

## BASIC GEOLOGY OVERVIEW / PLATE TECTONICS

### I. Minerals

A. Mineral - naturally occurring inorganic solid, consisting of atoms combined together as chemical compounds, possessing a definable internal structure.

1. Rocks are composed of 1 or more mineral crystals combined together as aggregates.
2. atoms---bonded----compounds/minerals----combined/lithified----rocks-----create structure of earth

B. Mineral Groups (over 2000 minerals types known to exist, only about 24 are most abundant)

1. Rock Forming Minerals - those minerals that are the most abundantly found on the earth and that most commonly comprise rocks.

a. 8 Elements constitute 98% of the earth's crustal minerals

oxygen	46.6%
Silicon	27.7%
Aluminum	8.1%
Iron	5.0%
Calcium	3.6%
Sodium	2.8%
Potassium	2.5%
Magnesium	2.1%
Others	1.5%

Total 100%

2. Silicates- Most common mineral groups composed of silica and oxygen...known as the silicates

a. composed primarily of silica and oxygen with subordinate amounts of other elements to maintain electrical neutrality on the subatomic level).

3. Carbonates - Ca and CO<sub>3</sub> - next common

4. Oxides - consist of metallic elements and oxygen

5. Native Elements - Au, Ag, and C (diamond).

a. e.g. of mineral uses, quartz = glass, calcite = cement, gypsum = plaster.

6. Silicate Minerals

a. Ferromagnesian Silicates - silicate minerals (compounds containing Si-O tetrahedron) that are linked together and include Fe and Mg.

(1) Typically dark in color, high specific gravity, and crystallize from magma at relatively high temperatures.

(2) e.g. Olivine, Pyroxene, Amphibole, Biotite, and Garnet)

b. Nonferromagnesian Silicates - silicate minerals that are linked together and do not include Fe and Mg.

(1) Typically lighter in color, less specific gravity, crystallize from magma at relatively lower temperatures

(2) e.g. quartz, feldspars, muscovite, clay)

C. Nonsilicate Minerals - minerals that are compounds that do not have silica and oxygen in their structure

1. carbonates,
2. sulfates,
3. oxides,
4. native elements,
5. halides,
6. phosphates

## II. Rocks and the Rock Cycle

A. Three Rock Types (based on their mode of origin)

1. Igneous: rocks crystallize from molten magma
2. Sedimentary: rocks form at near earth's surface
3. Metamorphic: rocks formed by alteration of pre-existing rocks

B. Igneous Rocks- a rock (or agglomeration of one or more minerals) that results from the cooling of magma, or molten rock.

1. As the magma cools, minerals crystallize from the molten rock.
  - a. Magma - molten or hot liquid rock, originates beneath the earth's surface (up to 120 miles beneath), composed of elements found in silicate minerals, water vapor, and gases.
  - b. Lava - magma that is extruded onto the earth's surface via volcanic eruptions (hot magma is confined at depth beneath surface, relatively lighter than confining rock, rises upward, may eventually erupt onto earth surface).
  - c. Extrusive Igneous Rocks or Volcanic Ig. Rocks - rocks which solidify from lava (or were extruded onto earth's surface)
  - d. Intrusive Igneous Rocks or Plutonic Ig. Rocks - rocks which solidify from magma beneath the earth's surface.
2. Naming Igneous Rocks - Based on composition and texture of igneous rock.
  - a. Mafic Rocks (from Mag and Fe) - generally darker colored rocks relatively high in iron, magnesium, calcium and low in silicon. Associated with high temp. end of bowens Reaction Series.

- (1) Gabbro = plutonic = phaneritic = mafic composition
- (2) Basalt = volcanic = aphanitic = mafic composition (Ca-rich plag., and Pyroxene).
- b. Felsic (from feldspar and silica) Rocks - generally lighter in color, high in silica, Na, Potassium - consist mainly of quartz, K-feldspar, and Plagioclase
  - (1) Granite = plutonic = phaneritic = felsic composition
  - (2) Rhyolite = volcanic = aphanitic = felsic composition
- c. Intermediate - admixtures of both felsic and mafic, dominated by amphibole, intermediate plagioclase feldspar, biotite.
  - (1) Diorite = plutonic = phaneritic = intermediate composition
  - (2) Rhyolite = volcanic = aphanitic = intermediated comp.
- d. Ultramafic = very rich in iron and mag., olivine and pyroxene, Ca-rich plagioclase
  - (1) intrusive variety only = Peridotite - common in upper mantle

### C. Sedimentary Rocks

- 1. Sedimentary Rocks- rocks that are derived and formed at the earth's surface.
  - a. A process of weathering in which the atmospheric processes at the earth's surface slowly disintegrate and decompose the igneous rocks. Sediment is generated (e.g. sand or gravel) via weathering and subsequently transported by running water, gravity, waves, glaciers, wind and sediment is deposited. After sediment is lithified or cemented into solid rock (analogous to concrete).
  - b. Sed. rocks account for only 5% of the earth's crust/lithosphere, however they cover 75% of the earth's surface exposures. The sedimentary environment is a surface environment (at surface pressures and temperatures)
  - c. Rock Interpretation = reconstruction of ancient sed. environments
    - (1) (e.g. river, shallow ocean, deep ocean, lagoon, lake, swamp).
      - (a) fossils
  - d. Sedimentary rocks are where we find many natural resources such as coal and oil, also many ore minerals are found in sedimentary rock "hosts".
- 2. Basic Terminology
  - a. Weathering - disintegration and decomposition of rock at or near the surface of the earth, fragmenting rock into particles
  - b. Sediment - fragments of rocks and/or minerals that are produced from the weathering of pre-existing rock

- c. Erosion - incorporation and transportation of sediment by a mobile agent, usually water, wind, or ice.
- d. Lithification - refers to the process of converting loose sediment or mud into solid rock.
  - (1) compaction - as sediments accumulate and become buried with time, the weight of overburden compact the sediment,
  - (2) cementation - solutions carry ions into pores between sediments, with time ions may be precipitated as cements under appropriate chemical condition.
    - (a) Common cements include calcite, silica, and iron oxide.

### 3. Sedimentary Rock Types/Classification

- a. Detrital vs. Chemical Sedimentary Rocks.
- b. Detrital Sedimentary Rocks: "Detrital" = Fragmented Origin.
  - (1) Composition: sediments composed of quartz, clay, feldspars, and associated array of just about any other mineral in lesser proportions (e.g. amphibole, or any of silicate/igneous minerals, as well as recycled sedimentary rocks).
    - (a) E.g. Granite is weathered - produces quartz, and feldspars, plus mica: quartz is most resistant mineral and as a result is most common remnant product.
    - (b) the composition of the original rock (ig., sed., met.) that is weathered will have a direct influence on the composition of the sediment/sed. rock that results.
  - (2) Texture of Sediment: i.e. grain size.
    - (a) silt/clay = shale or mudstone;
    - (b) sand = sandstone;
    - (c) granule to boulder = gravel = conglomerate or breccia.
  - (3) Detrital Rock Types (shale, sandstone, conglomerate)
    - (a) Shale - detrital sed. rock consisting of lithified clay and silt sized particles, very small particles < 1/16 mm (must use microscope to see particles),
    - (b) Sandstone - detrital sed. rock made up of sand sized grains.
    - (c) Conglomerate - lithified gravels (boulders, to pea sized sediment), often poorly sorted with finer sediment between gravel.

- c. Chemical Sedimentary Rock Types - Chemical sediments may be directly precipitated under high concentrations of ions in water (e.g. halite/rock salt), or ions may be "fixed" by organisms living in the water in shells, accumulation of shells may then provide material for chemical sedimentary rock.
- (1) Limestone - composed of a mosaic of the mineral calcite ( $\text{CaCO}_3$ ) and forms by either chemical precipitation or biochemical processes. Biochemical processes account for 90% of the limestones.
  - (2) Dolomite - similar to limestone, but has Mg incorporated into  $\text{CaCO}_3$ ,  $\text{CaMgCO}_3$ .
  - (3) Chert -  $\text{SiO}_2$ , microcrystalline silica deposited from solution in open ocean.
  - (4) Evaporites - chemical sed. rock that result from precipitation of minerals via evaporation of water.
    - (a) E.g. halite/rock salt ( $\text{NaCl}$ ) and Gypsum ( $\text{CaSO}_4$ ). Commonly associated with shallow seas and brine lakes (e.g. Salt Lake).
- d. Sedimentary Rock Classification System
- (1) Detrital Rocks - distinguished mainly by grainsize, composition to a lesser extent
  - (2) Chemical Rocks - distinguished mainly by composition of minerals and fossils.
  - (3) Clastic vs. nonclastic -
    - (a) clastic = fragmental. E.g. sandstone is a clastic detrital rock, fossiliferous limestone is a clastic chemical rock,
    - (b) non-clastic = massive, crystalline appearance; if limestone has no fossils evident, then would be considered non-clastic.

### III. ROCK CYCLE

- A. Full cycle: magma-----cooling/crystallization---igneous rocks---weathering----sediment--  
--lithification/compaction----sedimentary rocks---pressure and temperature----  
metamorphism----metamorphic rocks----remelting-----igneous rocks

#### IV. Introduction to Plate Tectonics

##### A. General

1. The theory of plate tectonics is a recent development in the geological sciences, really accepted by scientific community since the early 1960's.
2. Earlier in the century geologic paradigm was dominated by the belief that ocean basins and continental land masses were permanent and fixed on the surface of the earth.
3. The theory of Plate Tectonics now recognizes that the positions of land masses are not fixed and that they have moved about the earth's surface over geologic history
  - a. Ocean basins/oceanic crust are continually being created and destroyed through tectonic processes.

##### B. Terminology

1. "Tectonics" - is a term that refers to the deformation of the earth's crust.
2. "Plate" - refers to the subdivision of the earth's crust and lithosphere into a number of tectonically coherent blocks
3. "Plate Tectonics" - refers to the formation and migration of these lithospheric plates,
  - a. Problem: time spans of plate motion on order of 10' of to 100's of million's of years,
    - (1) theory has been deduced from evidence recorded in earth's rocks, often difficult to interpret and sometimes inconclusive.

#### V. Overview of Earth Interior

##### A. Crust- a relatively thin outer layer

1. oceanic crust- thin on order of several km's thick
  - a. volcanic / basalt in composition
2. continental crust-thicker on order of 10's of kms thick
  - a. plutonic/sedimentary/"granitic" in composition

##### B. Mantle- rocky layer located below the crust and having a thickness of 2885 km

1. Mantle- dense, iron-magnesium silicate rocks

2. "Moho"
    - a. Mohorovicic discontinuity or Moho-seismic discontinuity in which velocity of earthquake waves increases abruptly below a depth of 50 km
    - b. now known to be boundary between crust and upper mantle
  3. Asthenosphere- soft zone of partially melted rock
- C. Lithosphere- outer solid portion of the earth which includes the upper mantle above the asthenosphere and the crust.
- D. outer core- 2270 km thick, possesses characteristics of mobile liquid
1. Liquid, iron-rich,
- E. inner core- 1216 km thick, solid metallic sphere
1. Core- thought to be composed of iron and nickel, very speculative, based on study of meteorites and speculation that they represent the interior composition of earth.

VI. Historical Perspective on the Evolution of Plate Tectonic Theory: Continental Drift a Precursor to Tectonic Theory

- A. Continental Drift - Alfred Wegner (German earth Scientist) proposed a hypothesis in early 1900's that the world continents have been drifting about on the earth's surface
1. Supercontinent of "Pangaea" existed 200 M.Y. ago in which all of major world's continents were once amalgamated together, and have since broken apart and migrated or drifted to their present positions/configurations.
  2. Evidence for Wegner's hypothesis of Continental Drift
    - a. Jig-saw puzzle fit of the Continents:
    - b. Fossil Evidence
      - (1) Mesosaurus which is only found on east coast of South America and west coast of Africa.
      - (2) How did these critters migrate across the ocean basins?
    - c. Similar Rock Types and Structural Rock Deformation across ocean basin
    - d. Paleoclimatic Evidence
      - (1) Evidence for glacial conditions 250 m.y. ago are found in similar aged rocks from southern Africa, South America, India and Australia

3. Problem with Wegner's ideas
  - a. not widely accepted
  - b. suggested on the continents were "drifting" not ocean basins
  - c. did not have a viable mechanical explanation as to how continents would "drift"

## VII. Modern Plate Tectonic Theory

- A. Basic Model - Based on early work by Wegner, more recent mapping of seafloor, magnetic surveys of earth's magnetic field, and observation of earth's seismic activity or earthquake activity.
  1. Plates- Plate tectonics model suggests that the outer, rigid lithosphere of the earth consists of about twenty rigid segments known as "plates".
    - a. Plate Mobility - it is recognized that each moves as a distinct rigid unit in relation to other plates.
      - (1) These plates move on top of a semi-plastic aesthenosphere, and interact with one another along their boundaries.
  2. Plate Boundaries and Nature of Interaction between Plates
    - a. 3 types of plate boundary interaction: Divergent, Convergent, or Transform fault boundaries
    - b. Divergent Boundaries - boundary condition in which tectonic plates move apart, resulting in upwelling of magma and volcanic material to create new seafloor: i.e. creation of new crust.
      - (1) located at crests of mid-oceanic ridges, where plates move apart and molten rock is injected and cooled to form new seafloor.
        - (a) Mid-Oceanic Ridge System
      - (2) Seafloor spreading- process of plate divergence and injection of magma.
        - (a) E.g. Atlantic ocean basin, has undergone seafloor spreading over last 165 m.y. at avg. rate of 6 cm/year.
        - (b) e.g. Red Sea in Middle East is an example of a very young ocean basin that is just beginning the process of seafloor spreading.
      - (3) Continental Rifting
        - (a) Pulling apart of continental crust by faulting
        - (b) Incipient seafloor spreading center



- c. Convergent Boundaries- plate boundaries in which two plates move toward one another or collide.
  - (1) Collision of one plate into another results in downbending of one plate and descent of that plate beneath the other,
  - (2) subduction zone- a zone of plate convergence in which where an oceanic plate descends into the upper mantle beneath the overriding plate.
  - (3) trenches - zone where subducting slab dives beneath over-riding plate
  - (4) volcanic arc - an arcuate chain of volcanoes on continental crust that result from subduction of oceanic crust beneath continental crust.
    - (a) Cascade mountains in U.S., Andes in SAM, Sierra Mtns in CA are eroded core of volcanic arc.
    - (b) Forearc region - zone in front of arc, towards trench
      - i) e.g. Willamette Valley, west of Cascades
    - (c) Backarc region - zone behind the arc, away from trench
      - i) e.g. central Oregon, east of Cascades
  - (5) Types of convergent boundaries
    - (a) Oceanic-Continental Plate Convergence-
      - i) e.g. W. Coast of North America
    - (b) Oceanic-Oceanic Plate convergence
      - i) e.g. Japan
    - (c) Continent-Continent Plate Convergence
      - i) e.g. India / Asia / Himalayas
- d. Transform Fault Boundaries: condition where plates slide horizontally past one another along a fault (or fracture along which there is movement)
  - (1) Crust is neither consumed nor destroyed.
  - (2) Transform faults connect convergent and divergent boundaries into a worldwide network of interconnected plate boundaries.
    - (a) (e.g. San Andreas Fault in Ca).

## VIII. Evidence to Support Modern Plate Tectonic Theory

### A. Magnetism and Paleomagnetism (result of search for German submarines in WWII)

1. Earth has a magnetic field about it with a magnetic north pole and south pole

similar to a bar magnet with lines of magnetic force flowing from North to south.

2. Paleomagnetism - iron-rich minerals such as magnetite ( $\text{Fe}_3\text{O}_4$ ) act as tiny magnets, when these minerals cool from a magma there is a temperature at which they align with the magnetic field of the earth (curie point),
  - a. Polar Wandering -
  - b. Polar Reversals
    - (1) Normal Polarity -So rocks have been found with paleomagnetism similar to todays polar arrangement termed "normal" polarity
    - (2) Reversed Polarity- rocks which indicate magnetic north pole at current position of south magnetic pole
  - c. Seafloor Stripes

B. Evidence from Seismic Records of Earthquakes

1. the distribution of earthquake focii or origination points of earthquakes was examined around the world and at convergent plate boundaries or subduction zones.

C. Evidence from Ocean Drilling

D. Evidence from obducted slabs of seafloor / upper mantle

1. Ophiolite Complexes
  - a. Sheet Dike (Gabbro) overlain by Pillow Lavas (Basalt) overlain by deep water sedimentary rocks

E. Hot spots tracks

1. Hawaiian Islands

IX. Driving Mechanism for Plate Tectonics: what force causes the plates to move about the earth's surface?

A. Heat Transfer/Convection within Mantle

1. Model: the lower or inner portion of the mantle, near the core, is hotter than the upper mantle, this unequal distribution of heat results in circulation of heated, semi-plastic mantle material...warm, less dense material of lower mantle rises very slowly in regions of spreading centers, spreads laterally, cools, and slowly sinks back into the mantle and reheating process repeats, these mantle convection currents result in shear force being applied to overriding crustal plate and drive plate tectonic motion.

B. Other Ideas

1. active subduction pull
  - a. cold, dense subducting slab pulls plate into interior of Earth
2. ridge push
  - a. active spreading centers push slab into interior of Earth