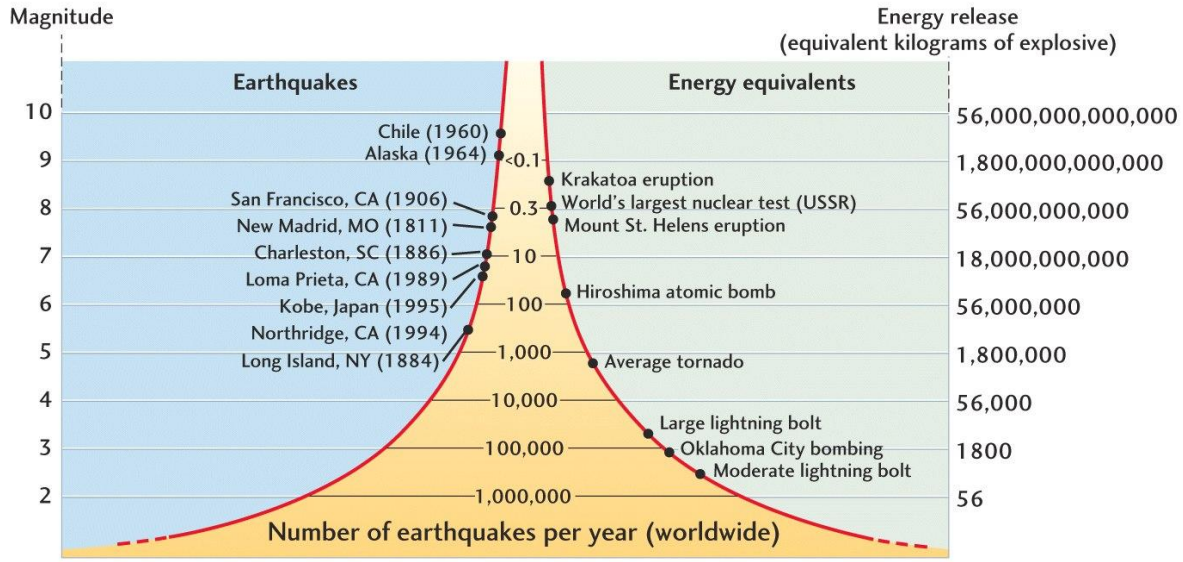
- seismic gap: a segment of an active fault known to produce significant earthquakes, that has not slipped in an unusually long time when compared with other segments along the same structure. Seismic gap hypothesis/theory states that, over long periods of time, the displacement on any segment must be equal to that experienced by all the other parts of the fault. Any large and longstanding gap is therefore considered to be the fault segment most likely to suffer future earthquakes
- seismic waves: waves of energy that travel through the Earth's layers, and are a result of an earthquake, explosion, or a volcano
- seismograph: instruments that measure motion of the ground, including those of seismic waves
- shadow zone: an area of the Earth's surface where seismographs cannot detect an earthquake after its seismic waves have passed through the Earth
- stress: a physical quantity that expresses the internal forces that neighboring particles of a continuous material exert on each other, while strain is the measure of the deformation of the material
- surface wave: travel across the surface. Surface waves decay more slowly with distance than do body waves, which travel in three dimensions
- travel-time curve
- tsunami: series of waves in a water body caused by the displacement of a large volume of water, generally in an ocean or a large lake. Earthquakes, volcanic eruptions and other underwater explosions, landslides, glacier calvings, meteorite impacts and other disturbances above or below water all have the potential to generate a tsunami

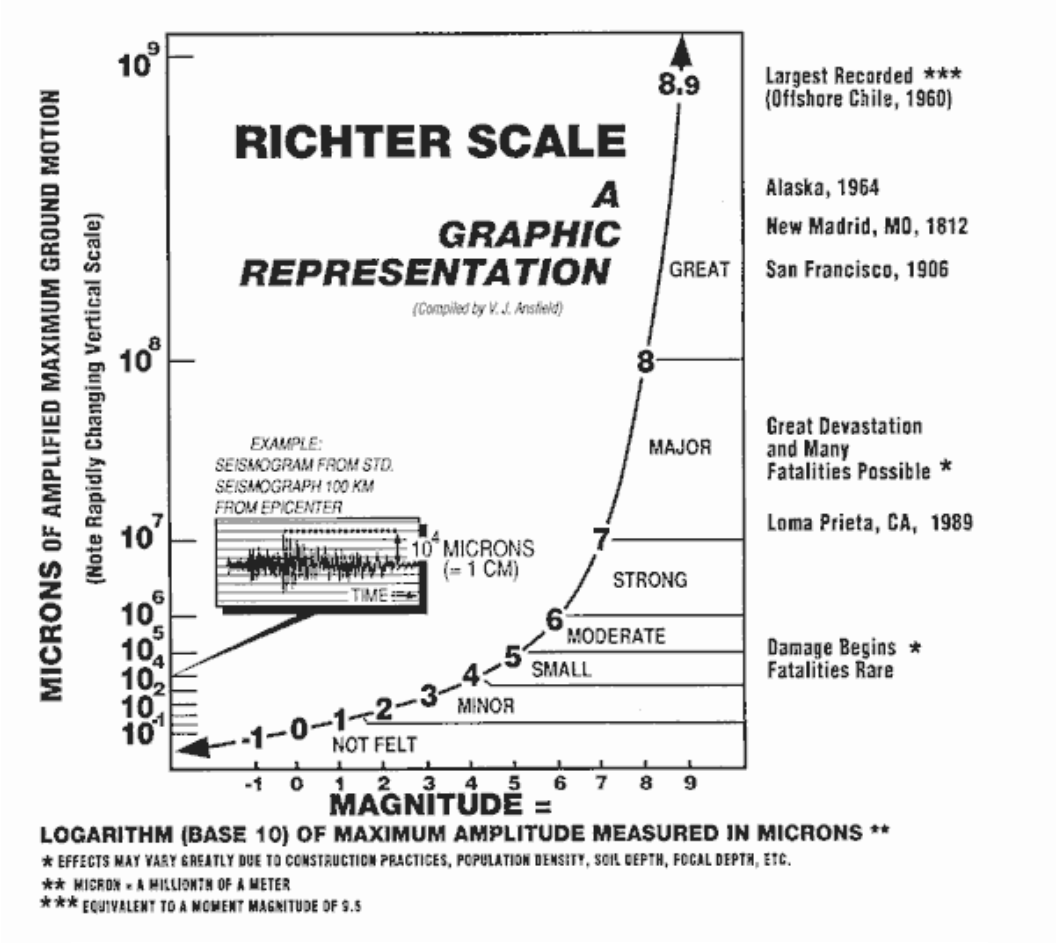
Rock Strain and Earthquakes

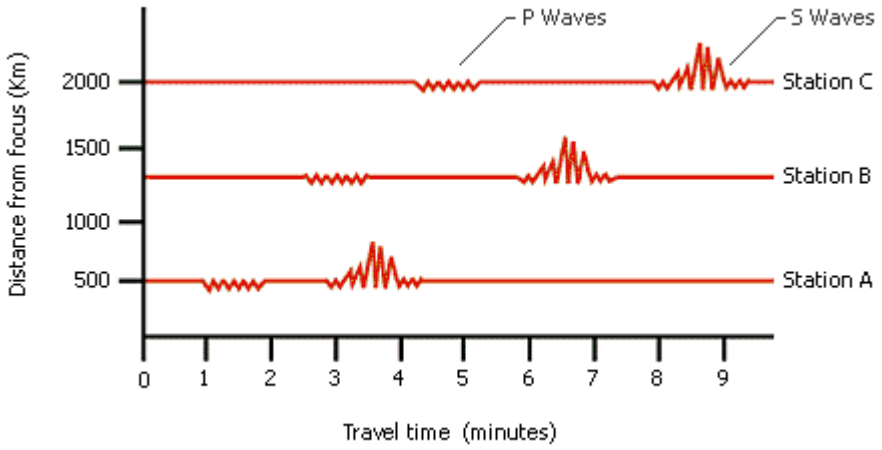
- Lithosphere is brittle and will fracture when deforming stress exceeds elasticity
- At depths greater than lithosphere, high temperature and pressure allows ductile deformation of rock
- The most accurate method of determining the focal depth of an earthquake is to read a depth phase recorded on the seismogram. This is the characteristic phase pP wave - a P wave reflected from the surface of the Earth.
- At distant seismograph stations, the pP follows the P wave by a time interval that changes slowly with distance but rapidly with depth. This time interval between the P wave and reflected P wave is used to compute depth-of-focus tables.



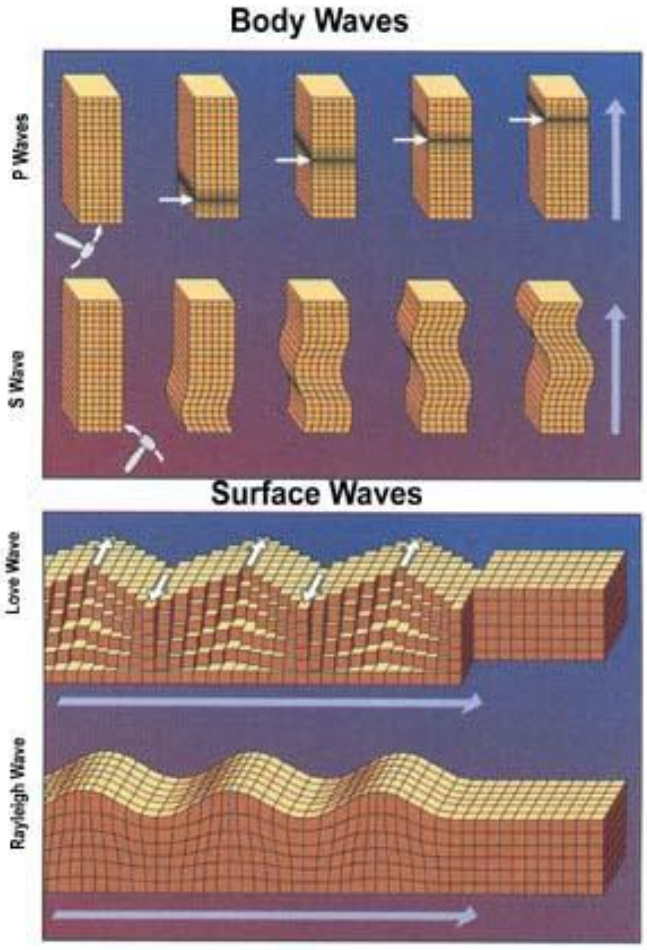
Measuring Earthquake Magnitude

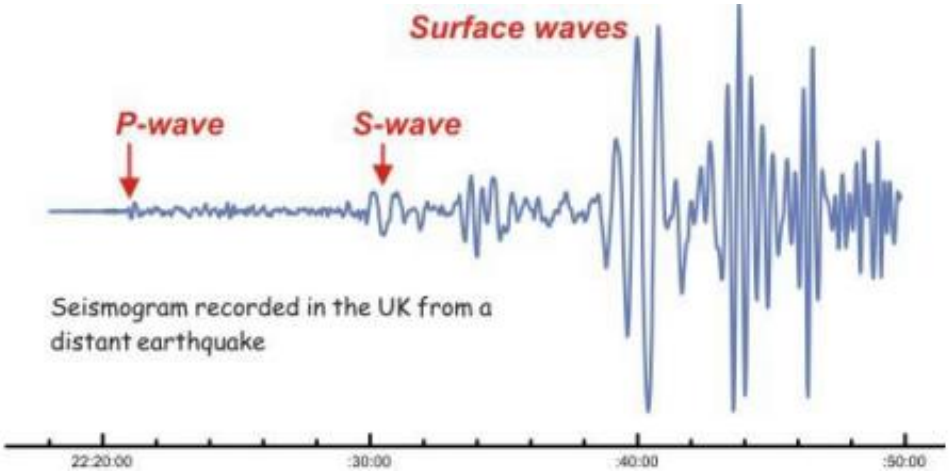



RICHTER SCALE
A GRAPHIC REPRESENTATION
(Compiled by V. J. Ansfield)
MICRONS OF AMPLIFIED MAXIMUM GROUND MOTION
(Note Rapidly Changing Vertical Scale)
EXAMPLE:
SEISMOGRAM FROM STD. SEISMOGRAPH 100 KM FROM EPICENTER
10^4 MICRONS (= 1 CM)
TIME
GREAT
MAJOR
STRONG
MODERATE
SMALL
MINOR
NOT FELT
MAGNITUDE =
Largest Recorded *** (Offshore Chile, 1960)
Alaska, 1964
New Madrid, MO, 1812
San Francisco, 1906
Great Devastation and Many Fatalities Possible *
Loma Prieta, CA, 1989
Damage Begins * Fatalities Rare
LOGARITHM (BASE 10) OF MAXIMUM AMPLITUDE MEASURED IN MICRONS **
* EFFECTS MAY VARY GREATLY DUE TO CONSTRUCTION PRACTICES, POPULATION DENSITY, SOIL DEPTH, FOCAL DEPTH, ETC.
** MICRON = A MILLIONTH OF A METER
*** EQUIVALENT TO A MOMENT MAGNITUDE OF 9.5


P Waves
S Waves
Station C
Station B
Station A
Distance from focus (Km)
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
9
Travel time (minutes)

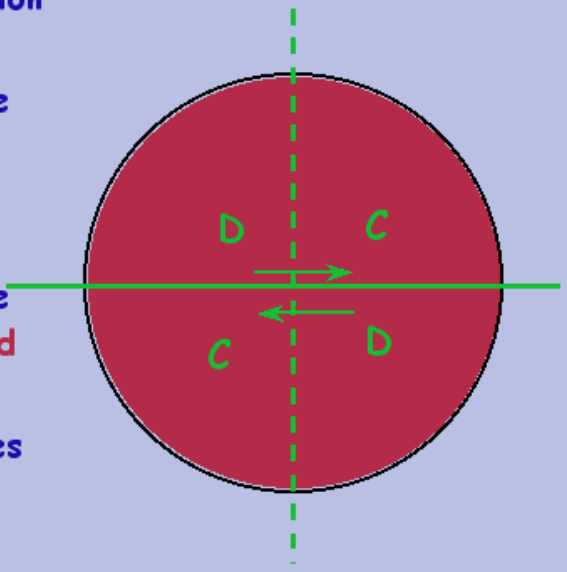
Types of Seismic Waves



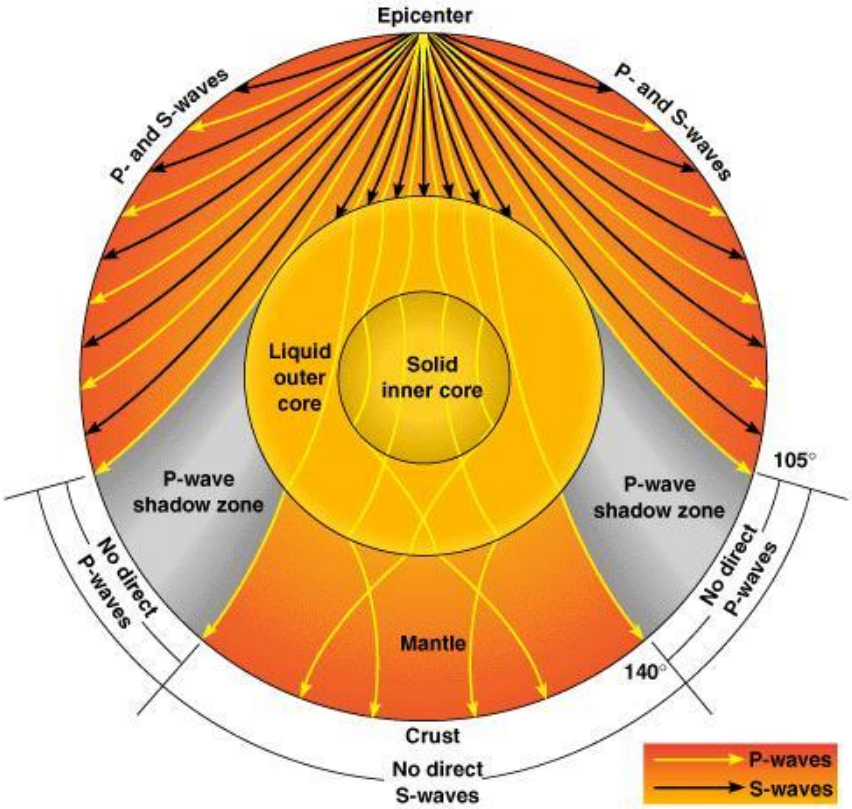


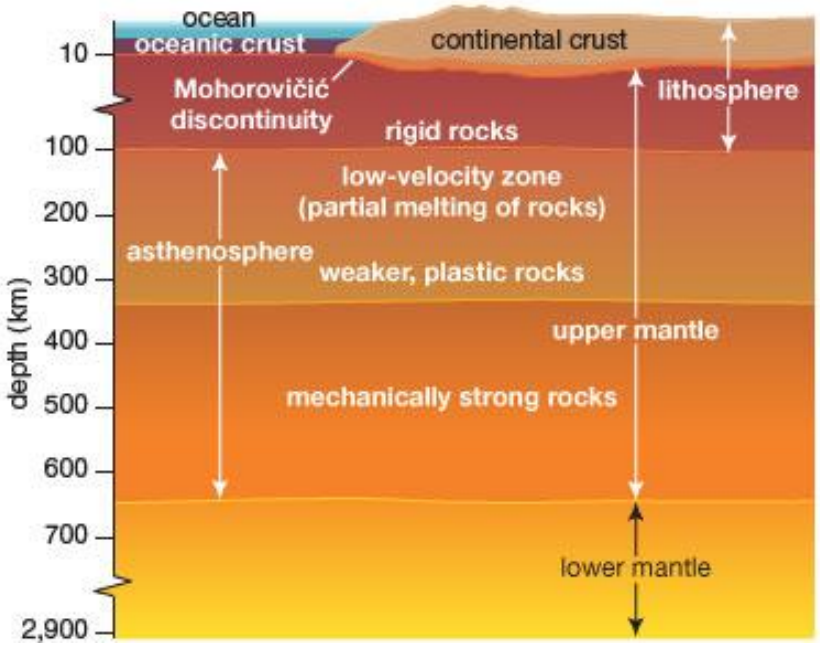
Earthquake first-motion studies

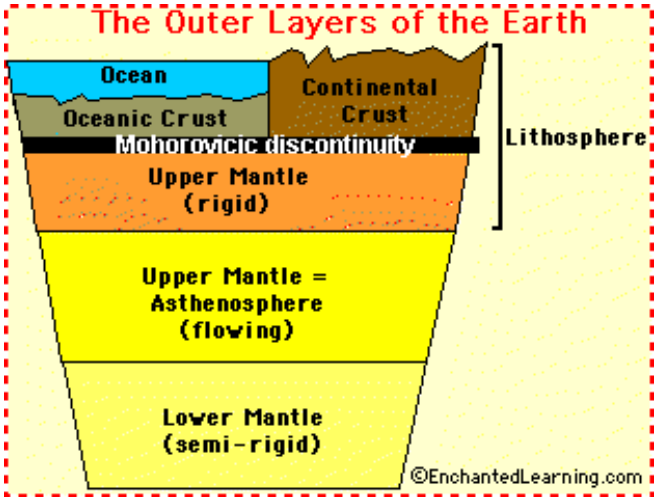
- Seismogram may indicate that a rock mass initially moved toward or away from a recording station
- If first-motion is toward recording station, leading edge of P wave is a region of compressed rock
- If first-motion is away from recording station, leading edge of P wave is a region of dilated rock
- Every fault slip event generates a systematic pattern of compressions and dilations

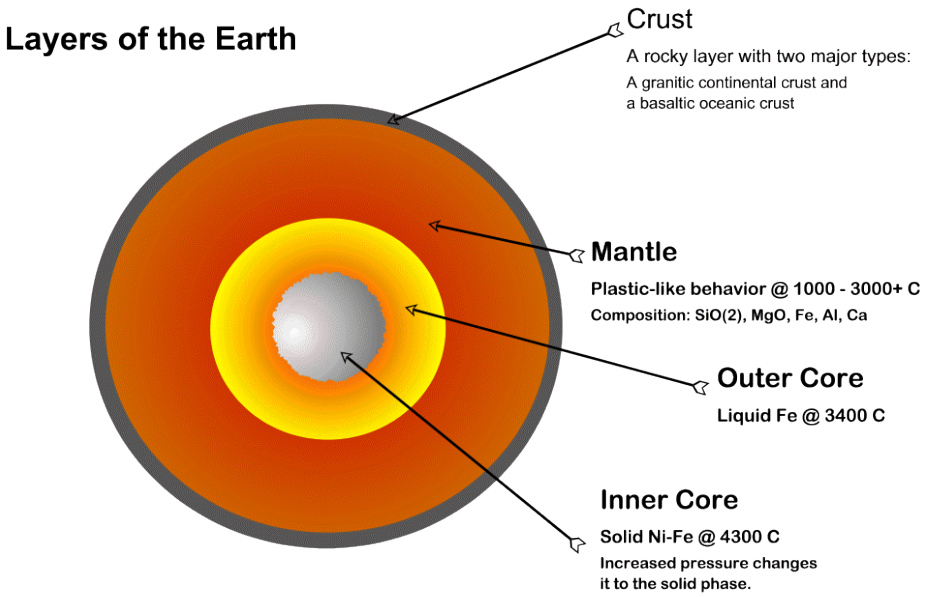


Inferring Earth's Internal Structure

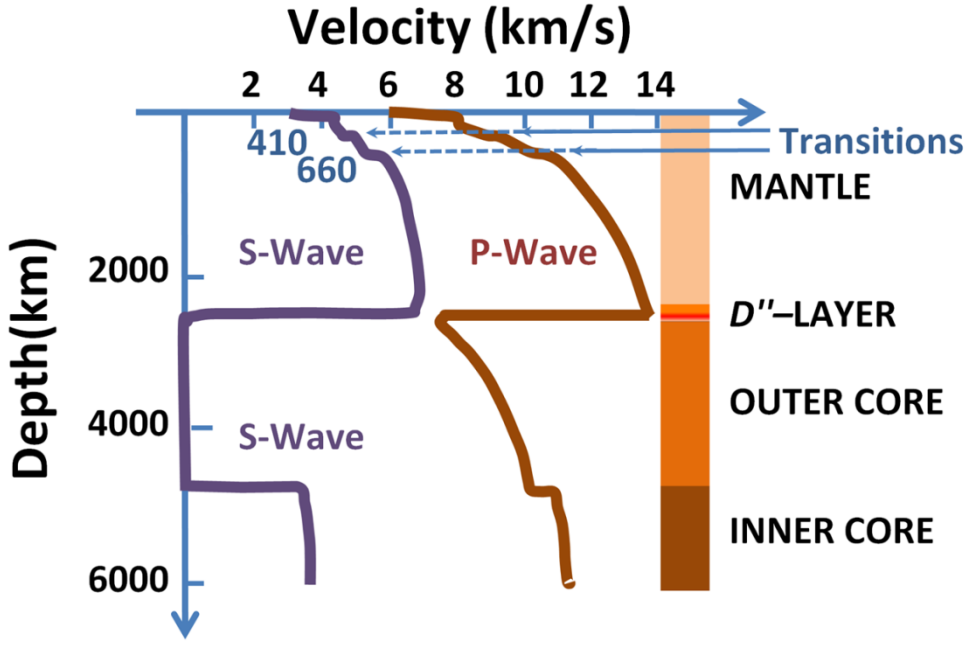





The Outer Layers of the Earth
Ocean
Continental Crust
Oceanic Crust
Mohorovicic discontinuity
Lithosphere
Upper Mantle (rigid)
Upper Mantle = Asthenosphere (flowing)
Lower Mantle (semi-rigid)
©EnchantedLearning.com


Layers of the Earth
Crust
A rocky layer with two major types:
A granitic continental crust and
a basaltic oceanic crust
Mantle
Plastic-like behavior @ 1000 - 3000+ C
Composition: SiO(2), MgO, Fe, Al, Ca
Outer Core
Liquid Fe @ 3400 C
Inner Core
Solid Ni-Fe @ 4300 C
Increased pressure changes
it to the solid phase.

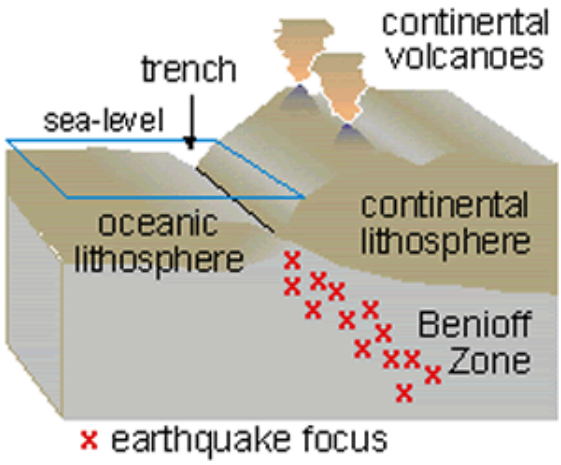
Seismic Discontinuities

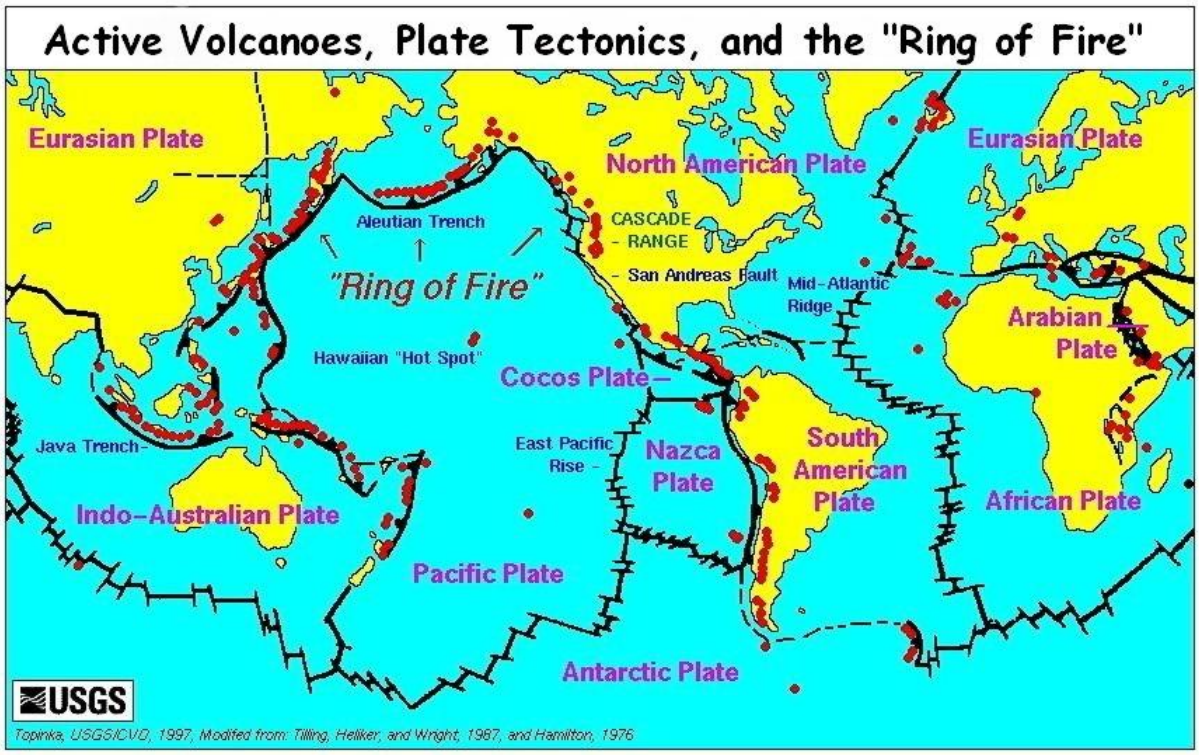


Depth	Observation	Explanation
Base of crust to 100km	P-wave velocity rises slowly to 8 km/s	Composition of mantle does not change, but mantle is more ductile in this region than surrounding regions
100 km to 350 km	**The Low Velocity Zone** P-wave velocity drops to below 8 km/s (more defined below oceans)	
~ 400 km	**The 400 km Seismic** Discontinuity P- and S-wave velocities increase sharply	Olivine-spinel polymorphic transition causes a density increase of 10 %
~ 670 km	**The 670 km Seismic Discontinuity** Increase in P-wave velocities Slight increase in S-wave velocities	Difficult to discern whether change in velocity is due to compositional change, polymorphic transition, or both A 10 % density change is apparent

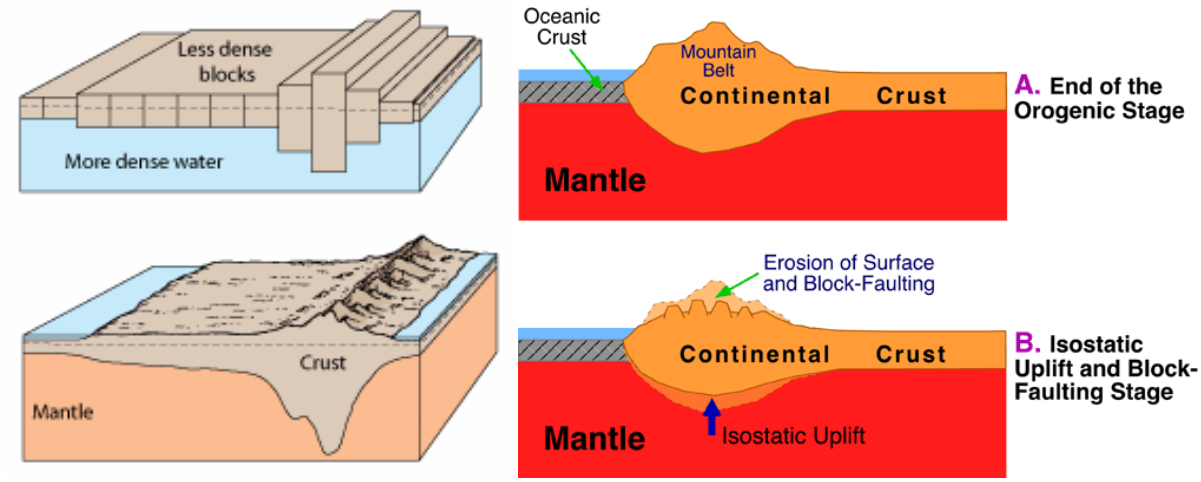
Earthquakes and Plate Tectonics

- Most foci < 100 km deep (earthquakes occur around plate edges of lithosphere which is only 100 km thick)
- Deep earthquakes (**up to 700 km deep**) related to seafloor trenches where lithosphere sinks down into mantle





Isostactic Adjustment



10. Movement of Material

Mass Wasting

- angle of repose: the steepest angle of descent or dip relative to the horizontal plane to which a material can be piled without slumping

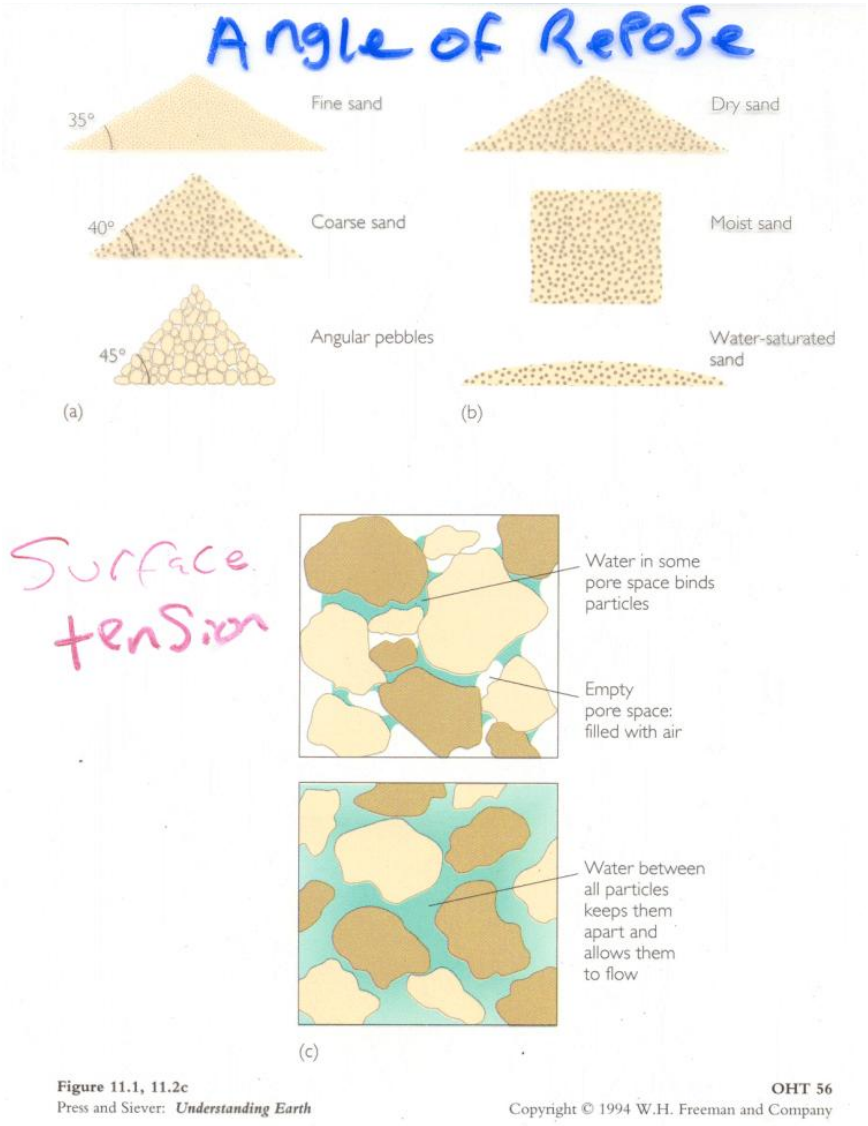
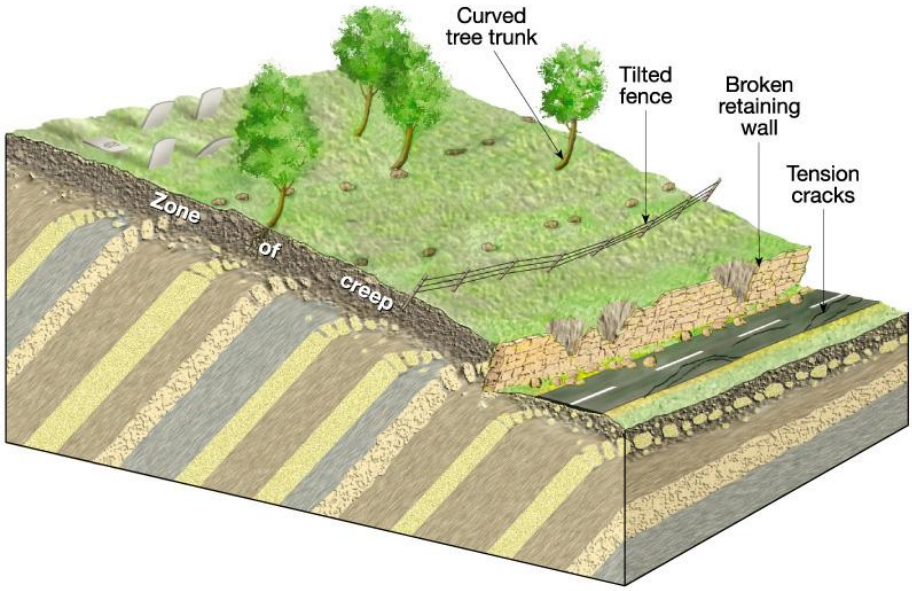


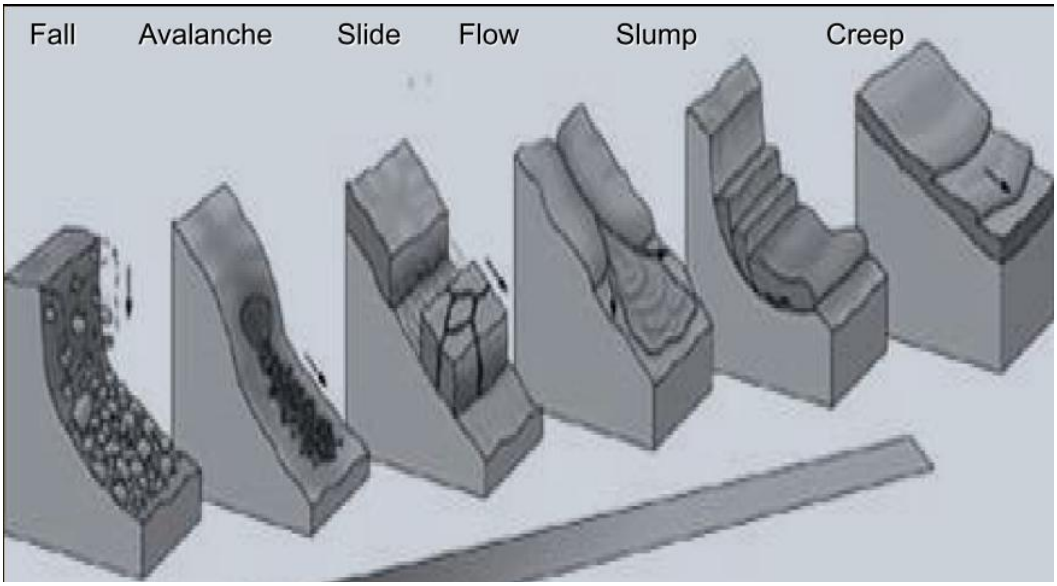
Figure 11.1, 11.2c
Press and Siever: *Understanding Earth*

OHT 56

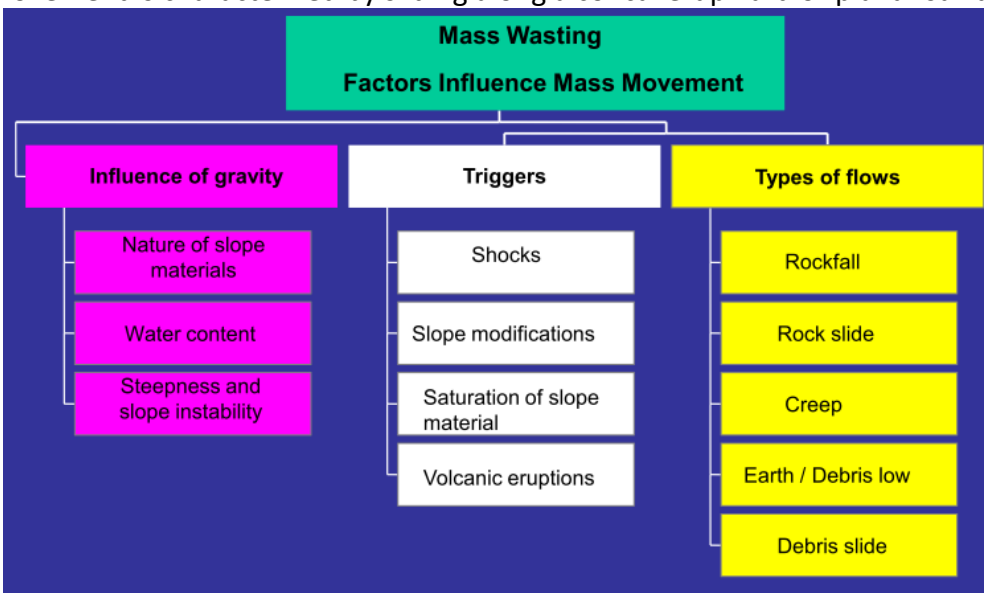
- creep: slow downward progression of rock and soil down a low grade slope; it can also refer to slow deformation of such materials as a result of prolonged pressure and stress



Material / Type of Movement	ROCK	"DEBRIS"	MUD
FALLS	Rockfall	Debrisfall	N/A
SLIDES	Rockslide	Debris Slide	Mudslide
AVALANCHES	Rock Avalanche	Debris Avalanche	N/A
FLOWS	N/A	Debris Flow	Mudflow



- earthflow: flow of fine-grained materials that have been saturated with water, and moves under the pull of gravity. Intermediate between creep and mudflow
- mass movement: movement of surface material caused by gravity
- mass wasting: geomorphic process by which soil, sand, regolith, and rock move downslope typically as a mass, largely under the force of gravity,
- mud flow: saturated with water and moves as liquid
- rock avalanche: chaotic motion of rocks downslope
- rockfall: freefall of rocks
- rockslide: rocks move as a coherent mass
- **talus**: sediment formed from a rockfall
- slump debris slide: a form of mass wasting that occurs when a coherent mass of loosely consolidated materials or rock layers moves a short distance down a slope. Movement is characterized by sliding along a concave-upward or planar surface



ii. Describe the factors that influence the mass movement of materials.

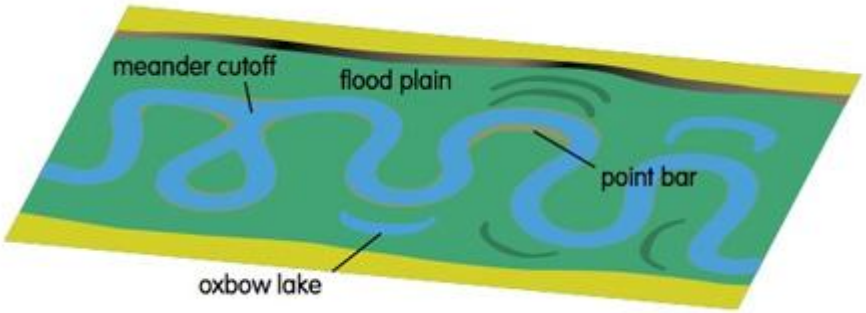
- Shocks, such as earthquakes
- Slope modification, particularly local steepening or removal of toe of slope. The latter is a natural result of undercutting by streams or wave erosion

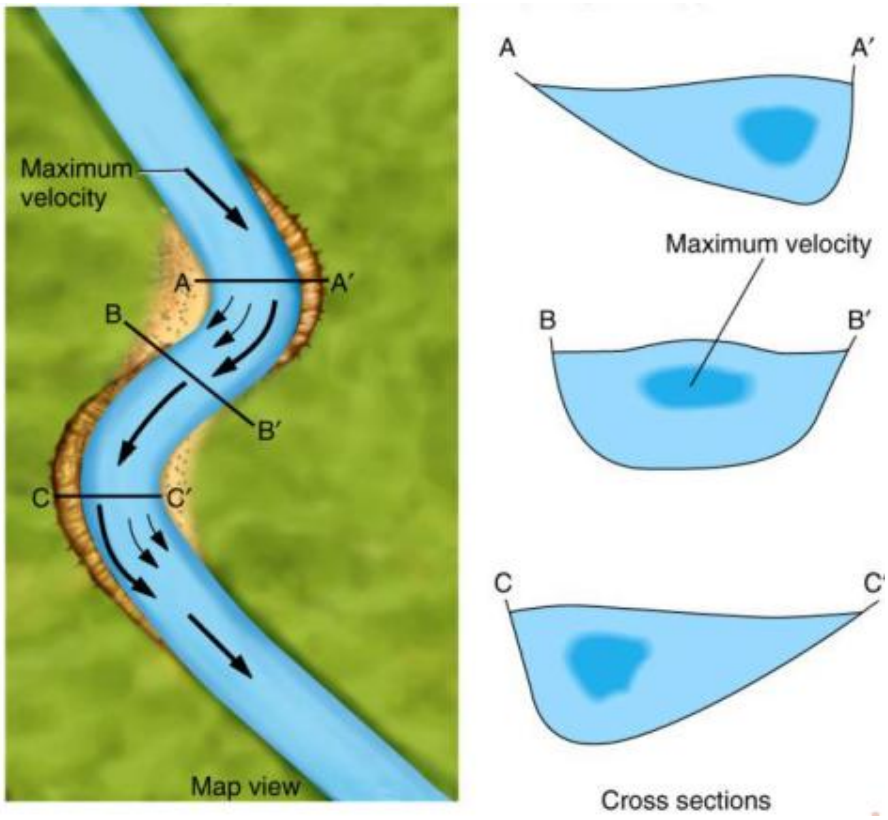
- Saturation of slope material. Heavy or prolonged rain may saturate soil or upper layers of sediment
- Volcanic eruptions. Rapid production of water-saturated, unconsolidated material on slopes creates a slumping and mudflow hazard
- Rock structure joints dipping downslope usually assists landslides, rockfalls, rockslide, rock creep

Rivers and Streams

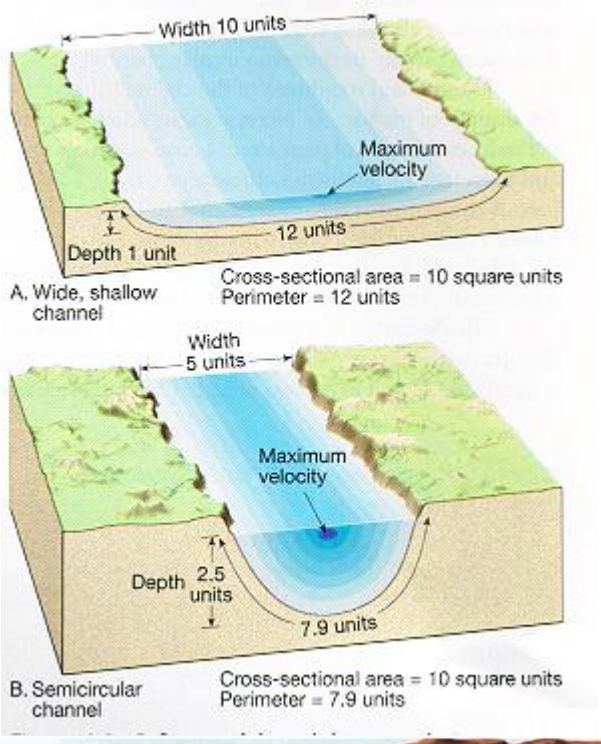
- alluvial fan: a fan- or cone-shaped deposit of sediment crossed and built up by streams. Fans are typically found where a canyon draining from mountainous terrain emerges out onto a flatter plain
- bed load: material slides and rolls along the stream bed
- braided stream: a channel that consists of a network of small channels separated by small and often temporary islands called braid bars. Occur in regions with high sediment loads
- discharge: volume of water flowing past a certain point in a given unit of time; equal to area times velocity. Discharge increases as more water is added through rainfall, tributary streams, or from groundwater seeping into the stream. As discharge increases, generally width, depth, and velocity of the stream also increase.
- delta: a landform that forms at the mouth of a river, where the river flows into an ocean, sea, estuary, lake, or reservoir. Deltas form from deposition of sediment carried by a river as the flow leaves its mouth
- flood plain: an area of land adjacent to a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge
- laminar flow: parallel flow lines
- meander: meanders get bigger (meander more), until finally the meander gets cut off, usually in a flood
- natural levee: elongated ridges along the side of a river forming from deposition of heavy sediment during river floods
- **oxbow lake**: a U-shaped body of water that forms when a wide meander from the main stem of a river is cut off, creating a free-standing body of water
- **point bar**: a depositional feature made of alluvium that accumulates on the inside bend of streams and rivers below the slip-off slope. Point bars are found in abundance in mature or meandering streams
- pothole: holes that were eroded away in bedrock. They are most commonly found in desert environments
- river terrace: remnants of earlier floodplains that existed at a time when either a stream or river was flowing at a higher elevation before its channel downcut to create a new floodplain at a lower elevation
- saltation: a specific type of particle transport by fluids such as wind or water. It occurs when loose material is removed from a bed and carried by the fluid, before being transported back to the surface; pebbles
- stream: a body of water that carries rock particles and dissolved ions and flows down slope along a clearly defined path, called a channel
- suspended load: the portion of the sediment that is carried by a fluid flow which settle slowly enough such that it almost never touches the bed. Silt, sand, clay
- turbulent flow: swirling flow lines, eddy flow

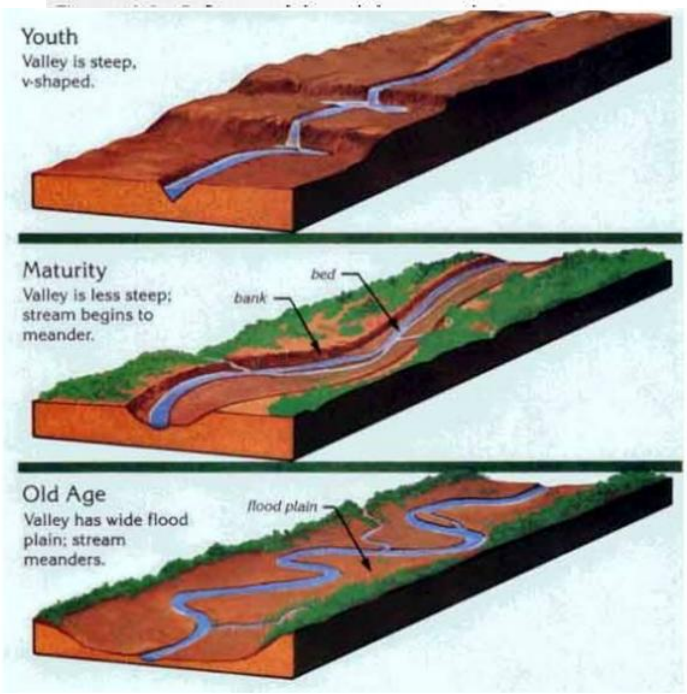
v. Describe how streams erode their channels and transport sediment.



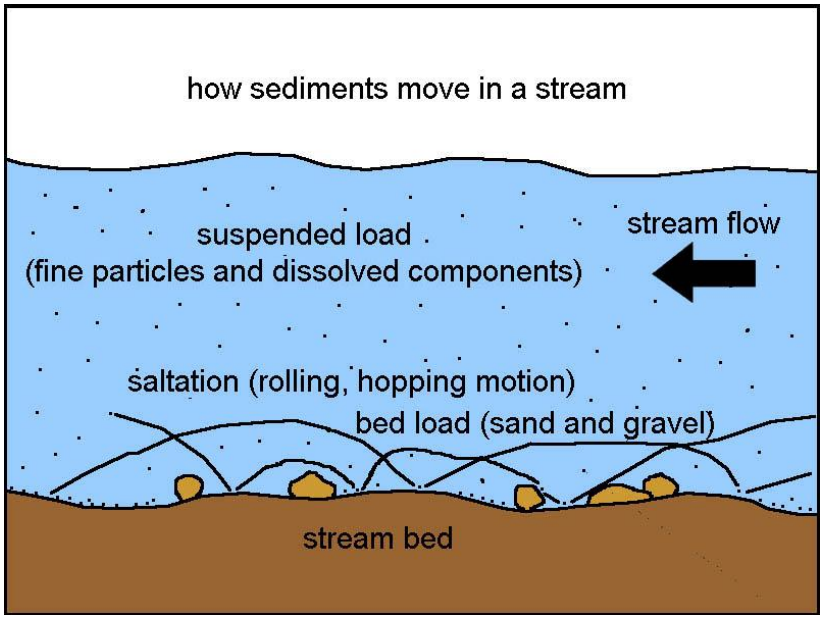


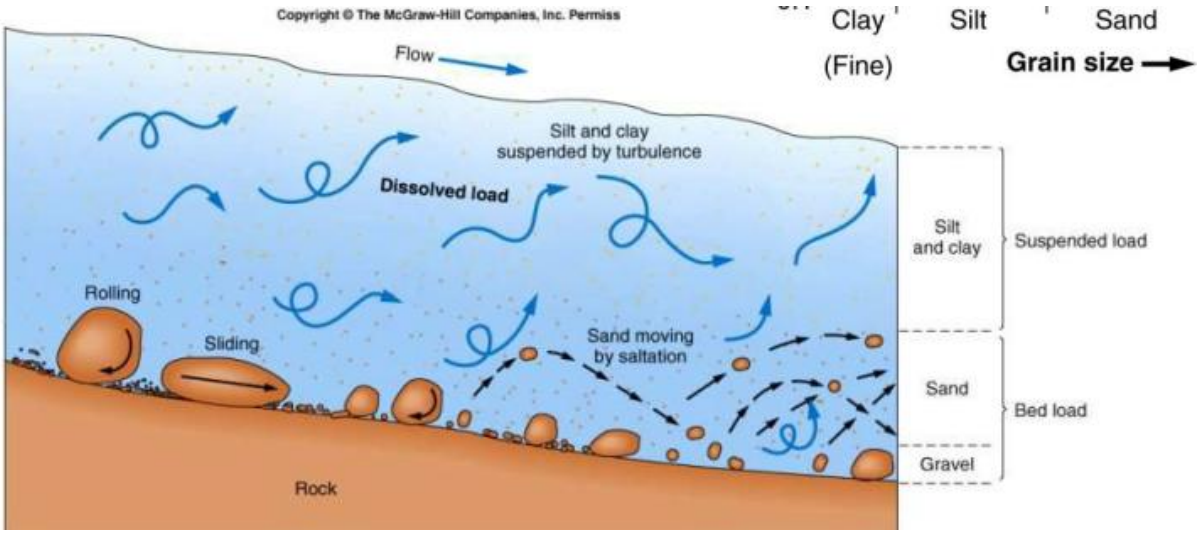
vi. Describe the characteristic forms of stream valleys, channels and floodplains, and the ways in which they form.





vii. Describe the sediments associated with stream processes. You must be able to relate sediment types to the energy of transporting medium and energy at the deposition site.





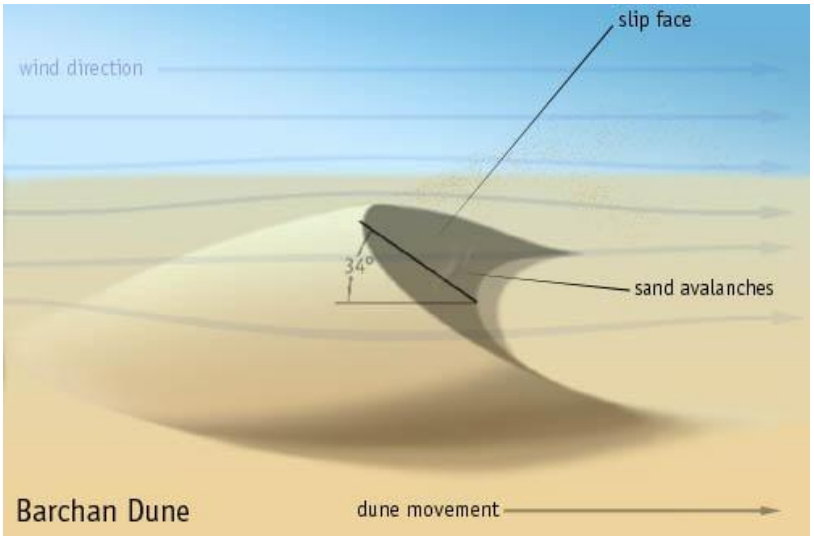
Wind and Deserts

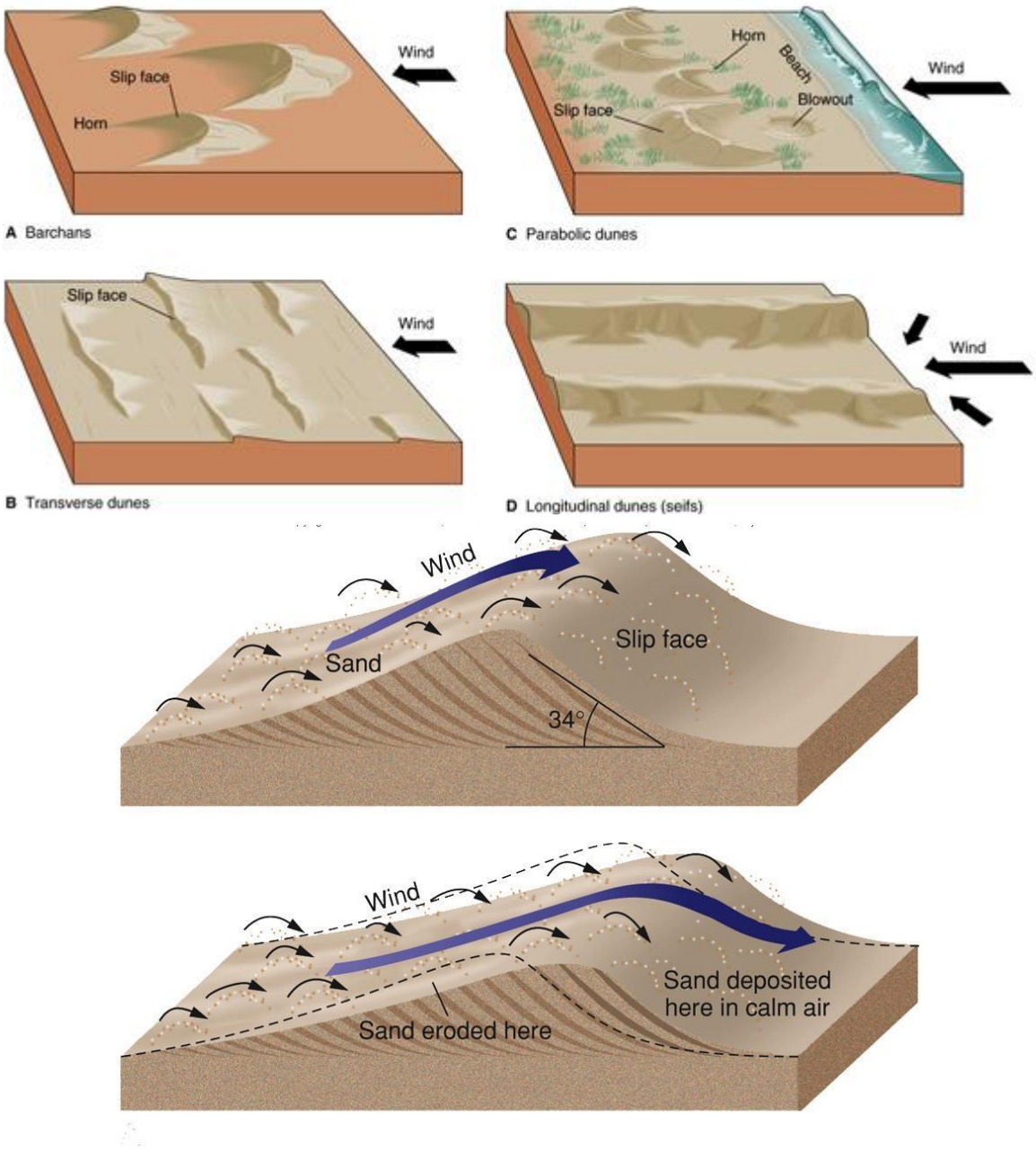
- abrasion: occurs when rock is scoured by windborne grains of sedimen, forming flattened rock services called ventifacts
- **bajada**: a series of coalescing alluvial fans along a mountain front
- barchan: crescent shaped sand dunes that face the wind
- blowout: sandy depressions in a sand dune ecosystem caused by the removal of sediments by wind
- **deflation**: the process by which the wind erodes the surface of Earth. It refers to a lowering of the land surface
- desert pavement: residual gravels that could not be lifted off by wind.
- desert pediment: very gently sloping (.5°-7°) inclined bedrock surface caused by erosion
- aeolian processes: wind erosion and transportation processes
- evaporite: a water-soluble mineral sediment that results from concentration and crystallization by evaporation from an aqueous solution. Type of sedimentary rock

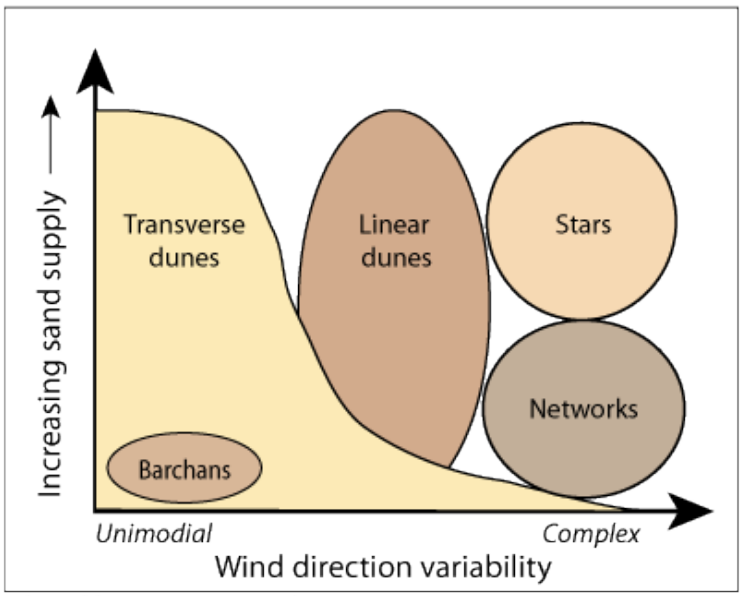
- loess: predominantly silt-sized sediment that is formed by the accumulation of wind-blown dust. Homogenous, pale yellow, made up of quartz, feldspar and mica. Reistant to slumping; rich farm soil. Much loess was derived from debris left by glacial erosion and winds blowing across desert regions
- playa lake: dry desert lake beds where salts build up through precipitation
- sand drift: movement of sand dunes over time as sand accumulates at the upper edge of the lee slope (slope on opposite side to wind direction), the angle of repose is exceeded and sand slips down the lee side

xii. Describe how winds erode, transport and deposit fine-grained sediment; explain the process of dune formation.

- Ample supply of sand, strong, unidirectional winds and little vegetation lead to bigger dunes (not surprisingly)
- **Barchan Dunes** - are crescent-shaped dunes with the points of the crescents pointing in the downwind direction, and a curved slip face on the downwind side of the dune. They form in areas where there is a hard ground surface, a moderate supply of sand, and a constant wind direction.
- Transverse Dunes - are large fields of dunes that resemble sand ripples on a large scale. They consist of ridges of sand with a steep face in the downwind side, and form in areas where there is abundant supply of sand and a constant wind direction. Barchan dunes merge into transverse dunes if the supply of sand increases.
- Longitudinal Dunes - are long straight dunes that form in areas with a limited sand supply and converging (bidirectional) wind directions.
- Parabolic Dunes - are "U" shaped dunes with an open end facing upwind. They are usually stabilized by vegetation, and occur where there is abundant vegetation, a constant wind direction, and an abundant sand supply. They are common in coastal areas.




Wind
Slip face
Horn
A Barchans
Horn
Beach
Wind
Slip face
Blowout
C Parabolic dunes
Slip face
Wind
B Transverse dunes
Wind
D Longitudinal dunes (seifs)
Wind
Sand
Slip face
34°
Wind
Sand deposited
here in calm air
Sand eroded here



Adapted from Livingstone and Warren (1996, 80)

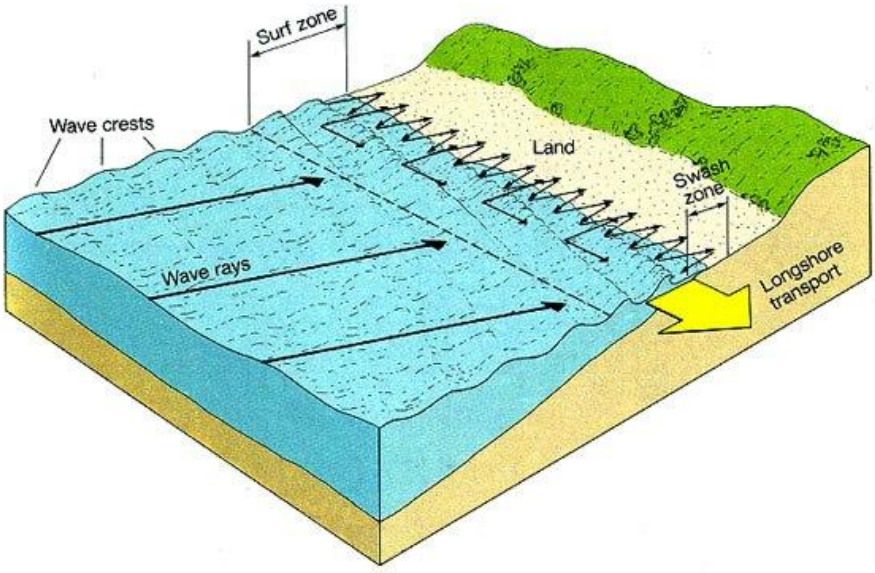
Oceans and Coasts

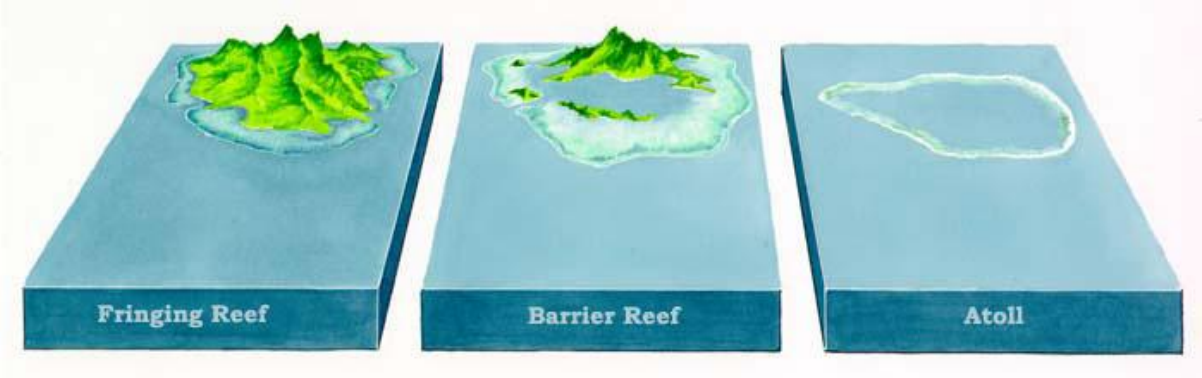
- active margin: a convergent plate boundary
- **atoll**: a ring-shaped coral reef including a coral rim that encircles a lagoon partially or completely, often atop an extinct volcano
- backwash: turbulent layer of water that washes down on the beach after an incoming wave has broken (swash)
- barrier island: long coastal islands thought to form from detached spits
- beach: a landform along the coast of an ocean, sea, lake or river. It usually consists of loose particles, which are often composed of rock
- emergence: coastal landform produced by falling local sea levels
- estuary: a partly enclosed coastal body of brackish water with one or more rivers or streams flowing into it, and with a free connection to the open sea
- **guyot**: an isolated underwater volcanic mountain (seamount), with a flat top over 200 metres (660 feet) below the surface of the sea
- longshore beach drift: transportation of sediments (clay, silt, sand and shingle) along a coast at an angle to the shoreline
- oozes: a siliceous pelagic sediment that covers large areas of the deep ocean floor. Siliceous oozes consist predominantly of the remains of microscopic sea creatures
- passive margin: the transition between oceanic and continental lithosphere which is not an active plate margin
- pelagic sediment: a fine-grained sediment that accumulates as the result of the settling of particles to the floor of the open ocean, far from land. These particles consist primarily of either the microscopic, calcareous or siliceous shells of phytoplankton or zooplankton
- **sea mount**: a mountain rising from the ocean seafloor that does not reach to the water's surface
- shoreline: the fringe of land at the edge of a large body of water
- spit: a deposition bar or beach landform found off coasts. It develops in places where re-entrance occurs, such as at a cove's headlands, by the process of longshore drift and longshore currents

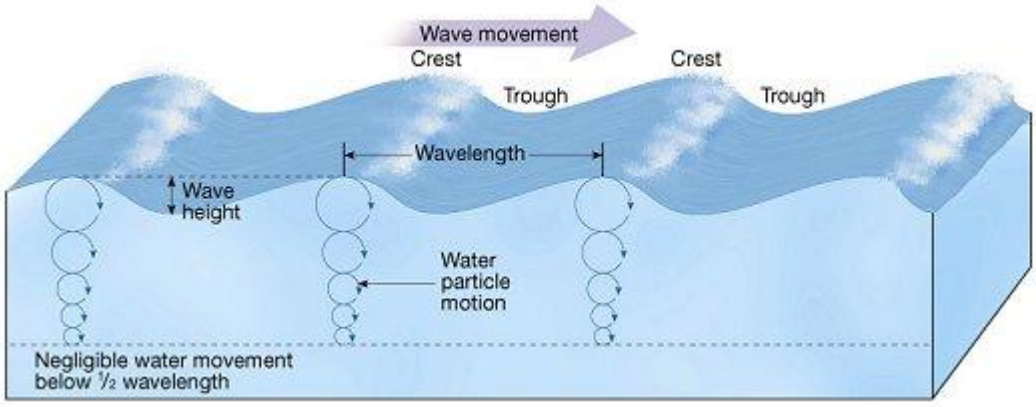
- stack: a geological landform consisting of a steep and often vertical column or columns of rock in the sea near a coast, formed by erosion
- submarine canyon: a steep-sided valley cut into the sea floor of the continental slope
- submarine fan: underwater geological structures associated with large-scale sediment deposition and formed by turbidity currents
- submergence: drowned coastal landform, for example an estuary
- surf: wave activity in the area between the shoreline and outer limit of breakers
- surf zone: region of breaking waves
- turbidite: the geologic deposit of a turbidity current
- **turbidity current**: a current of rapidly moving, sediment-laden water moving down a slope through water
- wave refraction: occurs when wave fronts are inclined with respect to the shoreline wave-cut terrace/bench
- wind wave: formed by the action of wind or from severe storm centres at various distances from the coast (may be far away)
- wave-cut platform: a wave-cut platform, coastal benches, or wave-cut benches is the narrow flat area often found at the base of a sea cliff or along the shoreline of a lake, bay, or sea that was created by the erosion of wave

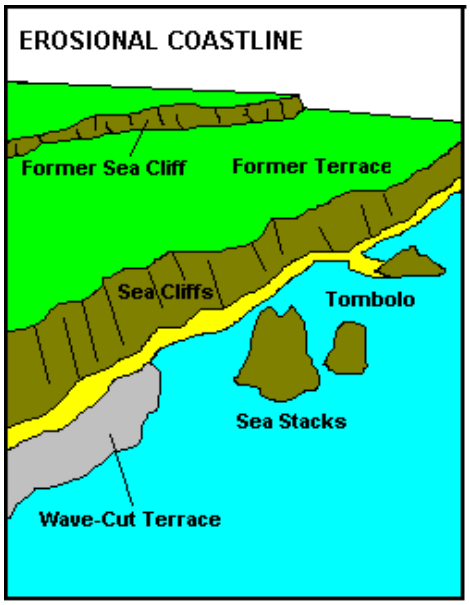
viii. Explain the processes that control the formation and dynamics of shorelines. Recognise, and explain the origins of, common landforms that form coastlines.

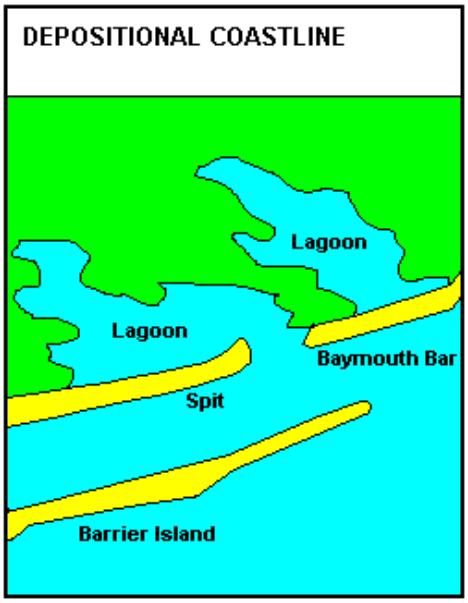
- Erosional landforms: rock cliffs, stacks, caves, wave-cut terraces
- Depositional landforms: beaches, spits and barrier islands



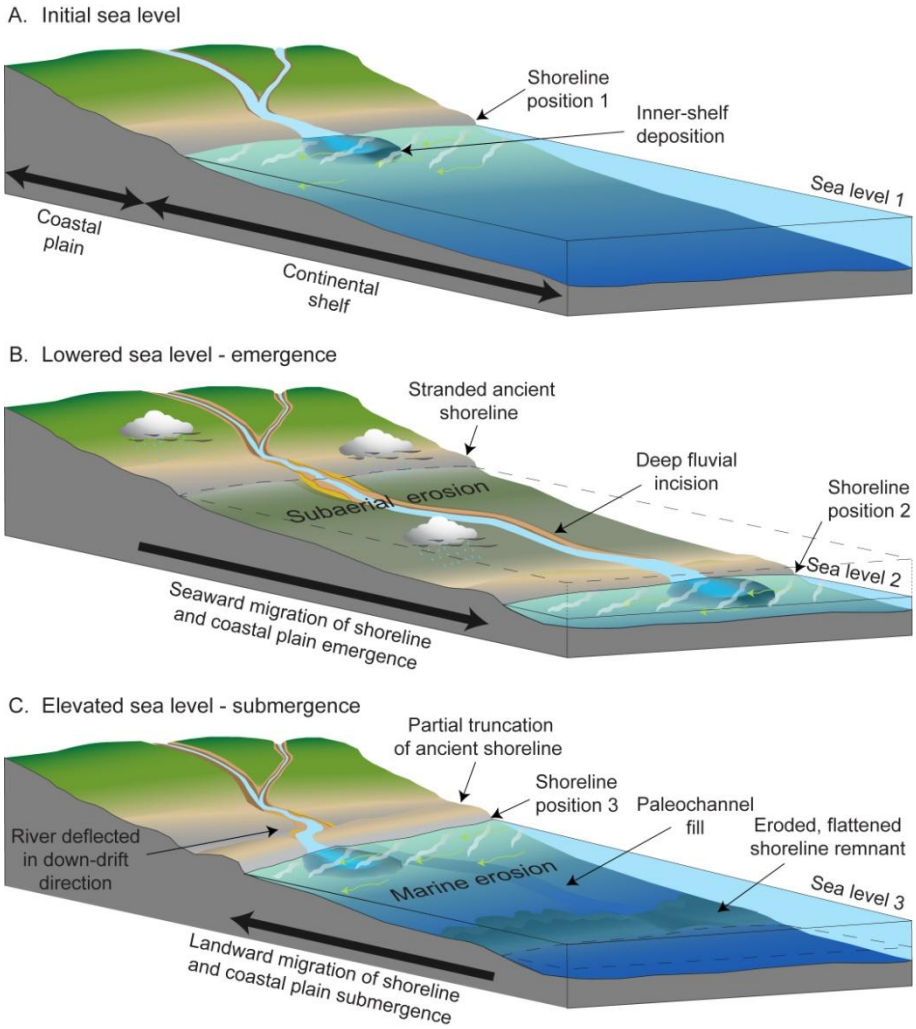


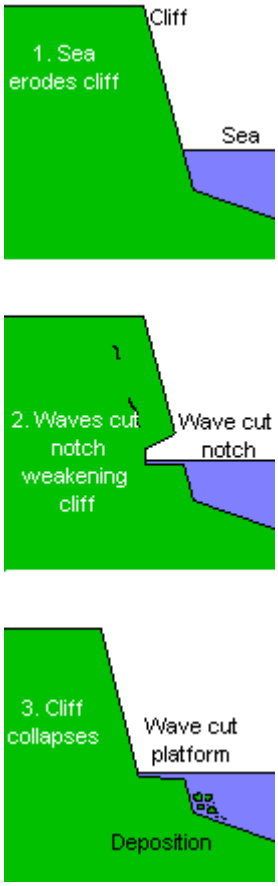






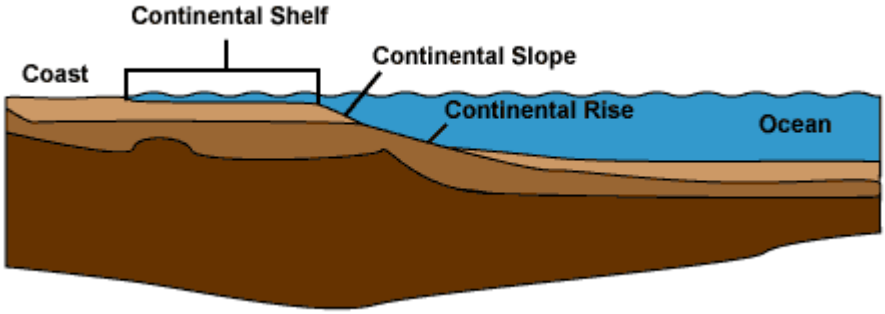
ix. Distinguish between landforms formed on emerging and submerging shorelines.

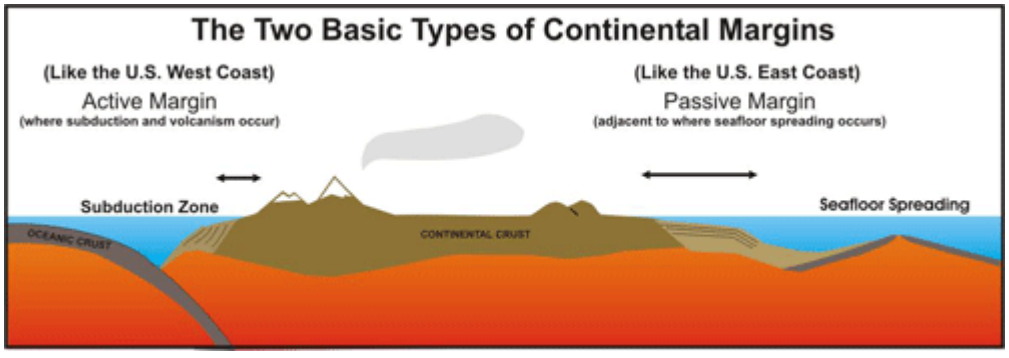

A. Initial sea level
Shoreline position 1
Inner-shelf deposition
Sea level 1
Coastal plain
Continental shelf
B. Lowered sea level - emergence
Stranded ancient shoreline
Deep fluvial incision
Shoreline position 2
Subaerial erosion
Sea level 2
Seaward migration of shoreline and coastal plain emergence
C. Elevated sea level - submergence
Partial truncation of ancient shoreline
Shoreline position 3
Paleochannel fill
Eroded, flattened shoreline remnant
River deflected in down-drift direction
Marine erosion
Sea level 3
Landward migration of shoreline and coastal plain submergence



x. Describe and explain the origin of **active and passive continental margins and the sediment associated with them.**

- Passive continental margin: located well away from plate margins, characterised by wide continental shelves and by clastic, well-sorted sedimentation
- Active continental margins: located close to plate margins, associated with subduction and characterised by poorly sorted sediments with a significant volcanic component

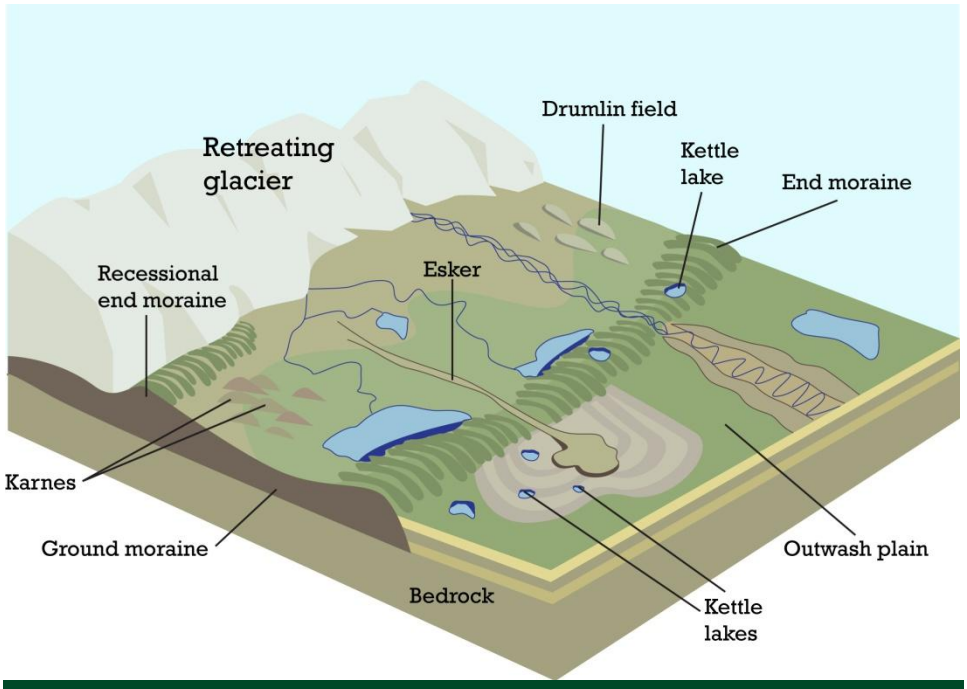


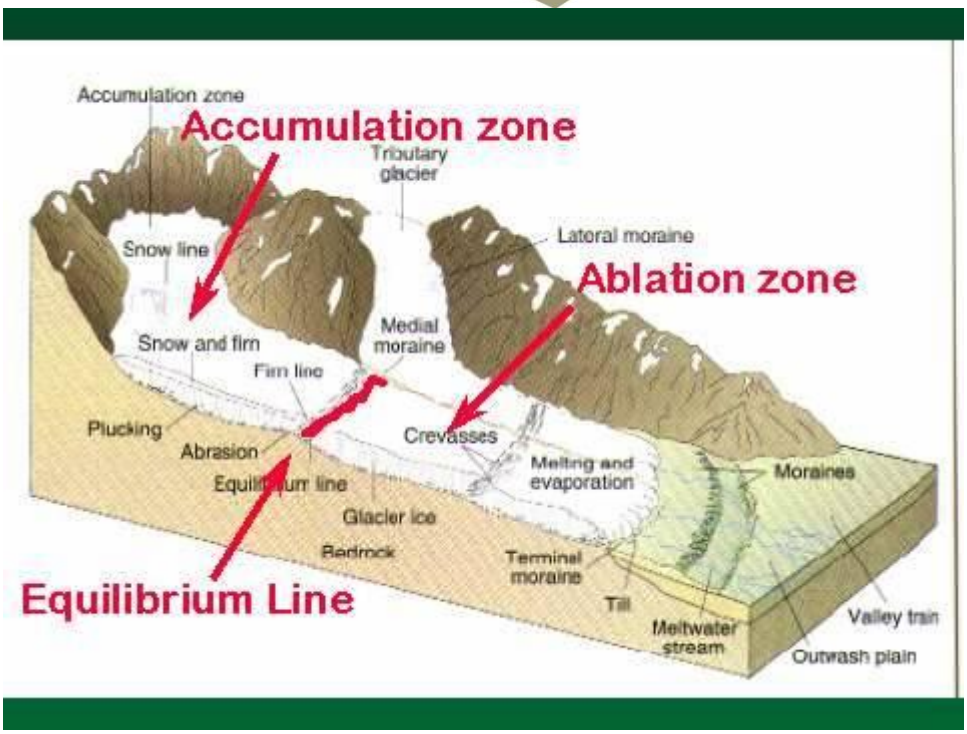


Glaciers and Polar Ice

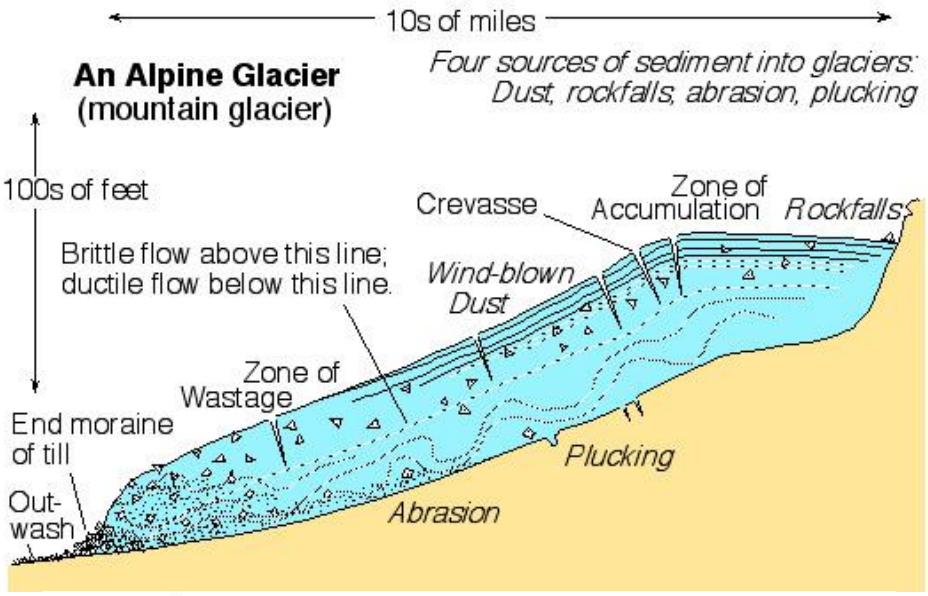
- ablation: ablation—the opposite of accumulation—refers to all processes that remove snow, ice, or water from a glacier or snowfield
- accumulation: adding of ice to glacier by snowfall
- alpine glacier: form by accumulation of snow and movement of ice (under gravity) down valleys
- basal slip: the act of a glacier sliding over the bed due to meltwater under the ice acting as a lubricant
- continental glacier: extensive domes of ice up to 3000 km thick
- continental ice sheet: ice sheets floating on the ocean after a continental glacier is pushed out to sea
- crevasse: deep fractures in the surface of glacial ice
- **drumlin**: an elongated hill formed by glacial ice acting on underlying unconsolidated till or ground moraine
- erratic boulder: a piece of rock that differs from the size and type of rock native to the area in which it rests, carried by glacial ice, often over distances of hundreds of kilometre
- firn: a compressed form of snow
- fiord: a long, narrow inlet with steep sides or cliffs, created by glacial erosion
- glacier: a persistent body of dense ice that is constantly moving under its own weight
- glacial drift
- hanging valley: a tributary valley that is higher than the main valley. They are most commonly associated with U-shaped valleys when a tributary glacier flows into a glacier of larger volume. The main glacier erodes a deep U-shaped valley with nearly vertical sides while the tributary glacier, with a smaller volume of ice, makes a shallower U-shaped valley
- medial moraine: forms when two glaciers meet and the debris on the edges of the adjacent valley sides join and are carried on top of the enlarged glacier
- moraine: any glacially formed accumulation of unconsolidated glacial debris (soil and rock) that occurs in currently glaciated and formerly glaciated regions on Earth
- outwash: a plain formed of glacial sediments deposited by meltwater outwash at the terminus of a glacier
- **rock flour**: fine-grained, silt-sized particles of rock, generated by mechanical grinding of bedrock by glacial erosion or by artificial grinding to a similar size. Because the material is very small, it becomes suspended in meltwater making the water appear cloudy, which is sometimes known as glacial milk
- striation: scratches or gouges cut into bedrock by glacial abrasion, the result of gravel and bounders carried at the base of the glacier
- till: unsorted sediment deposited directly by glaciers
- **varve shale**: an annual layer of sediment or sedimentary rock, often found in glacial lake sediments from annual thawing

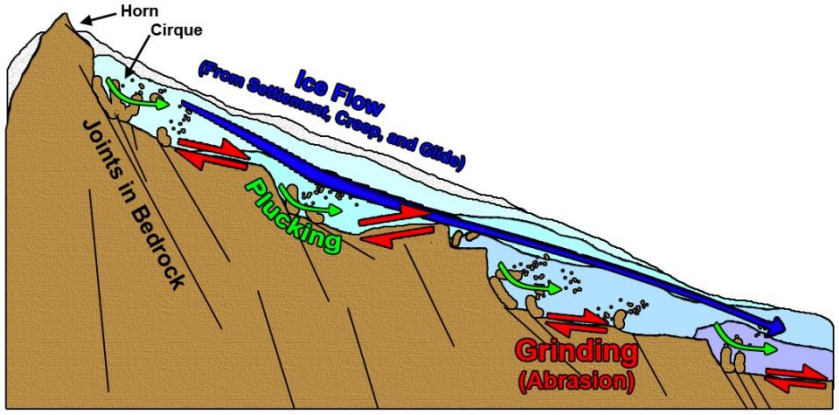
xiii. Describe how glaciers and ice sheets form and how they move.



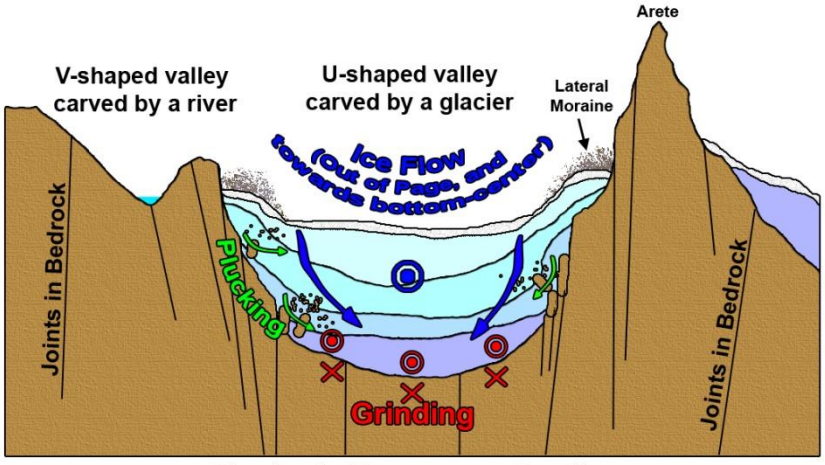


xiv. Describe how glaciers erode bedrock, transport and deposit sediment, and shape the landscape.





Glacier in Longitudinal Section



Glacier in Transverse Section

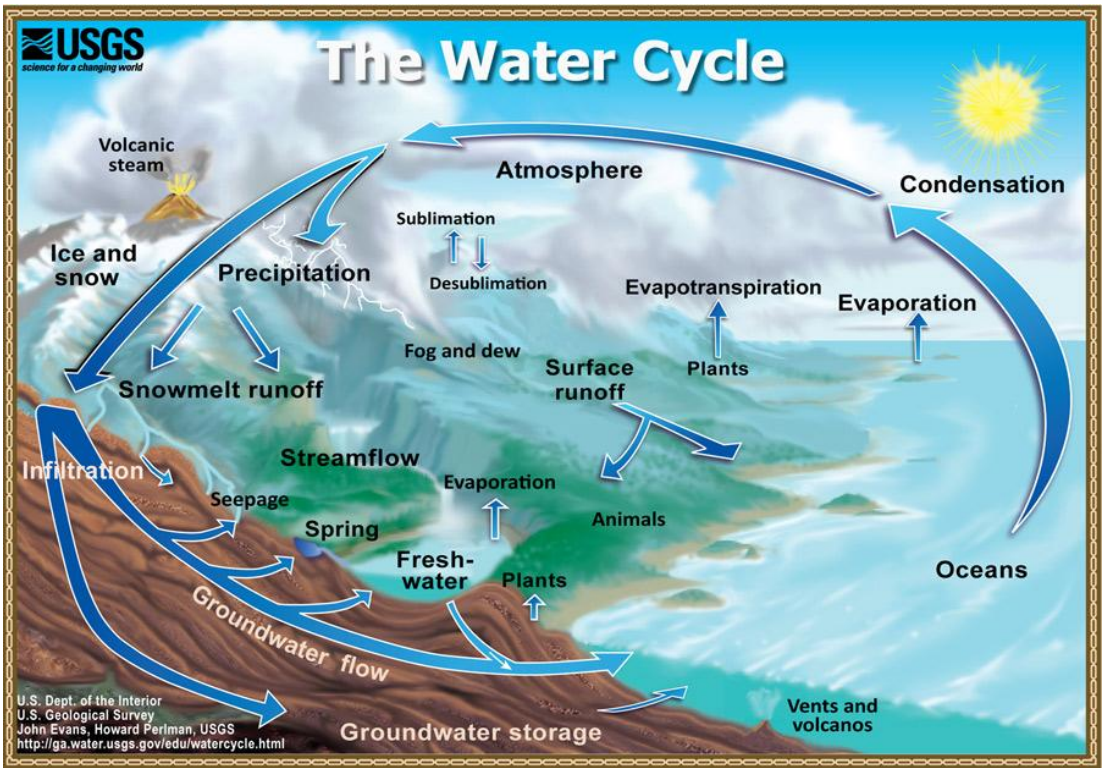
11. Groundwater

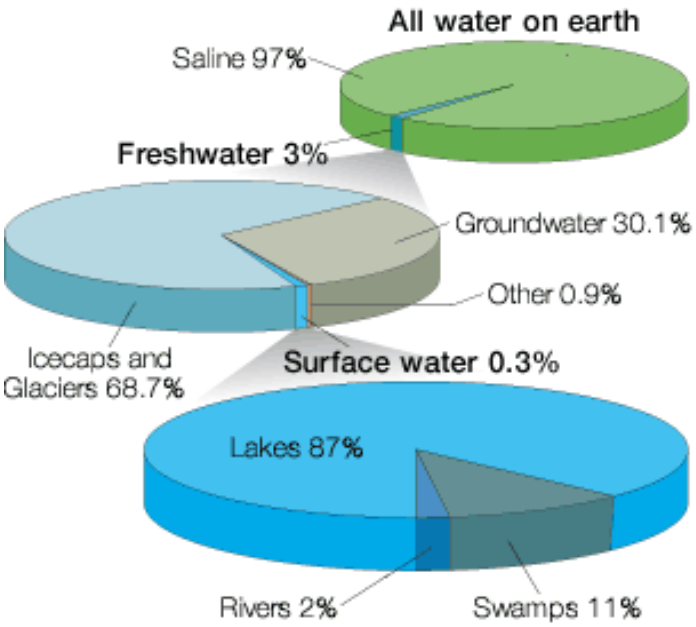
Key Concepts

- aerated zone: zone of regolith or bedrock beneath moist (top) layer of soil in which open spaces are filled with air
- aquiclude: a solid, impermeable area underlying or overlying an aquifer
- aquifer: an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt) from which groundwater can be extracted using a water well
- **artesian spring**: occur when the groundwater, under pressure, finds its way to the land surface
- artesian well: a confined aquifer containing groundwater under positive pressure
- capillary fringe: area (about 60 cm thick) above the water table in fine-grained sediment that is kept wet by capillary action pulling water from the water table
- cone of depression: occurs in an aquifer when groundwater is pumped from a well
- confined aquifer: bounded by aquicludes
- connate water: liquids that were trapped in the pores of sedimentary rocks
- discharge: areas where sub-surface water is discharged to streams, lakes, ponds
- drawdown: a lowering of a reservoir or a change in hydraulic head in an aquifer, typically due to pumping a well
- hard water: water that has high mineral content, formed when water percolates through deposits of limestone and chalk
- **hydraulic head**: a specific measurement of liquid pressure, equals pressure + elevation
- infiltration: he process by which water on the ground surface enters the soil
- **juvenile water**: water that exists within, and in equilibrium with, a magma or water-rich volatile fluids that are derived from a magma. This magmatic water is released to the atmosphere during a volcanic eruption
- karst topography: a landscape formed from the dissolution of soluble rocks such as limestone, dolomite, and gypsum. It is characterized by underground drainage systems with sinkholes, dolines, and caves
- **meteroic water**: water derived from precipitation, as opposed to e.g. magmatic water
- percolation: the movement and filtering of fluids through porous materials.
- permeability: a measure of how easily a solid allows fluids to pass through it. clay: has a high porosity but low permeability due to its ability to absorb water
- porosity: percentage of the volume of a body of regolith or bedrock that contains pores
- recharge: areas where precipitation seeps downward beneath the surface and reaches the saturated zone
- reservoir: a natural or artificial lake, storage pond, or impoundment from a dam which is used to store water
- runoff: If the precipitation rate exceeds the infiltration rate, water will flow over the earth's surface as runoff unless there is some physical barrier
- saturated zone: zone beneath saturated zone in which opening in regolith or bedrock are filled with water
- seawater intrusion: movement of saline water into freshwater aquifers, which can lead to contamination of drinking water sources and other consequences
- sinkhole: a depression or hole in the ground caused by some form of collapse of the surface layer
- spring: a flow of groundwater emerging naturally at the ground surface
- transpiration: the process by which moisture is carried through plants from roots to small pores on the underside of leaves, where it changes to vapor and is released to the atmosphere
- unconfined aquifer: upper surface coincides with the water table

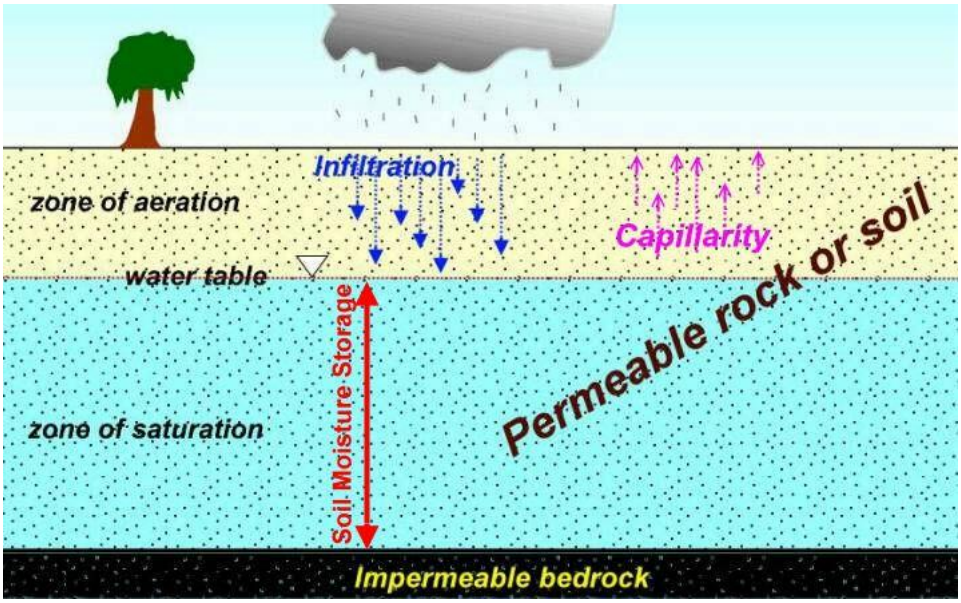
- water-table: upper surface of the zone of saturation
- well: intersects the water table and is able to provide water

Distribution of Water

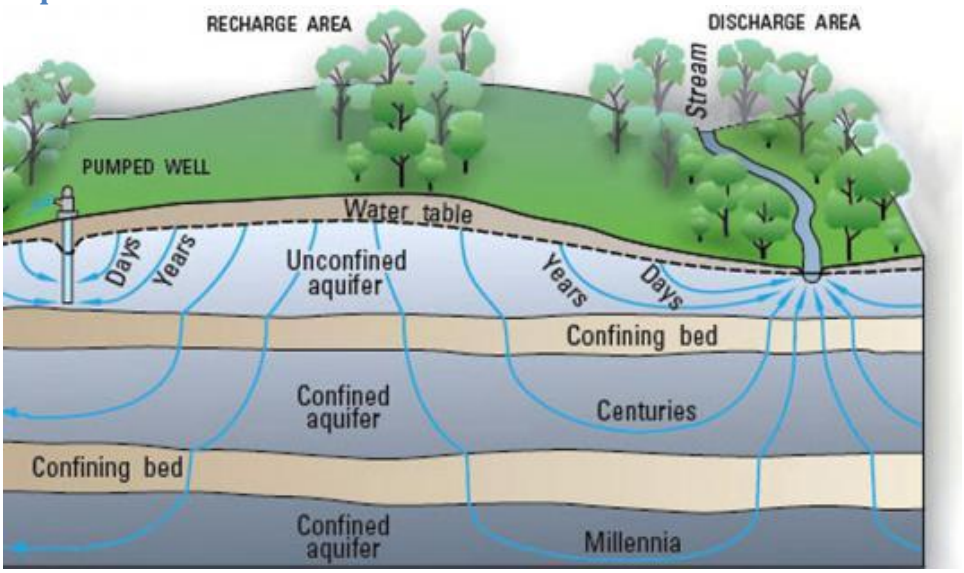


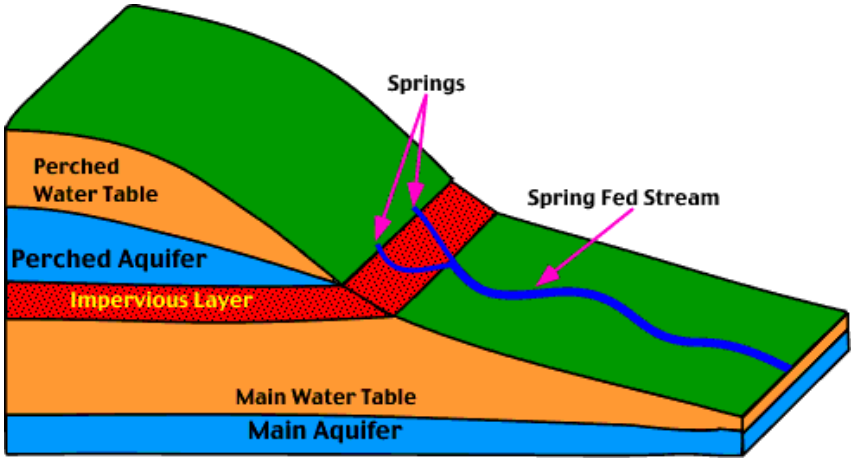


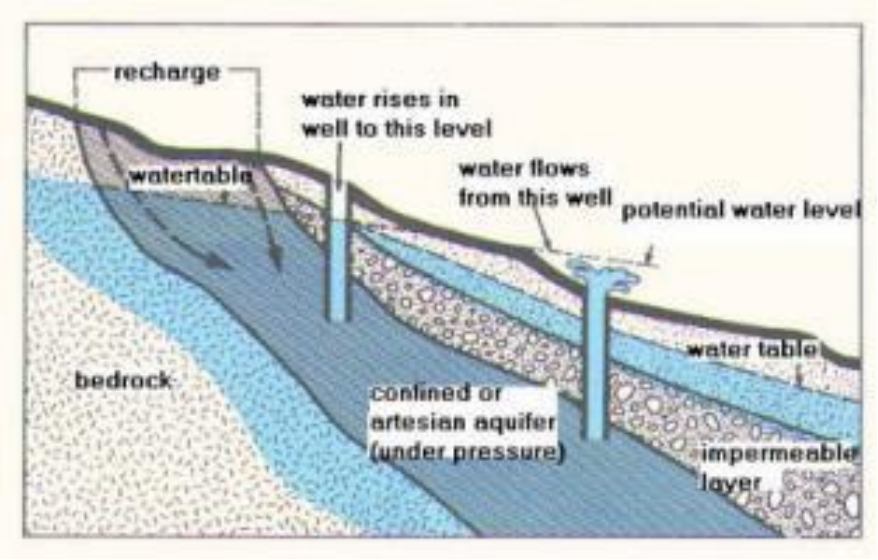
Zone of Saturation



Types of Aquifers

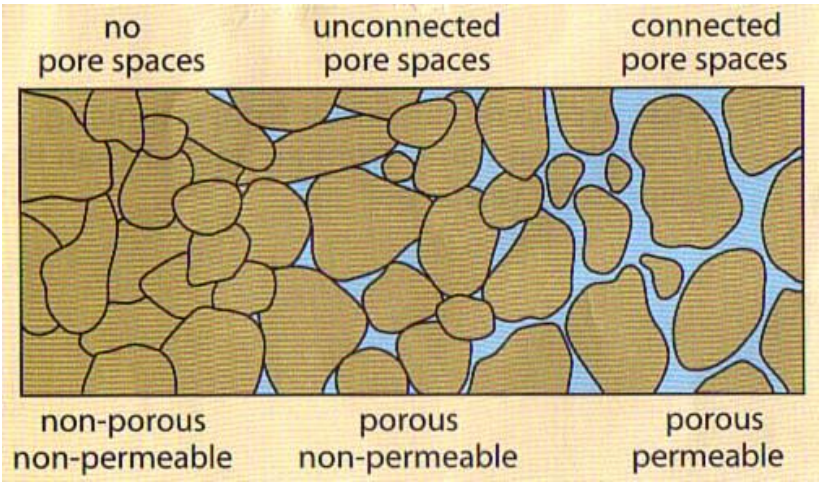




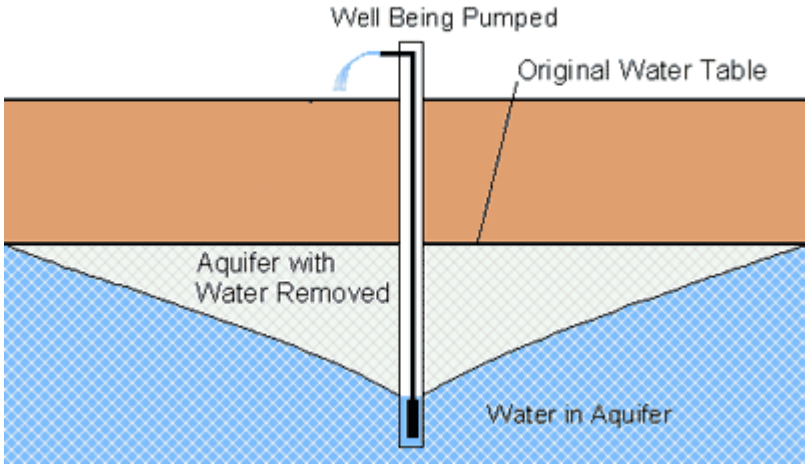


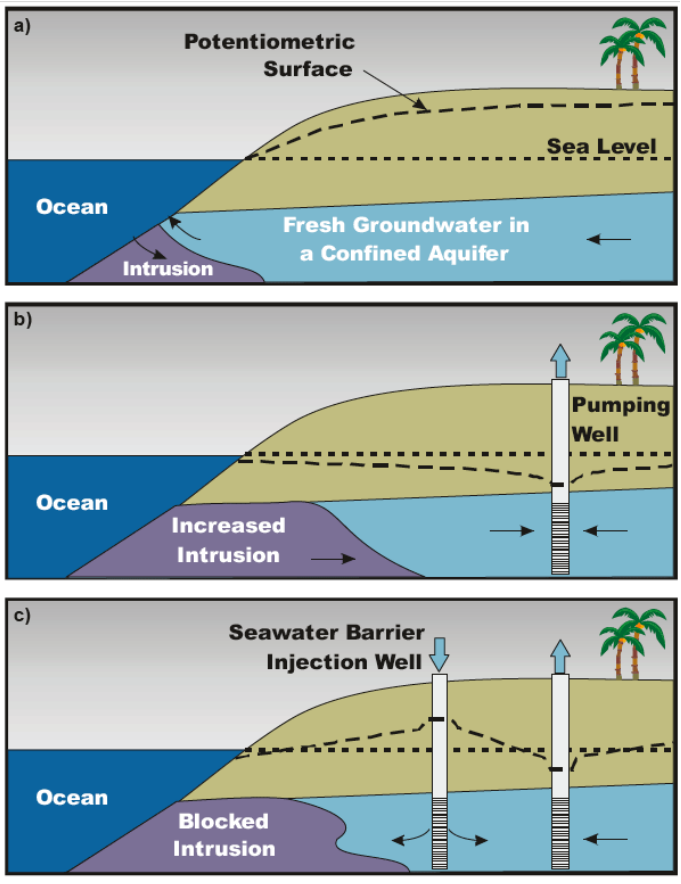
Porosity and Permeability

- Effected by sizes and shapes of rock particles, compactness of their arrangement, degree of sorting, extent of cementation etc.
- Porosity of igneous and metamorphic rocks is low, while a sedimentary rock with little cementation will have high porosity
- A well-sorted sediment may have a porosity of around 20 %, while a swell-able clay may have a porosity of 50 %

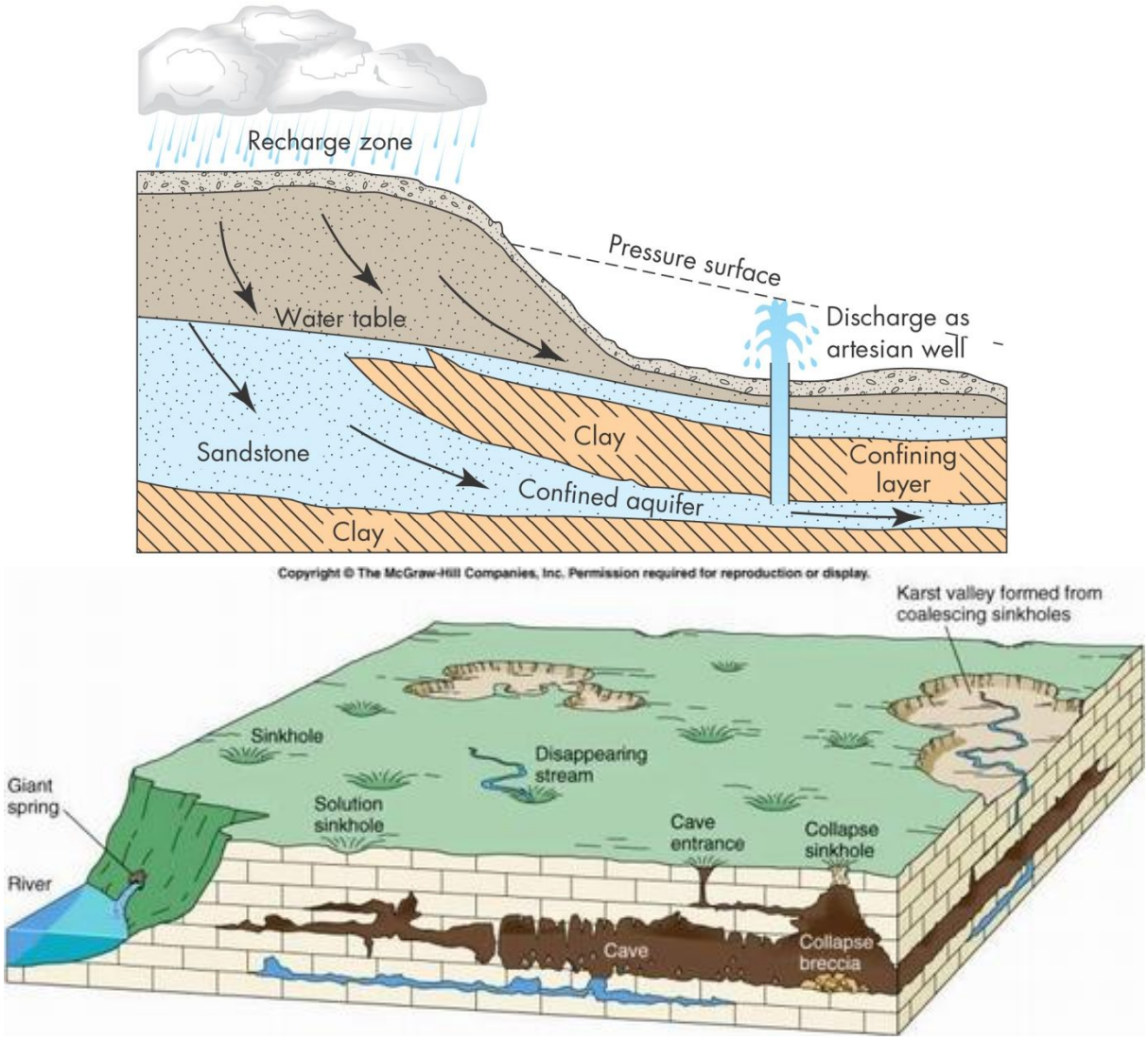


Aquifer Pumping





Artesian Wells



12. Plate Tectonics

Key Concepts

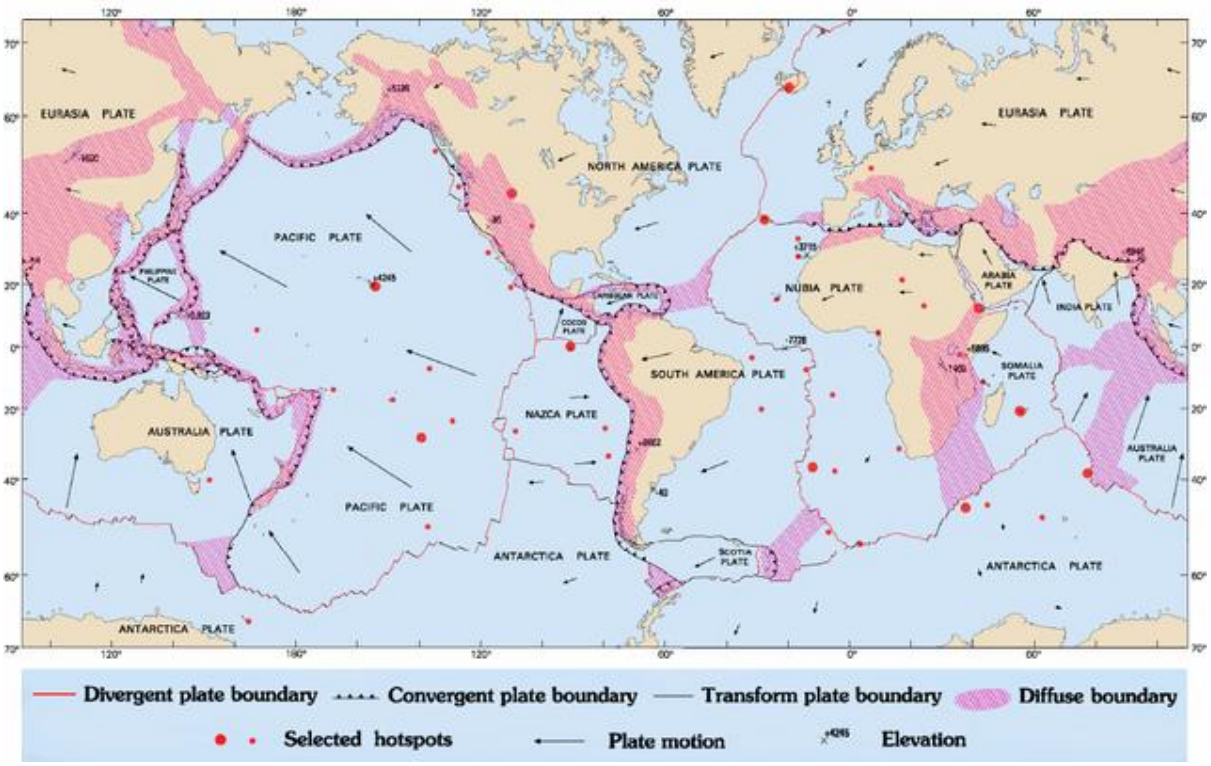
- active zones: a fault that is likely to become the source of another earthquake sometime in the future
- apparent polar wandering: the perceived movement of the Earth's paleo-magnetic poles relative to a continent while regarding the continent being studied as fixed in position, mostly in fact due to continental motion as magnetic poles don't move much
- **back-arc basin**: submarine basin that forms behind an island arc. Such basins are typically found along the western margin of the Pacific Ocean near the convergence of two tectonic plates
- conservative margin: like a transform fault
- cratons: ancient cores of continents (e.g. Pilbara Craton)
- orogens: ancient folded mountain belts that have been eroded to expose their deformed and metamorphosed roots
- continental collision margin: because it contains thick continental crust, this lithosphere is less dense than the underlying asthenospheric mantle and normal

subduction is disrupted. The volcanic arc on the upper plate is slowly extinguished. Resisting subduction, the crust buckles up and under, raising mountains where a trench used to be

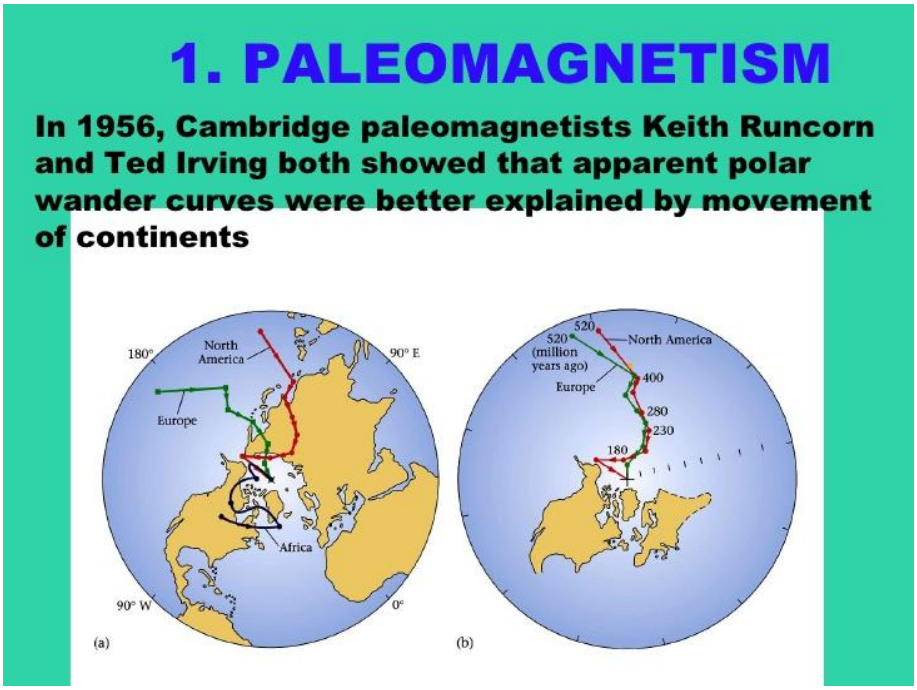
- convergent margin: plates move toward each other
- divergent margin: plates move away from each other
- **fore-arc basin**: the region between an oceanic trench and the associated volcanic arc. As such, forearc regions are found at convergent margins, and include any accretionary wedge and forearc basin that may be present
- **fore-arc ridges**: form by crumpling and thrusting at the edge of the overriding plate
- geological fit: fit between the continents indicating previous joining
- hot-spot: volcanic regions thought to be fed by underlying mantle that is anomalously hot compared with the surrounding mantle
- isochron: a line of best fit connecting measurements of isotope concentrations for two different elements, which enables calculation of an estimated age of the sample
- magmatic island arc: a chain of volcanoes formed above a subducting plate, positioned in an arc shape as seen from above. The oceanic plate is saturated with water, and volatiles such as water drastically lower the melting point of the mantle. As the oceanic plate is subducted, it is subjected to greater and greater pressures with increasing depth. This pressure squeezes water out of the plate and introduces it to the mantle. Here the mantle melts and forms magma at depth under the overriding plate. The magma ascends to form an arc of volcanoes parallel to the subduction zone.
- magnetic striping: alternating patterns of the magnetic polarity of igneous rocks forming the oceanic crust as a result of periodic reversals in the polarity of Earth's magnetic field
- mantle plume: posited to exist where hot rock nucleates at the core-mantle boundary and rises through the Earth's mantle becoming a diapir in the Earth's crust
- **melange**: slices of sediment that are caught between the overriding and subducting plates. Large-scale melanges formed in active continental margin settings generally consist of altered oceanic crustal material and blocks of continental slope sediments in a sheared mudstone matrix
- palaeomagnetism: the study of the record of the Earth's magnetic field in rocks, sediment, or archeological materials. Certain minerals in rocks lock-in a record of the direction and intensity of the magnetic field when they form. This record provides information on the past behavior of Earth's magnetic field and the past location of tectonic plates
- Pangaea: a supercontinent that existed during the late Paleozoic and early Mesozoic eras. It assembled from earlier continental units approximately 300 million years ago, and it began to break apart about 175 million
- passive continental margin: the transition between oceanic and continental lithosphere which is not an active plate margin. Passive margins are found at every ocean and continent boundary that is not marked by a strike-slip fault or a subduction zone.
- seafloor spreading: process that occurs at mid-ocean ridges, where new oceanic crust is formed through volcanic activity and then gradually moves away from the ridge. The phenomenon is known to be caused by convection currents in the plastic, very weak upper mantle, or asthenosphere

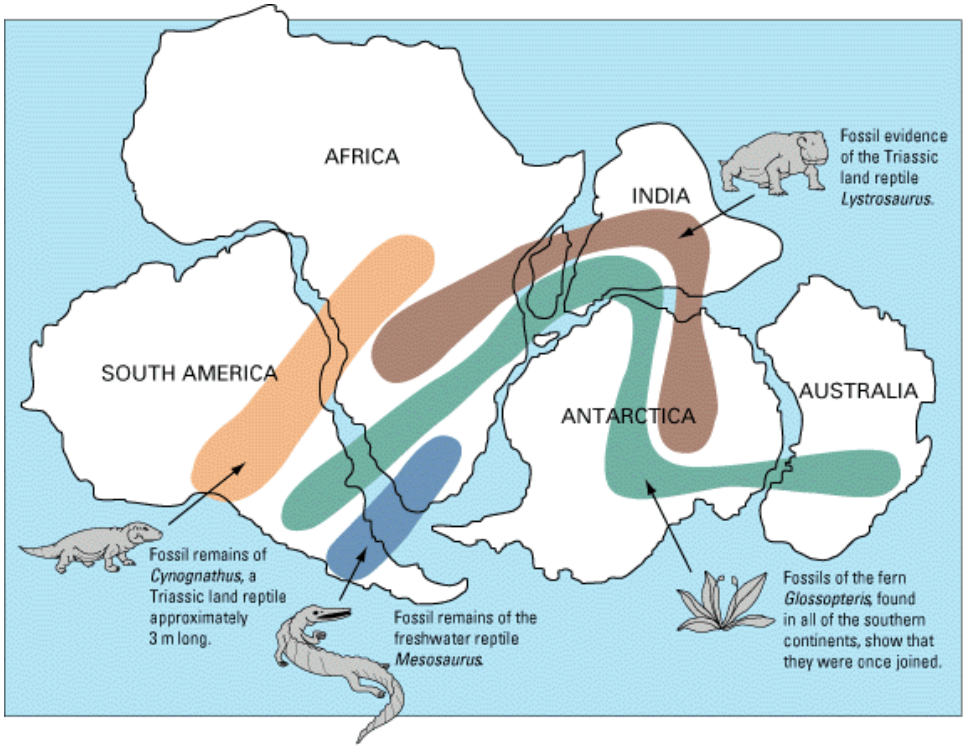
- subduction zone: the process that takes place at convergent boundaries by which one tectonic plate moves under another tectonic plate and sinks into the mantle as the plates converge
- transform fault margin: also known as conservative plate boundary since these faults neither create nor destroy lithosphere, is a type of fault whose relative motion is predominantly horizontal

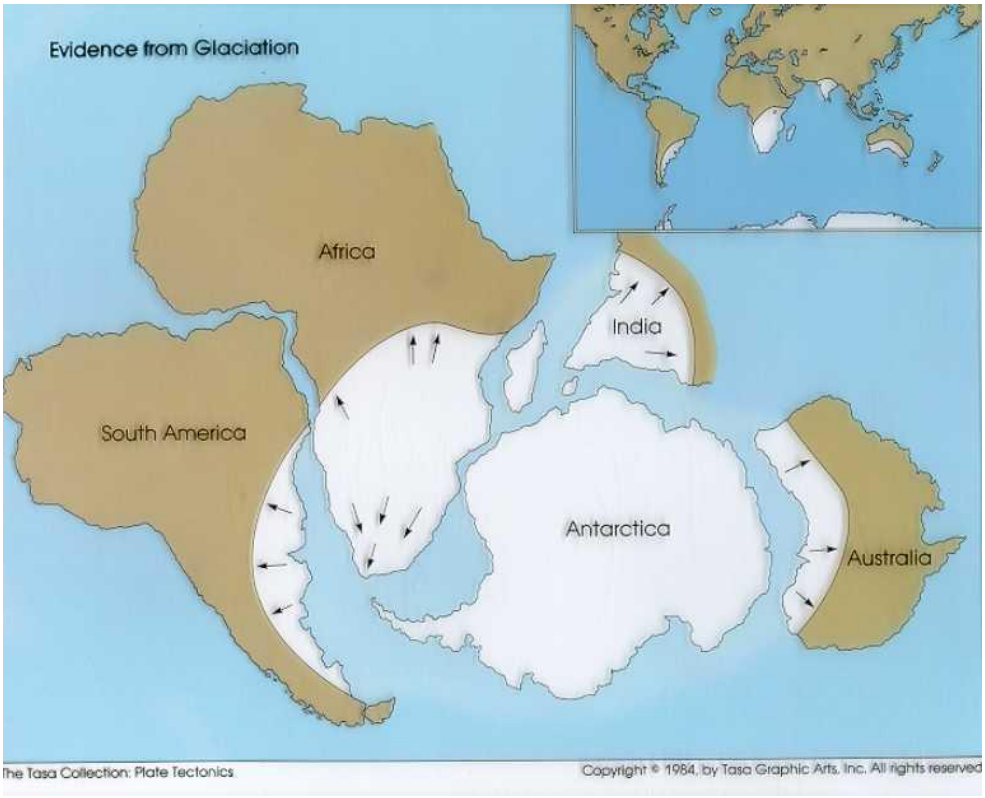
Map of Tectonic Plates



Evidence for Continental Drift




AFRICA
INDIA
SOUTH AMERICA
AUSTRALIA
ANTARCTICA
Fossil evidence of the Triassic land reptile *Lystrosaurus*.
Fossil remains of *Cynognathus*, a Triassic land reptile approximately 3 m long.
Fossil remains of the freshwater reptile *Mesosaurus*.
Fossils of the fern *Glossopteris*, found in all of the southern continents, show that they were once joined.


Evidence from Glaciation
Africa
India
South America
Antarctica
Australia
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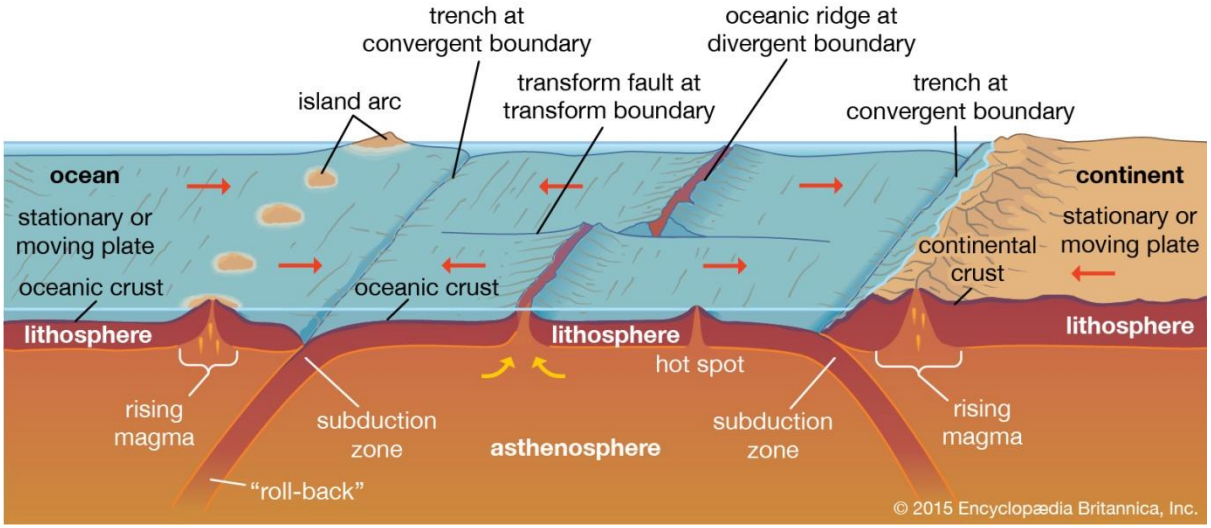
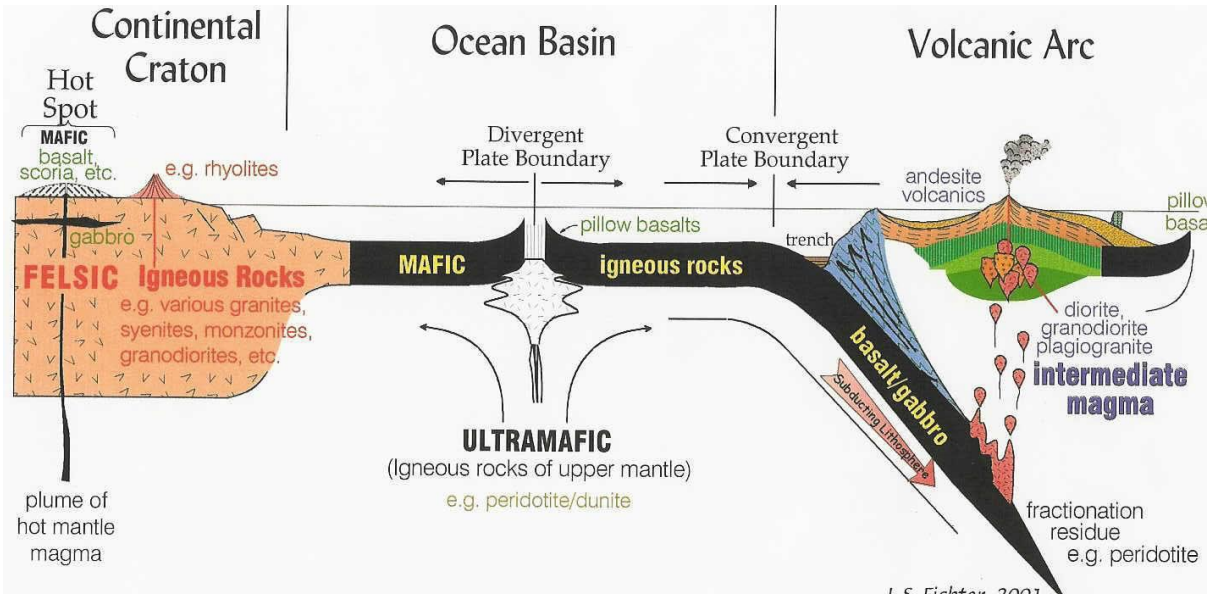
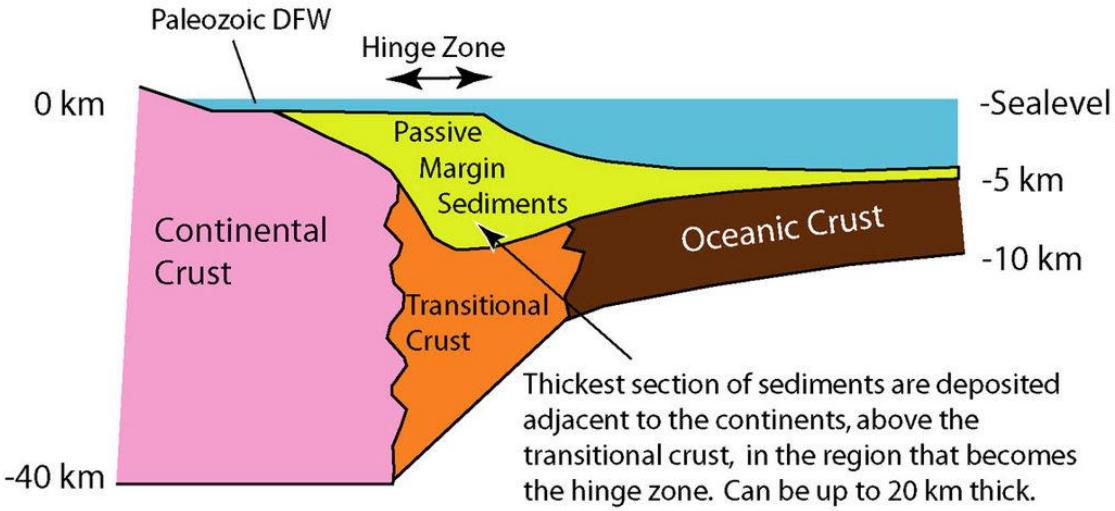
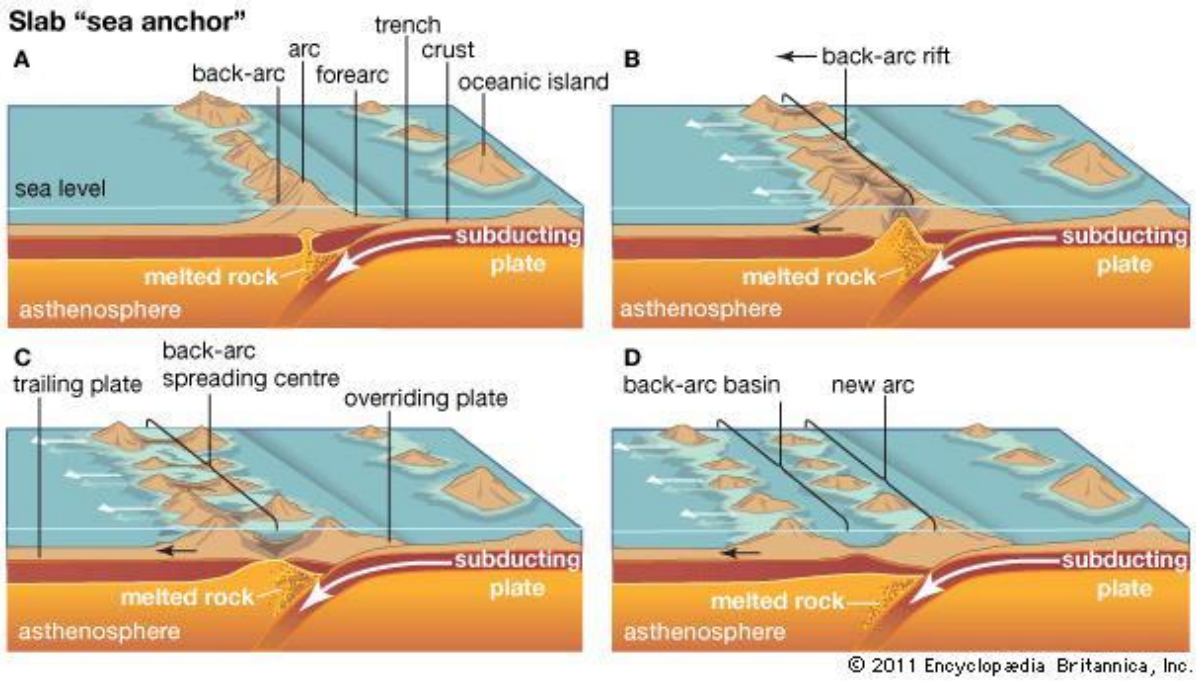
Oceanic and Continental Crust



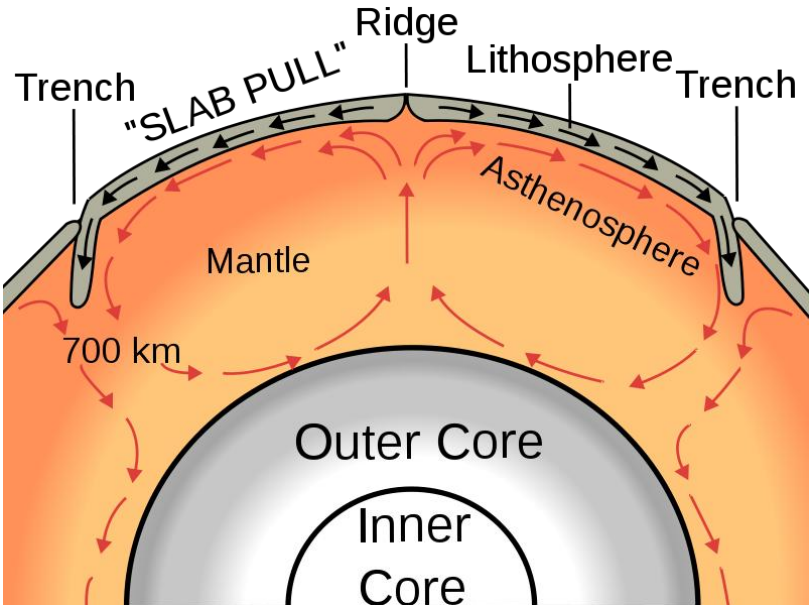




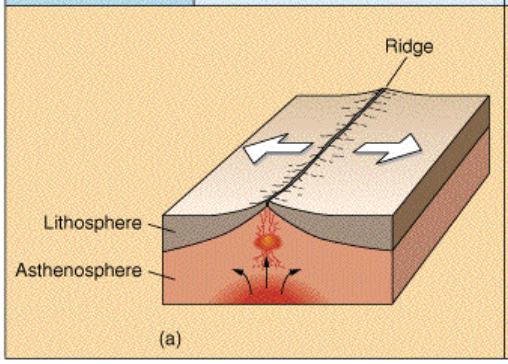
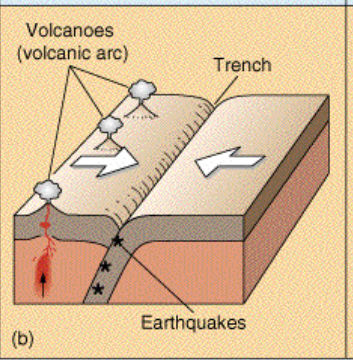
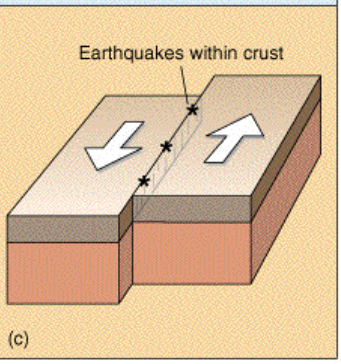


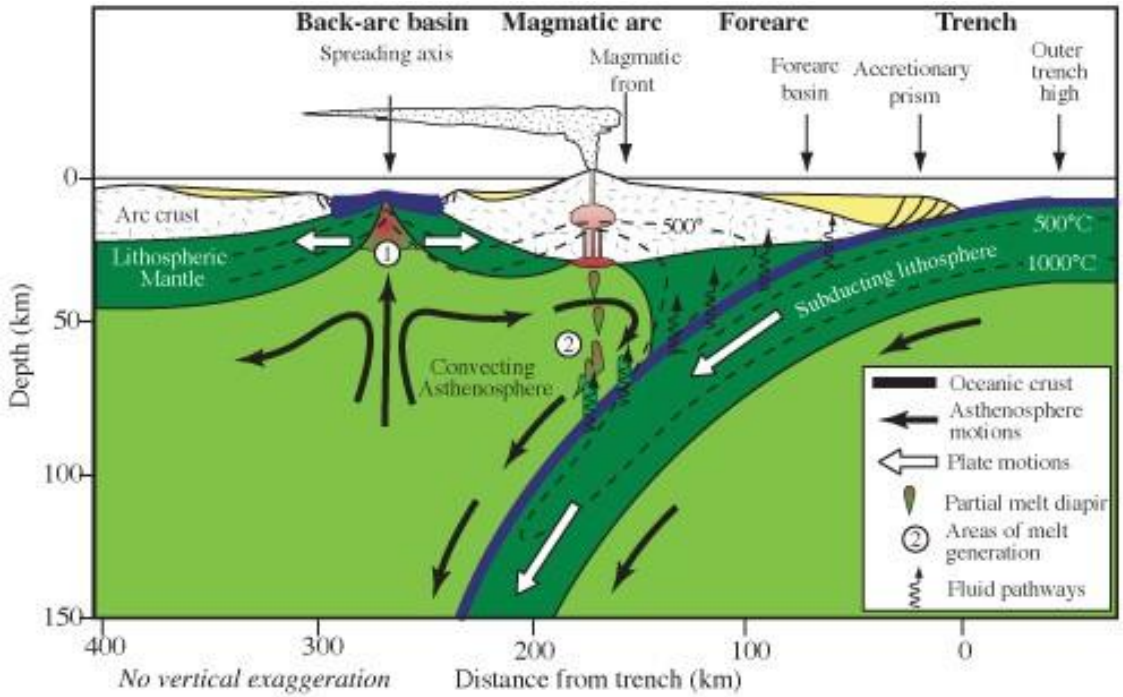
Causes of Plate Movement

- Rising magma creates new lithosphere and pushes plate apart
- A cold, dense lithospheric slab sinks into the mantle, thus pulling the entire plate. Hot asthenosphere flows back to the spreading edge
- Cooling lithosphere thickens and sinks to give a gentle slope away from the spreading centre, thus causing the lithosphere to slide over the asthenosphere at a rate of several cm/yr



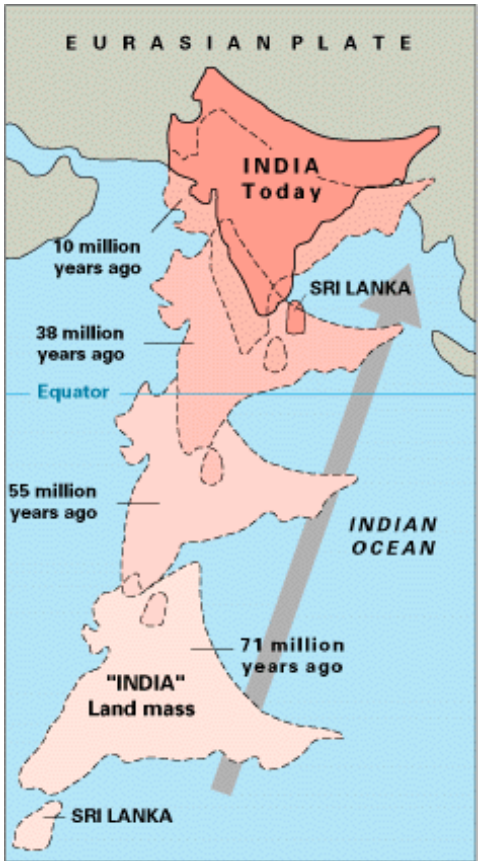
Types of Plate Margins

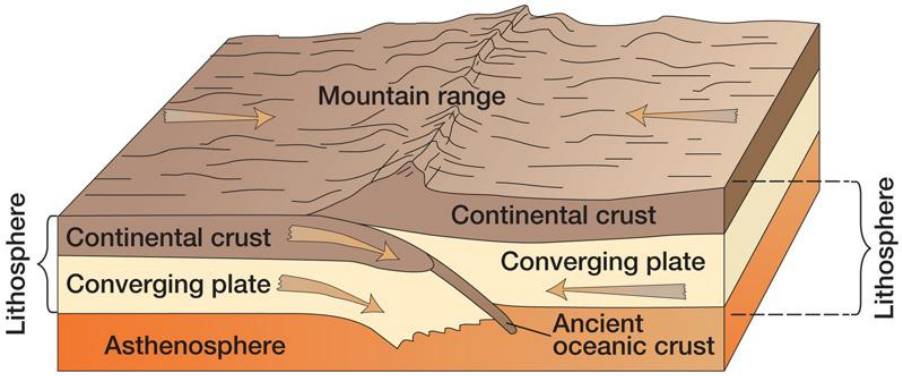
Type of Margin	Divergent	Convergent	Transform
Motion	Spreading	Subduction	Lateral sliding
Effect	Constructive (oceanic lithosphere created)	Destructive (oceanic lithosphere destroyed)	Conservative (lithosphere neither created or destroyed)
Topography	Ridge/Rift	Trench	No major effect
Volcanic activity?	Yes	Yes	No
			



Formation of the Himalayas

According to the modern theory of plate tectonics, its formation is a result of a continental collision or orogeny along the convergent boundary between the Indo-Australian Plate and the Eurasian Plate. The Arakan Yoma highlands in Myanmar and the Andaman and Nicobar Islands in the Bay of Bengal were also formed as a result of this collision.





San Andreas Fault