Physical Geology Exam 1 Study Guide

Geology – ("geo"-earth, "logos"-discourse/study)

-Physical Geology – focuses understanding of earth materials.

-Historical Geology – study's the origin of earth.

- Utilizes concepts & principles from 'Chemistry', 'Physics', and 'Biology'
- Branches of Geology: Archaeological, Engineering, Economic, Forensic, Geochemistry, Geophysics, Hydrology, Hydrogeology, Mineralogy, Oceanography, Paleontology, Petrology, Planetary, Seismology, Sedimentary, Structural, Tectonic, Volcanology

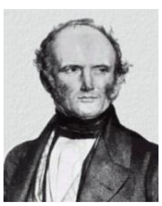
History of Geology

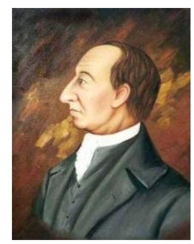
+ Greeks; 2,000 years ago?

- 'Aristotle' (explains fish fossils, stars, earthquakes, ect.)

+ ***Catastrophism***; 17th/18th century

- 'James Ussher' (Archbishop in Ireland)
  - Developed a chronology of earth's history
  - Earth was created in 4004 BC; By large events such as floods





+ ***Uniformitarianism***; the earth is OLDER than 4,004 years old!

-'James Hutton' (Scottish Physician; 1726-1797)

- Theory of the Earth (1795)
- Past conditions were NOT the same as todays

-'Charles Lyell' (English Geologist; 1797-1875)

-Principles of Geology (11 editions)

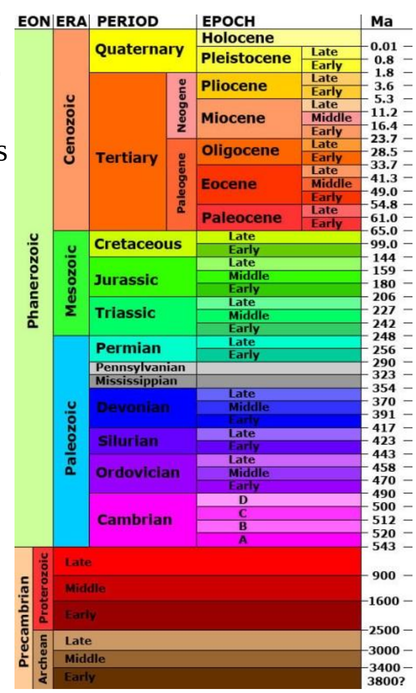
-Convincingly showed evidence for Uniformitarianism

Concepts of Geologic Time

Relative Dating – events placed in their proper sequence/order.

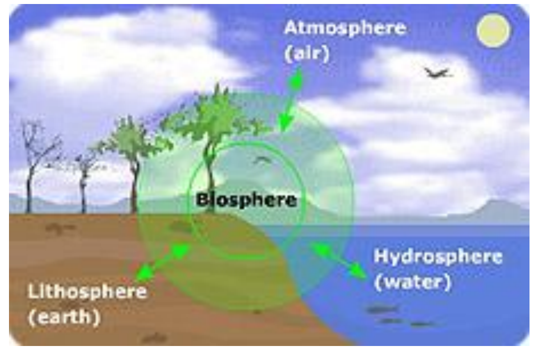
Law of Superposition – states that younger layers are on top, older layers on the bottom. **Assumes nothing has turned layers upside-down.**

Principle of Fossil Succession – fossil organisms succeed one another in a definite and determinable order. Any time period may be recognized by its fossil content. Allows geologists to identify/age rocks in separated places.



Geologic Time Scale

- Developed during the 19th century
- Divides time into ***Eons***, ***Eras***, ***Periods***, and ***Epochs***



4 Earth Spheres

Hydrosphere – a dynamic mass of water.
-Ocean covers 71% of earth's surface
-Ocean is 97% of earth's water

Atmosphere – gaseous envelope.
-A relatively thin layer; 90% is within 10 miles of Earth's surface.
- Protects us from Sun's radiation

Biosphere – life on earth.
-Within a relatively narrow zone at or near the Earth's surface.

Geosphere – solid earth.
-The largest of the Earth's spheres.

Earth System Science – study of earth as a system, rather than separate studies of geology, atmosphere science, chemistry.

Open System- most natural systems are open; both energy & matter flow into and out of the system.

Closed System- energy moves in and out, but matter does not enter or leave.

Subsystems

-*Hydrologic Cycle* – connects hydrosphere, atmosphere, biosphere, geosphere.

-*Rock Cycle* – rock type changed to another rock type.

-*Carbon Cycle* – carbon moves through the 4 spheres

Nebular Theory – currently the most widely accepted view on the origin of 'our solar system'.

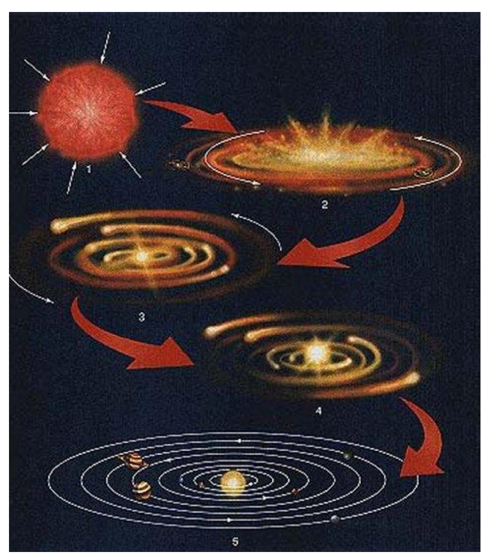
-14 billion years ago; 'THE BIG BANG' condenses into the first stars/galaxies.

-5 bya; clouds of gases and dust contracts and collapse into a spiraling disk, with the sun in the center.

-Gravitational energy after the collapse converted to thermal energy with high temperatures near the center.

-'Inner Planets' formed from dust particle collision

-'Outter Plantes' are more gaseous/iceous



<u>**Formation of Earth**</u>

-Early temperatures; melted ***iron/nickel*** (2,647^{oF} -2795^{oF})
-Separation into an ***Inner Core / Outer Core / Mantle / Crust***
-Releases of gases forming primitive atmosphere

<u>**Crust**</u> – (low density rock) Both '*Continental*' (light;granitic) & '*Oceanic*' (dark;basaltic)
-Part of the '*Lithosphere'.*

<u>**Mantle**</u> – (higher density rock; Dark colored, Dense, also called "Peridotite")

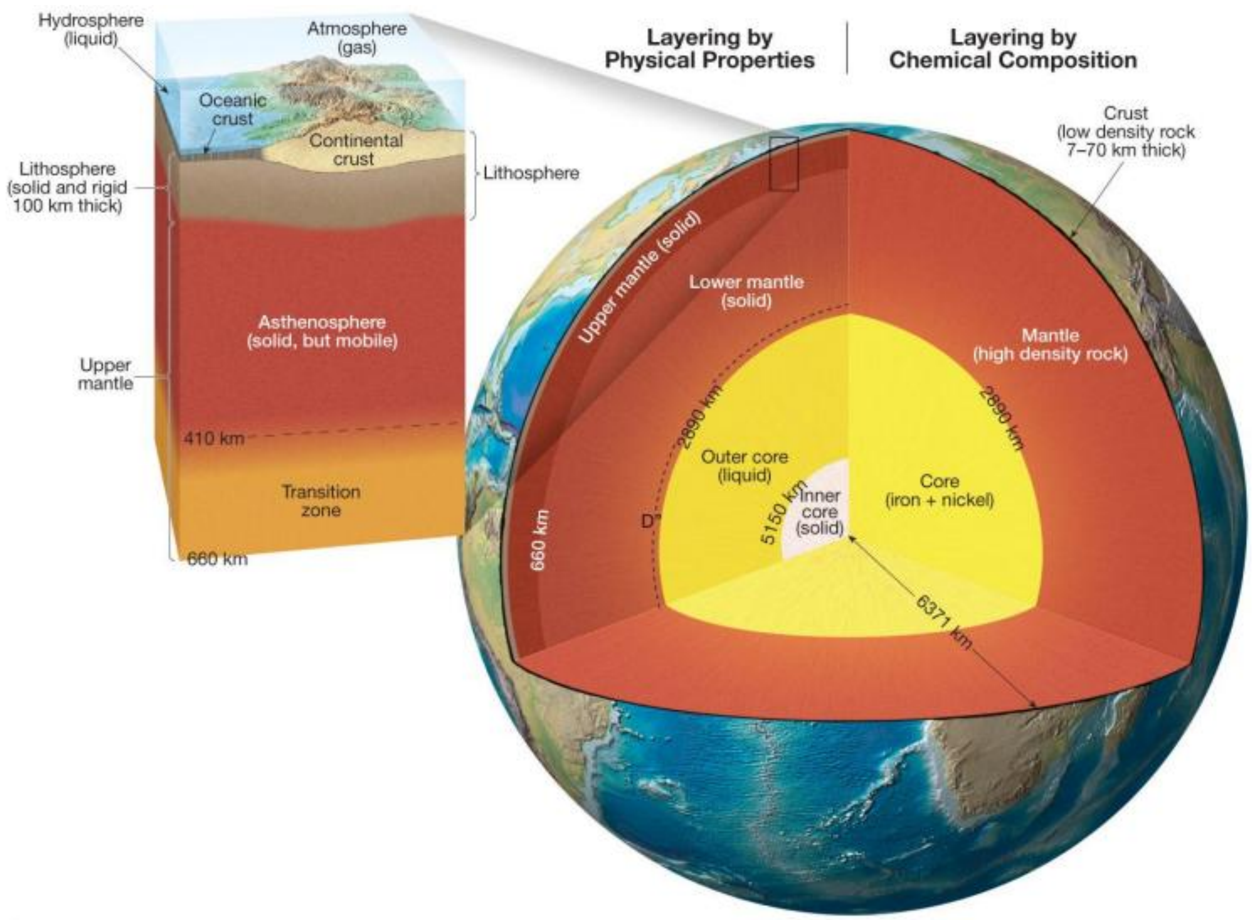
-'<u>*Upper Mantle*</u>'; 70-660 kilometers deep, *Lithosphere* & *Asthenosphere*
-'<u>*Lower Mantle*</u>'; 660-2900 kilometers deep, Solid, High Strength

<u>**Core**</u> – (high density material)

-'<u>*Outer Core*</u>'; Iron & Nickel "LIQUID", earth's magnetic field
-'<u>*Inner Core*</u>'; 'Solid' Iron & Nickel

<u>**Lithosphere**</u> - Consists of the crust and upper mantle; relatively cool and rigid shell that is 100 km thick on average.

<u>**Asthenosphere**</u> - Has a thin upper layer that experiences melting and is therefore weaker. This upper layer allows the asthenosphere to remain separate from the overlying lithosphere.



3 Rock Types

Igneous – Formed when molten rock (magma) cools.

-*Extrusive* (rock is ejected from the Earth's surface and then cools)

-*Intrusive* (rock remains below the Earth's surface, cooling slowly).

Sedimentary – Formed when sediment layers that accumulated at the Earth's surface are lithified (compacted and cemented) into a rock mass.

Metamorphic - New rocks formed from existing sedimentary or igneous or metamorphic rocks that are subjected to heat and pressure.

Rock Cycle

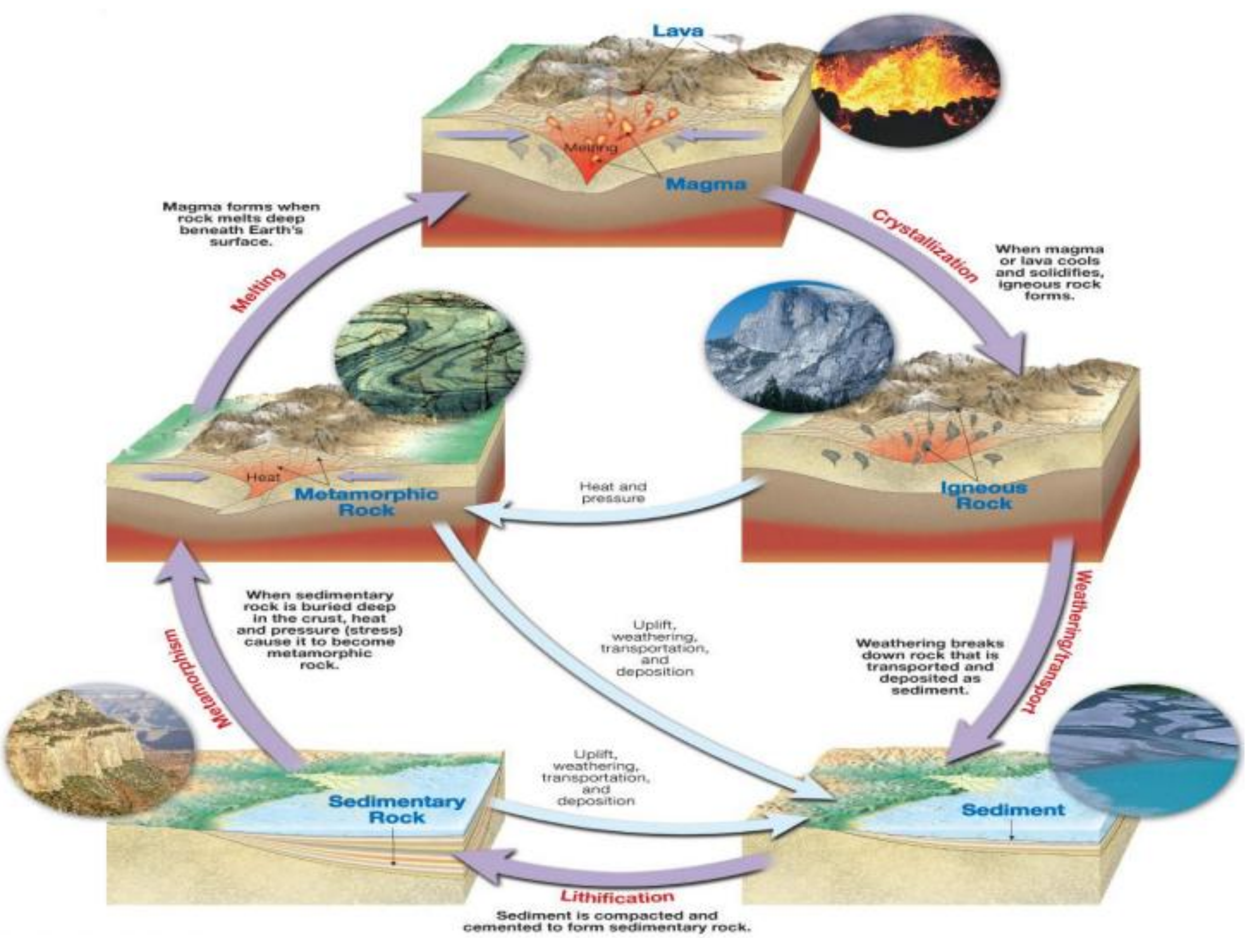


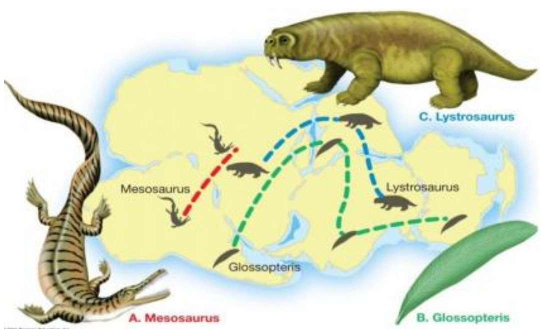
PLATE TECTONICS

Continental Drift Theory – '*Alfred Wegener'* (1880 – 1930) proposed the concepts of Continental Drift and the supercontinent Pangaea in his book 'The Origin of Continents and Oceans' (1915).

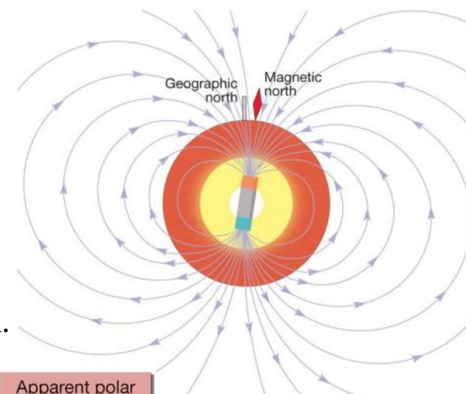
1.) Identical fossil organisms are evident in both South America and Africa. *Glossopteris* – a fossil subpolar plant with large seeds and tongue-shaped leaves unlikely to become airborne. *Mesosaurus* - an aquatic reptile that lived during the Permian (about 260 mya). *Lystrosaurus*- a land-living reptile.

2.) Matching mountain ranges in the U.S.A. (Appalachians) and North Atlantic (British Isles and Caledonian Mountains).

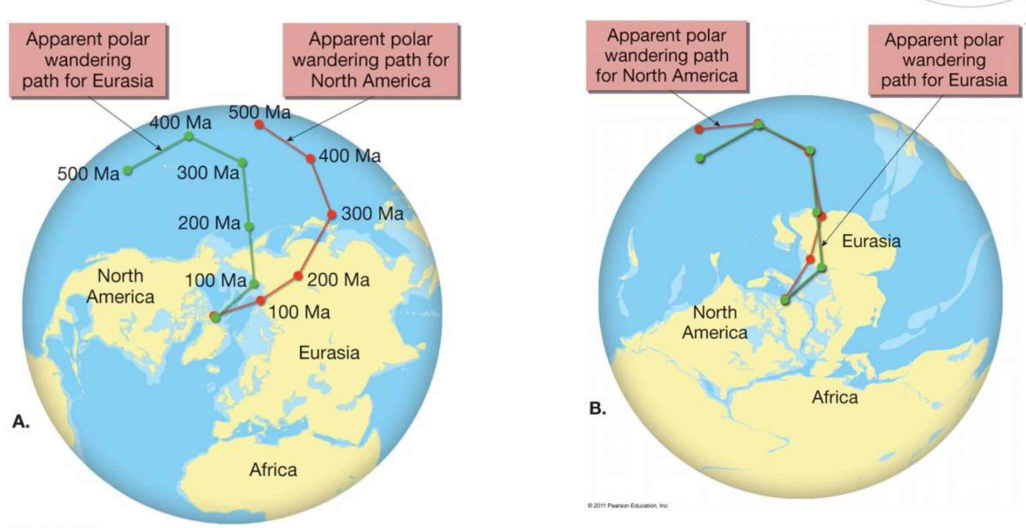
3.) Paleoclimatic research had showed evidence of glacial striations in bedrock, suggesting a glacial period in the late Paleozoic (300 mya) in S. Africa, S. America, Australia and India.



Paleomagnetism - The Earth has a *magnetic field*, similar to the magnetic field of a bar magnet.



Magnetite (a magnetic, ironrich mineral found in basaltic lavas) grains will become oriented with the Earth's magnetic field as the lava cools. Early studies of rock magnetism suggested that either the locations of the magnetic poles moved over time, or the rocks moved.



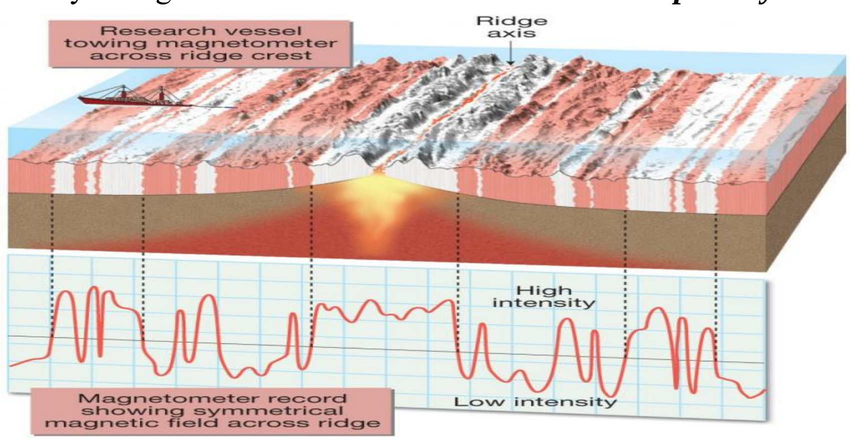
Wegner's Hypothesis
1. Approximately 200 million years ago the continents were joined together to form Pangaea. The continents have since separated to their current configuration.
2. The gravitational forces of the Moon and Sun were the driving force that moved the continents.
3. Larger continents broke through the oceanic crust, plowing their way along.

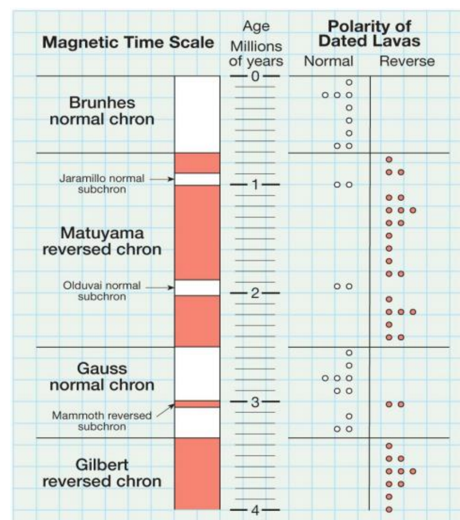
Wegner's Failure
Wegener got the general idea correct, but failed to thoroughly understand two key details:
1.) "*Drift*" mechanism: Continents do not plow, or break, through the ocean floor.
2.) Driving Force: Tidal energies are not sufficient to power the movement of continents.

Paleomagnetism: Magnetic Reversals

Additional rock magnetism studies by geophysicists in the 1960's found that throughout Earth's history the magnetic field has reversed, with north becoming south, and vice versa.

-Today's magnetic field is considered to be "***normal polarity***".





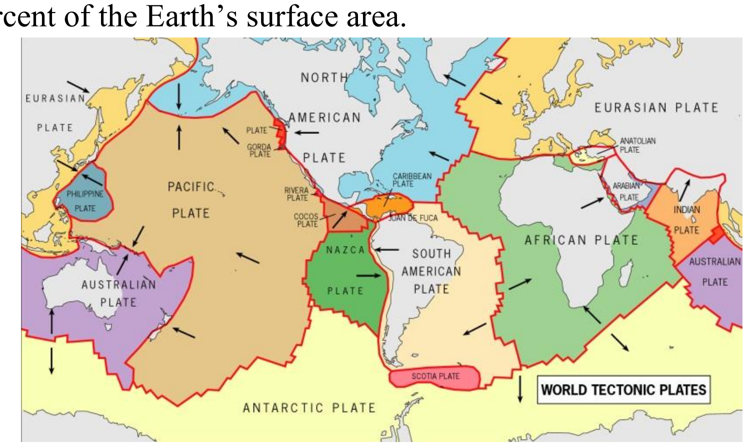
By the early 1960's an *oceanic ridge system* had been identified and evidence, such as paleomagnetic reversals, gathered by 'Harry Hess' pointed toward ***seafloor spreading***.

The concepts of *continental drift* and *seafloor spreading* were combined, and by 1968, had become what is known as the ***Theory of Plate Tectonics***.

Tectonic Plates

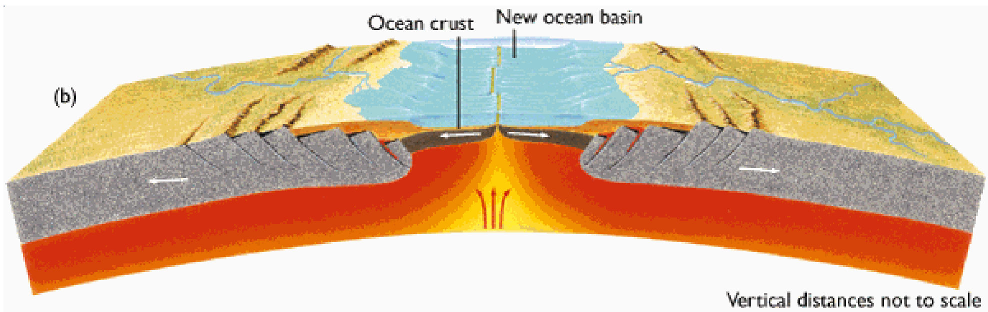
The lithosphere is segmented into approximately 20 tectonic (lithosperic) plates, with seven major plates that account for 94 percent of the Earth's surface area.

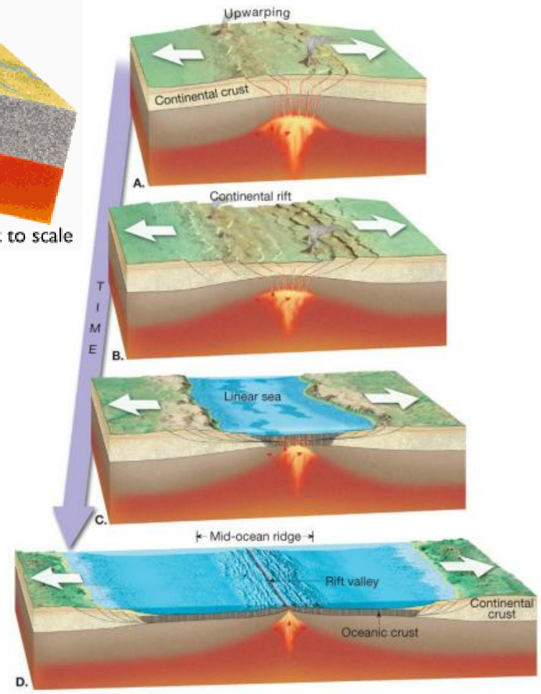
Seven Major Plates;
African,
Antarctic,
Australian/Indian,
Eurasian,
North American,
Pacific (the largest plate),
South American



<u>Tectonic Boundaries</u>

<u>Divergent Boundaries</u> ***(oceanic crust)***
-Two plates move away from one another.
-Commonly called spreading centers, as the mechanism causing the divergent boundary is seafloor spreading.
-Often a deep, down-faulted structure called a *rift valley* forms along the ridge axis
-Most divergent boundaries are located along oceanic ridges such as the 'Mid-Atlantic Ridge'.
-The global ridge system is over 43,000 miles long.
-New, hot oceanic crust is less dense than old and cold crust, thus causing an elevated ridge

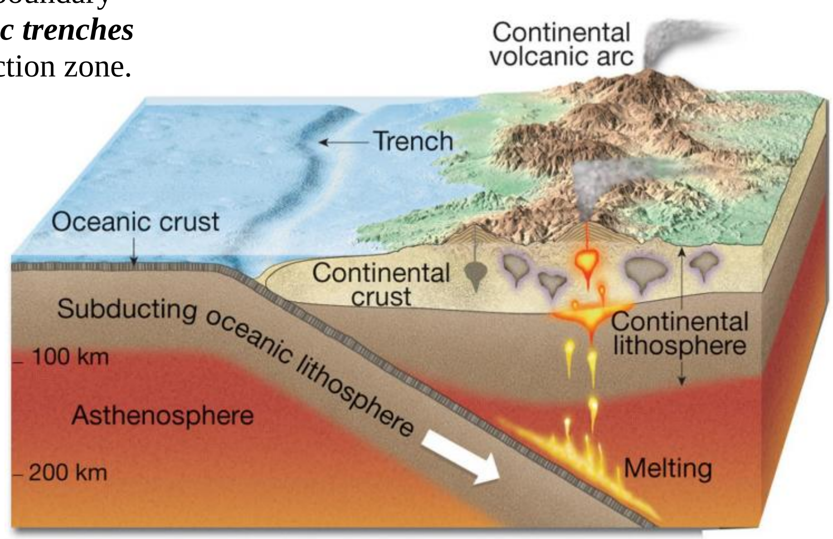




<u>Divergent Boundaries</u> ***(continental crust)***
-'*<u>Continental Rifting'</u>*: Continental crust is stretched and thinned by opposing tectonic forces; upwelling magma beneath causes the landscape to upwarp; brittle crustal rocks fragment, settle, and form a topographic depression.
-The 'East African Rift' is a modern example of an early-stage continental rift.
-The 'Red Sea' is an example of a late-stage continental rift

<u>Convergent Boundaries</u>
A ***Convergent Boundary*** is one where two tectonic plates are coming together. This type of boundary is also called a ***Subduction zone***. ***Oceanic trenches*** are the surface representation of a subduction zone.

<u>Types of convergent boundaries include</u>:
Oceanic – Continental
Oceanic – Oceanic
Continental - Continental



<u>Convergent Boundary</u> (Oceanic – Continental)

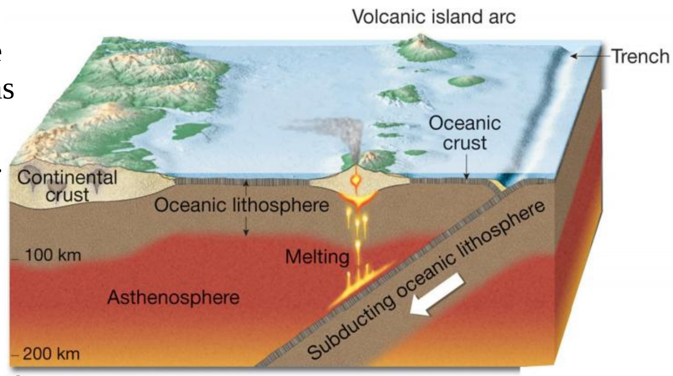
When dense oceanic and less dense continental lithospheric
plates collide, the oceanic plate will dive beneath the continental plate.

Partial melting of the oceanic plate occurs within the upper mantle. The melt (really a mush), being less dense than the surrounding mantle, rises toward the surface, in some instances resulting in ***continental volcanic arcs***. (diagram, previous page)

<u>Convergent Boundary</u> (Oceanic – Oceanic)

When two dense oceanic plates collide one will dive beneath the other. Partial melting will occur, much as with Oceanic – Continental boundaries, however, resultant volcanic activity may produce ***Island Arcs***. Islands in an arc tend to be spaced 80 km apart.

<u>Island arcs</u>;
Aleutian Islands, Mariana Islands, Tonga Islands, Lesser Antilles arc, Japan, islands of Indonesia, and Phillipines

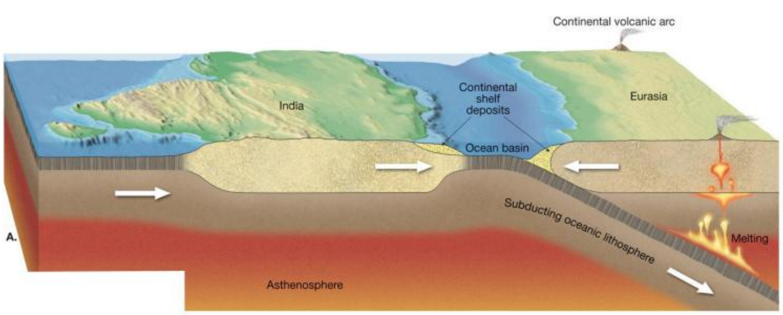


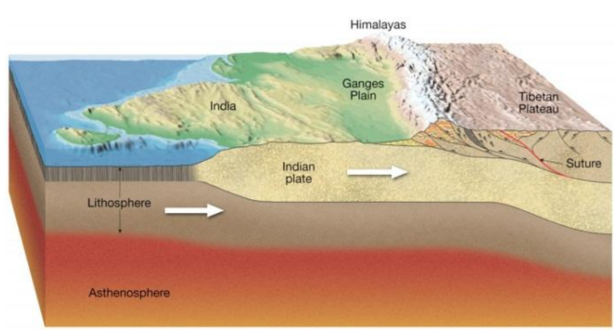
<u>Convergent Boundary</u> (Continental – Continental)

This type of boundary typically occurs after an Oceanic – Continental subduction zone has completely consumed the oceanic lithosphere. The low density of both continental lithospheric masses results in a collision, deforming sediments and rocks along the margins of each land mass, resulting in mountain building.

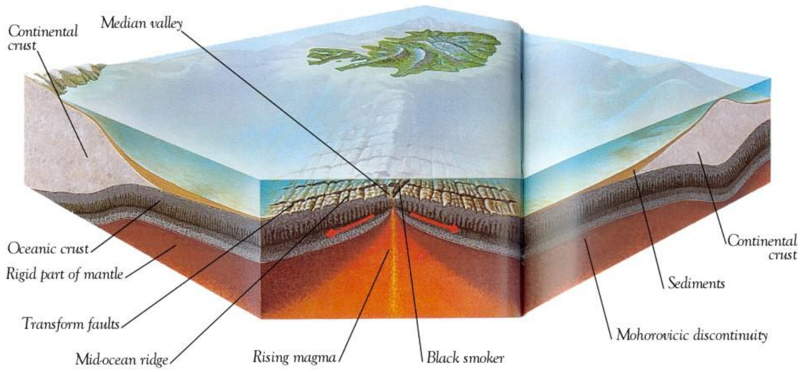
The collision of the Australian-Indian plate with the Eurasian plate caused the formation of the Himalayas

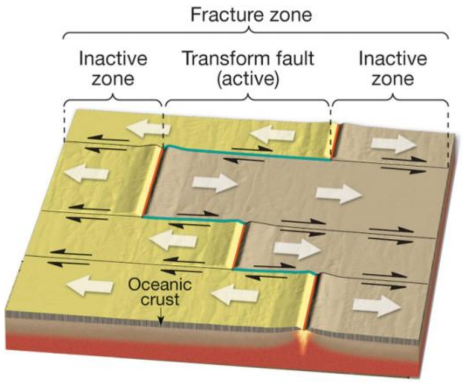
Suture – where two continental crusts meet.





<u>Transform Fault Boundaries</u> - forms when two tectonic plates slide past one another. This type of boundary was proposed by '*J. Tuzo Wilson'* (Canadian Geologist).There is no destruction or production of the lithosphere along a transform fault boundary.
Transform faults are most common on the seafloor, in spreading center ***fracture zones***, but there are some that cut across continental crust.
"Transform faults are only active between the offset ridge segments."



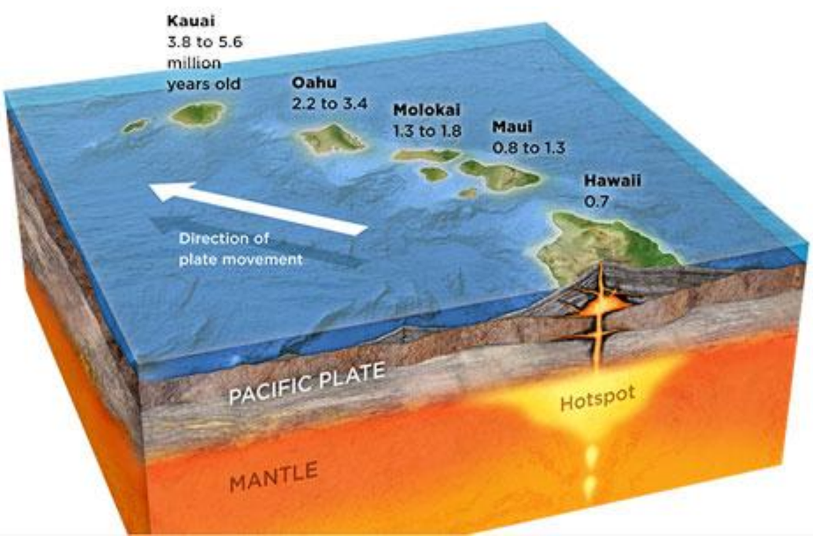


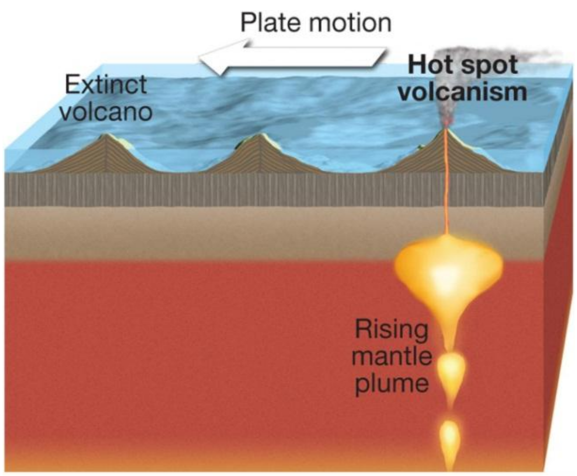
<u>Hot Spots</u>

Linear chains of volcanic islands formed as oceanic crust passed over a ***mantle plume***, a rather cylindrical shaped upwelling of abnormally hot rock that originates at the core-mantle boundary and stays anchored in roughly the same location.

The mantle plume causes ***partial melting*** of mantle rocks and, as these melts rise, melting of the overlying oceanic plate rocks.

A ***hot spot*** is an area less than a few hundred kilometers across and characterized by volcanism, high heat flow, and subtle crustal uplift.





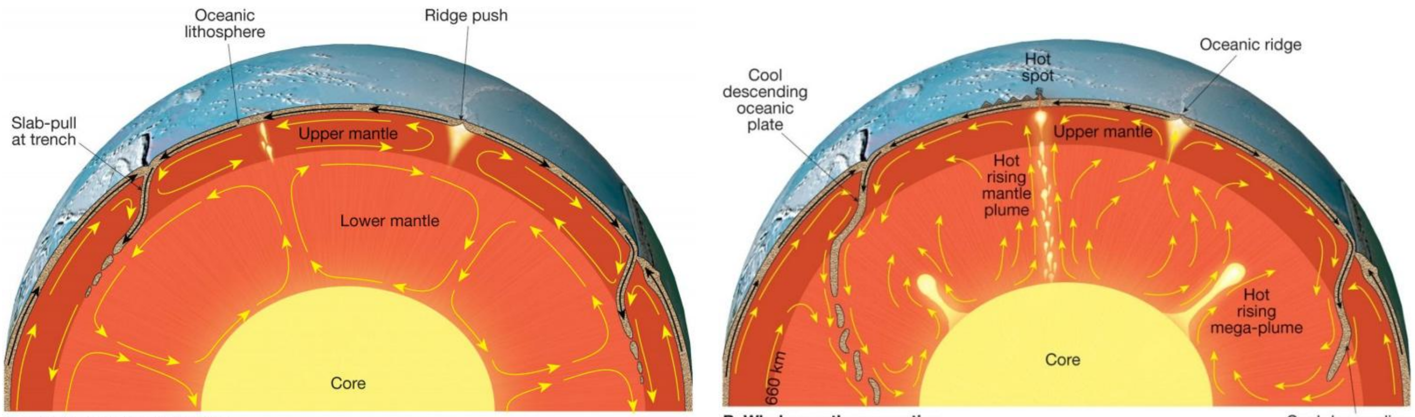
Mantle Convection

Convective heat transfer is a major mode of transferring heat, and convection is also a mode of transferring mass. In a cyclical manner, material is heated, rises, eventually cools, sinks down and is re-heated.

The mantle is solid, but hot and weak enough to permit convective flow.

Convection in the mantle is driven by:

• Heat loss from the Earth's core
• Internal heating due to decay of radioactive isotopes
• Cooling from the top of the mantle



A. Layering at 660 kilometers   B. Whole mantle convection

Two models have evolved in an effort to explain why basalt from oceanic ridges is chemically different from "*hot spot*" basalt.

Layering at 660 kilometers

• The mantle is split into layers at a depth of 660 km.
• Cold oceanic lithosphere sinks into a thin upper mantle layer that is well mixed. The cold material is melted, rises, and erupts along mid-ocean ridge spreading centers.
• A separate, more sluggish and primitive mantle convective regime is present below 660 km.
• The lower mantle convective process feeds hot spot locations via mantle plumes, thus generating basalt of a different chemical composition than that from midocean ridges.

Whole Mantle Convection

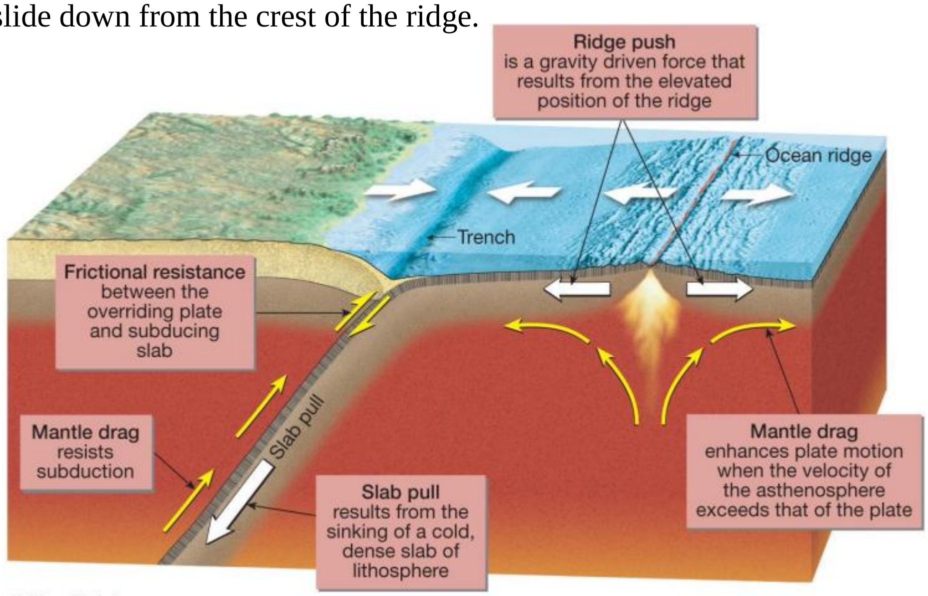
• Cold oceanic lithosphere sinks deep into the mantle before melting, perhaps to the core-mantle boundary.
• Melted material rises in a mantle plume.
• Entire mixing of the mantle in a few hundred million years.
• Con: A homogenized mantle of this sort would not produce chemically distinct magmas, like those seen along ridges.

Plate Tectonics: Driving Forces

Horizontal movement of tectonic plates away from a spreading center causes mantle upwelling.

Slab Pull – A cold, dense slab of oceanic lithosphere sinking into the asthenosphere will exert a pull on the trailing plate.

Ridge Push – Because the ridge along a spreading center is elevated, gravity causes the newly formed slab to slide down from the crest of the ridge.



Rock - An aggregate of two or more minerals.

Rocks that are composed of one mineral;

[Limestone – calcium carbonate]
[Dunite – almost entirely olivine]
[Anorthosite – plagioclase feldspar]

Rocks composed of non-mineral matter;

[obsidian & pumice – glassy quartz]

Mineral –
-Naturally occurring,
-Homogeneous solid,
-A definite (but usually not fixed) chemical composition,
-Ordered atomic arrangement.

Mineralogy - relatively recent science;
Early humans used natural pigments of hematite (red) and manganese (black) in cave paintings and flint was highly prized.

5,000 years ago: Tomb paintings in the Nile show people weighing malachite and precious metals, smelting mineral ores, and making lapis lazuli and emerald gems.

(372-287 B.C.): The Greek philosopher ***Theophrastus*** recorded the first written work on minerals.

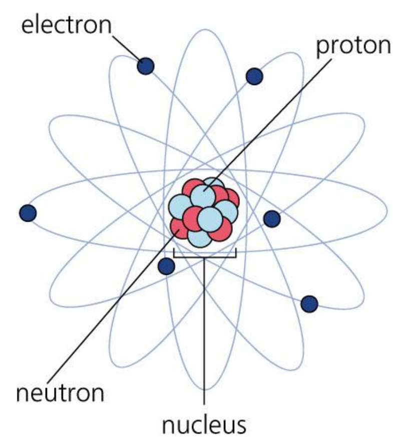
1556: German physicist ***Georgius Agricola*** published *De Re Metallica*. Many believe this document signals the emergence of mineralogy as a science.

1669: ***Nicolaus Steno*** (Danish) published results of his studies of quartz crystals.

1784: ***Rene J. Hauy*** showed that crystals were "built" by stacking together "tiny identical building blocks".

1779 – 1848: ***Berzelius*** (Swedish chemist) studied mineral chemistry and developed chemical classification of minerals.

Element – a group of the same kind of atoms.



8 elements make up about 99% of Earth's crust;

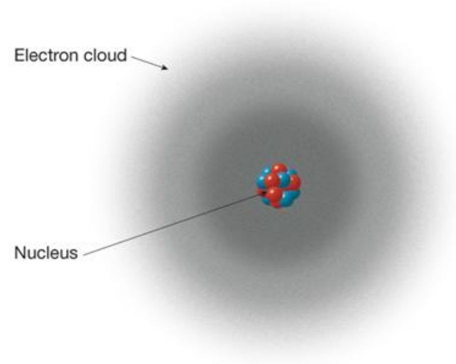
Element	Weight Percent	Atom Percent
Oxygen (O)	46.60	62.55
Silicon (Si)	27.72	21.22
Aluminum (Al)	8.13	6.47
Iron (Fe)	5.00	1.92
Calcium (Ca)	3.63	1.94
Sodium (Na)	2.83	2.64
Potassium (K)	2.59	1.42
Magnesium(Mg)	2.09	1.84
Total	**98.59**	100.00

Atoms - the smallest subdivision of matter that retains the characteristics of the elements. Each atom consists of protons and neutrons in a nucleus, and electrons surrounding the nucleus.

Protons - positive (+) charge, the number of protons in an atom is the atomic number.

Neutrons - No charge. Atoms of the same element but with differing numbers of neutrons are called isotopes.

Electrons – negative (-) charge.
The nucleus is surrounded by clouds of electrons called principal shells.The outer-most shell contains valence electrons, which are the electrons that bond with other atoms.



"Most substances in nature are electrically neutral."

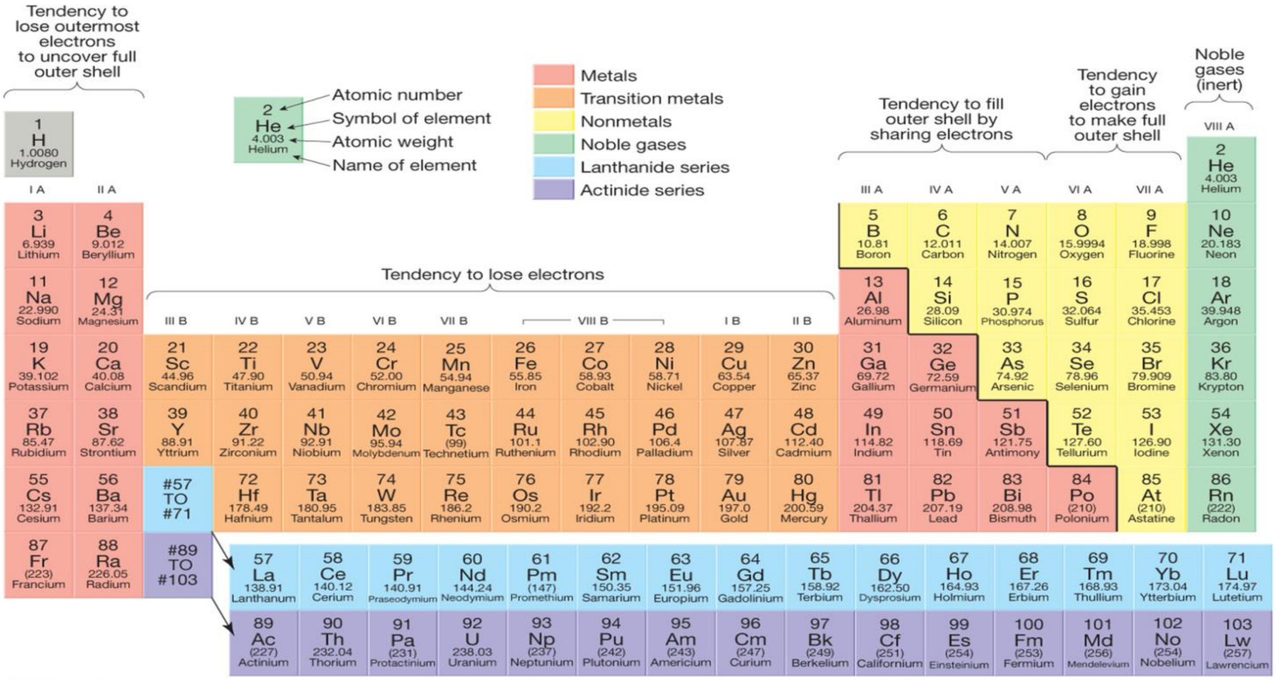
The Periodic Table

Atomic number –The number of protons in the nucleus.

Atomic weight – A number expressing the relative weight of an element in terms of the weight of the carbon-12 isotope, which is 12.000.

Characteristic Mass - The sum of the protons and neutrons of an element.

(The elements are arranged in the Periodic Table according to increasing atomic number)

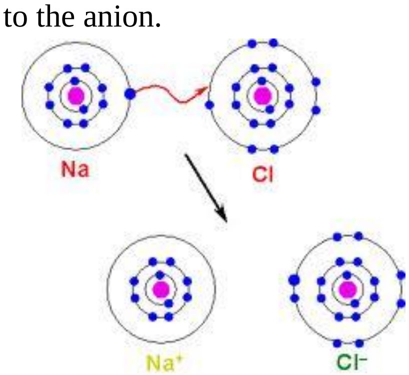


Atomic Bonding - The forces that bind together the atoms of crystalline substances are ***electrical*** in nature, meaning that they vary based on interactions of electrons in the outer shells. These electrical forces are ***chemical bonds***.

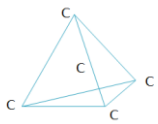
5 Principle Bond Types;

Ionic Bond (electrostatic bond) - involves the '*transfer'* of electrons.
Example: Table Salt, Sodium Chloride (NaCl)

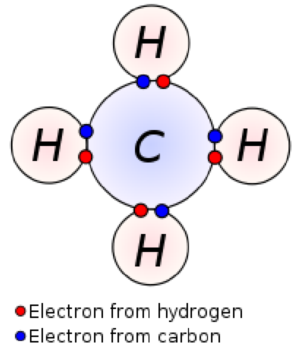
-The formation of an ionic bond between Na+ and Cl- has been achieved by the exchange of an electron from the metal to the anion.
-The attraction between their unlike electrostatic charges holds the ions together in a crystal.



Typical characteristics of ionic bonded crystals;
Moderate hardness and specific gravity
Fairly high melting points
Poor conductors of electricity and heat

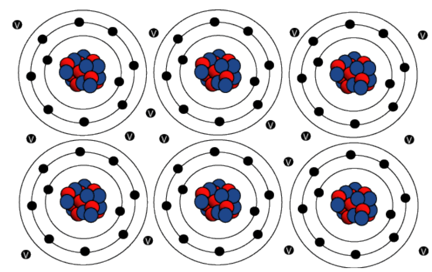


<u>Covalent Bond</u> - involves the '*sharing'* of an electron between two atoms.
Example: Carbon
-Covalent bonds are the '*strongest*' of the chemical bonds.

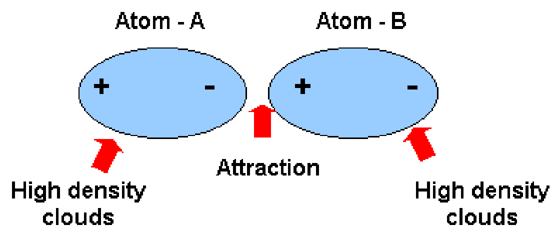


<u>Metallic Bond</u> - unique in that electrons are '*free to move*' throughout the atomic structure. Many of the electrons owe no allegiance to any particular nucleus. The attractive force between the nuclei and the cloud of negative electrons holds metallic structures together.

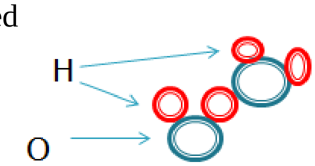
<u>*Because of this bonding type, metals exhibit high*</u>;
-Plasticity
-Ductility
-Conductivity



<u>Van der Waals Bond</u> - A '*weak bond'* that ties neutral molecules together using '*small residual charges'* on their surfaces. Is common in organic compounds, and is not common in minerals.



<u>Hydrogen Bond</u> - An electrostatic bond between a positively charged hydrogen ion and a negatively charged ion; such as O-2 and N-3.



1. Hydrogen has one electron and can easily lose it to another ion.

2. The hydrogen ion can lose that one electron to either of two adjoining ions.

3. The one electron resonates between the adjoining ions bringing them closer together in a relatively weak bond (weaker than covalent or ionic bonds, but stronger than VdW).

Crystallization - "The process by which matter becomes crystalline, from a gaseous, fluid, or dispersed state."

Crystalline: Having a regular molecular structure; of, or pertaining to the nature of a crystal.

There are three very general modes of crystal formation;
1. Salts precipitating from water-based solutions
2. Due to temperature/pressure changes
3. Biological processes

Crystal Forms

Crystal – a homogeneous solid possessing a three-dimensional internal order.

Euhedral – A crystalline solid with well-formed faces.
Subhedral – A crystalline solid with imperfectly developed faces.
Anhedral – A crystalline solid without faces.
Microcrystalline –The crystalline nature can only be determined with the aid of a microscope.
Cryptocrystalline –The crystalline nature can only be detected using X-ray diffraction.
Amorphous – A substance that lacks ordered internal atomic arrangement.

Variations in Minerals

Both the chemical composition and form (structure) of minerals can vary widely within one general mineral type.

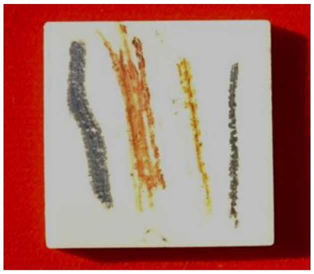
Compositional Variation - Ions of similar size may substitute into the mineral's internal framework. (Examples: Garnet, Alkali-Feldspar, and Hornblende)

+ ***Polymorphs*** – Two minerals with the same chemical composition with different internal ordering (and thus different external forms).
Examples: graphite & diamond (both are carbon) & calcite & aragonite (both are $CaCO3$)

Mineral Properties

Optical Properties

Color – Perhaps the most easily observable property of minerals. However, it is also the most variable and unreliable property.
Color is the result of the interaction of light waves with electrons. Major factors that cause color are;
-The presence of a major element essential to the mineral composition
-The presence of an impurity
-The occurrence of defects in the crystal structure
-The presence of a finely spaced physical boundary
(which may cause chatoyancy or a play of colors)



Streak - The color of a finely powdered mineral on white, unglazed porcelain.

<u>Luster</u> – Refers to the general appearance of a mineral surface in reflected light. There are two types of luster; '*metallic'* and '*non-metallic'*.
-***Metallic*** luster gives the appearance of metal.
-***Non-metallic*** luster is typically light colored and transmit light (at least along edges).
The streak will be either colorless or very light colored.

<u>*Types of non-metallic luster*</u>;
Vitreous, Resinous, Pearly, Greasy, Silky – Silklike, Adamantine

> **Chatoyancy** – A silky appearance caused in minerals exhibiting closely packed, parallel fibers. In reflected light, a band of light will appear at right angles to the length of the fibers. Example: Tiger's eye.
> **Asterism** – In crystals within the hexagonal system, inclusions may be arranged in three crystallographic directions at 120o to each other. Asterism occurs when beams of light form at right angles to each direction of inclusions, forming a six-pointed star.
> **Luminescence** – Any emission of light that is not the direct result of incandescence. Typically very faint.
> **Fluorescence** – A mineral that luminesces during exposure to ultraviolet light, x-rays, or cathode rays. This name comes from the mineral fluorite, which has a tendency to fluoresce.
> **Phosporescence** – A mineral that continues to luminesce after the removal of the exciting rays.

<u>Hardness (H)</u> – The resistance that a smooth surface of a mineral offers to scratching.

-The evaluation of hardness is merely an assessment of the reaction of a crystal structure to stress without '*rupture'* (cleavage, parting, or fracture) [Klein & Hurlbut, 1985].

- Metals tested for hardness will end up with a groove due to their ability to deform plastically.

- Ionic or covalently bonded materials react by microfracturing.

-In 1824 Frederick ***Mohs***, an Austrian mineralogist developed a series of 10 common minerals to use for comparison purposes.

<u>Cleavage</u> – The tendency of minerals to break parallel to atomic planes.

<u>Parting</u> – Occurs when minerals break along planes of structural weakness.

<u>Fracture</u> – The way minerals break when they do not yield along cleavage or parting surfaces. Different fracture types: conchoidal, fibrous/splintery, hackly, uneven.

Tenacity – The resistance that a mineral offers to breaking, bending, or tearing.

Brittle – Breaks and powders easily; ionic bonding.
Malleable – Able to be hammered into thin sheets; metallic bonding.
Sectile – May be cut into shavings with a knife; metallic bonding.
Ductile – May be drawn into a wire; metallic bonding.
Elastic - Able to return to its original shape when deforming pressure is released.

Crystal Habit (appearance) – The manner in which crystals grow together in aggregates.

Density – Mass per unit volume (often expressed in units of grams per cubic centimeter [g/cc]).

Specific Gravity (G) – A unitless number that expresses the ratio between the weight of a substance and the weight of an equal volume of water at 4oC.
Example: A mineral with G=2 weighs twice as much as the same volume of water.

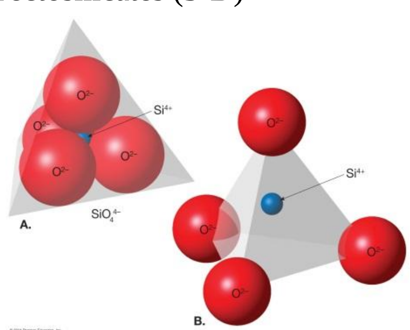
TABLE 3.1 Major Mineral Classes

Class	Anion, Anion Complex, or Elements	Example (Mineral species)	Chemical Formula
silicates	$(SiO_4)^{4-}$	quartz	SiO_2
halides	Cl^{1-}, F^{1-}, Br^{1-}, I^{1-}	halite	NaCl
oxides	O^{2-}	corundum	Al_2O_3
hydroxides	$(OH)^{1-}$	gibbsite	$Al(OH)_3$
carbonates	$(CO_3)^{2-}$	calcite	$CaCO_3$
nitrates	$(NO_3)^{1-}$	nitratite	$NaNO_3$
sulfates	$(SO_4)^{2-}$	gypsum	$CaSO_4 \cdot 2H_2O$
phosphates	$(PO_4)^{3-}$	apatite	$Ca_5(PO_4)_3(OH, F, Cl)$
native elements	Cu, Ag, S	copper	Cu
sulfides	S^{2-}	pyrite	FeS_2

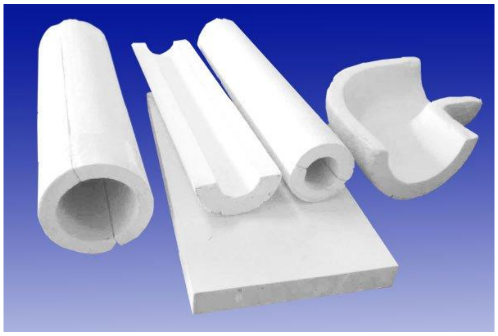
Silicates - All silicate minerals contain silica (Si) and oxygen (O) bound together in the form of the “silica tetrahedron”[four O2- anions covalently bonded to one Si4+ cation].

$SiO_4{}^{4}$-

Nesosilicates (independent structure), Sorosiliates (double structure),
Inosilicates (single,double chain), Phyllosilicates (sheet structure),
Cyclosilicates (ring structure), Tectosilicates (3-D)



"***Light silicates***" are light colored, '*non-ferromagnesian'* minerals.
Feldspars - There are two general types:
Potassium Feldspar (commonly called "K-spar"); and plagioclase feldspar
Quartz
Muscovite – a mica
Clay minerals – a complex type of sheet silicate



Typically, "***dark silicates"*** are '*ferromagnesian'*.

Olivine group – A dark greenish, high-temperature mineral often associated with mantle conditions.
Pyroxene group – A common mineral type in basalt.
Amphibole group – A typical mineral type in intrusive igneous and metamorphic rocks.
Biotite – Dark mica.
Garnet – A nesosilicate common in metamorphic and intrusive igneous rocks.