

**GLG101: Physical Geology Lecture Review Series**

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**Last Modified: August 20, 2005**

# **GLG101: Physical Geology Lecture Outlines for Exam#1:**

Introductory Concepts and Processes and Plate Tectonics (p. 2-7)  
Minerals (p. 8-20)

References to Tarbuck & Lutgens (or T & L) refer to the 8<sup>th</sup> or custom GCC edition.

20 pages including this cover

## GLG101: Introductory concepts and processes-Lecture Reviews

### Geology = scientific study of the Earth

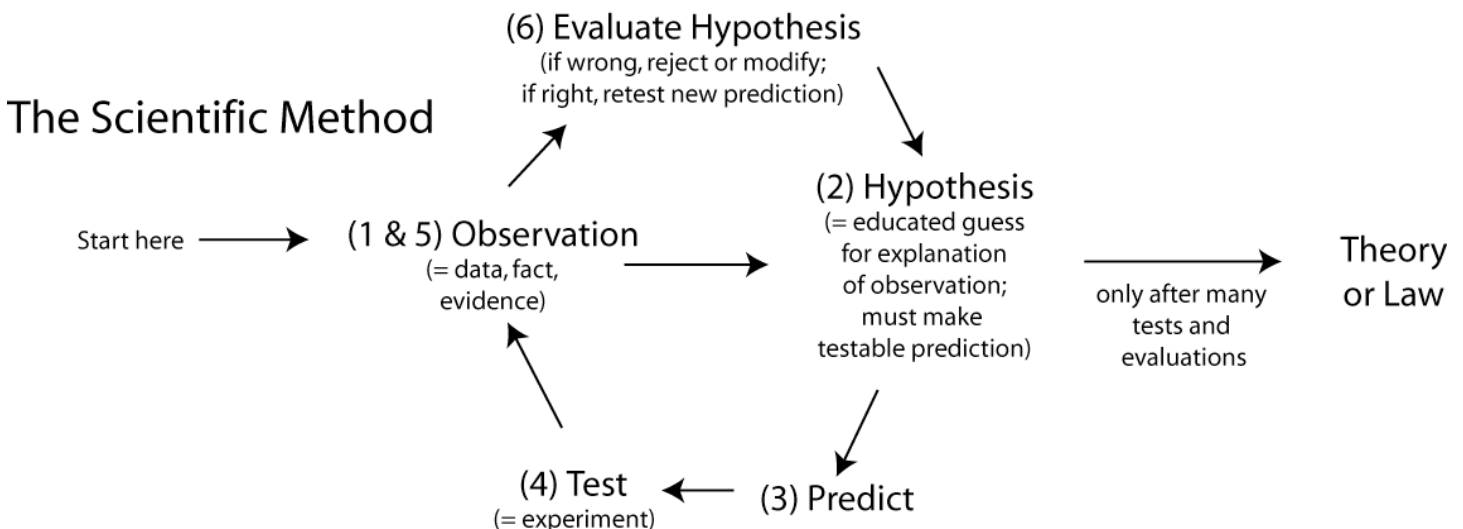
**Physical Geology:** How the Earth works; its composition and the processes which operate on and beneath its surface

### Practical uses of geology in our everyday life

- **Geologic Hazards:** Earthquakes      Volcanoes      Floods      Landslides
- **Earth Resources:** Everything we don't grow must be mined
- **Policy decisions:** Many public decisions require some knowledge of geology.

### Geology as a science

- **Scientific Philosophy** - there are orderly patterns in nature that can be explained naturally (without appeal to the supernatural) with the application of natural physical and chemical principles. Once such an explanation has been discovered it can be used to predict such patterns in the future; or determine their presence in the past. Such is the utility/power of science.
- **Scientific Method** (See following diagram)
  - Observation:** notice a pattern
  - Hypothesis:** Propose a natural explanation for the pattern. Because of limit to natural processes, hypothesis must make a testable prediction.
  - Prediction:** Define a prediction based on hypothesis. If you are right, then...
  - Test or experiment:** Test the hypothesis' prediction.
  - New Observation:** results from the experiment.
  - Evaluation of hypothesis:** if wrong need new hypothesis; if right test again.
  - Do over** until hypothesis explains all available data- then you have a **theory**.



- **Theory** is the best explanation of a particular phenomena/pattern accounting for all available observations (data, evidence). There is no certainty in science. Thus, we can't be sure that our theories are absolutely correct but they are the accepted explanations for their particular sets of observations. We spend billions of dollars based upon them. Sometimes called **models** or **paradigms**.
- **Law** is a theory that has stood the "test of time". Not usually known to be violated. Gravity is example

## Observations of the Earth's Surface- Patterns that need explanation (Coincidence?...)

### Ocean Basins (see Chapters 13)

Abyssal Plains	Ocean Trenches
Ocean Ridges (=Rises)	Island Arcs
Transform Faults & Fracture Zones	Island/Seamount Chains

### The Continents (see Chapter 13)

Passive Continental Margins	Active Continental Margins
Continental Shelves	Volcanic Arcs
	Mountain Belts

### Other Patterns

Distribution of Earthquakes

Distribution of Volcanoes

Age of Ocean Floor

Fit of Continents

## Early Hypothesis about the Earth: Wegener's Continental Drift:

Based on the following evidence, Alfred Wegener proposed that the continents were once together in a supercontinent called **Pangea**. Pangea broke up and the continents somehow "drifted" to their present positions.

- **Fit of the Continents:** Atlantic-bordering continents would fit together nicely- not only in geometry, but also in the match of the geological features
- **Rock sequences & continuity of mountain belts:** Mountain belts matched across Atlantic (Appalachians in N. America to Caledonian Mtns in Britain & Scandanavia. How to explain?)
- **Fossil Evidence:** Fossils of creatures whose modern analogs suggest latitudinal dependence are located in areas where they couldn't have lived. Fossils of identical creatures found on widely separated continents.
- **Paleoclimate Evidence:** Ancient glacial deposits now sit at equatorial latitudes.

**Wegener's problem. How do you do it? Could not find a feasible mechanism.**

### **Paleomagnetism and the rejuvenation of the Continental Drift Hypothesis.**

Rocks can record the position of the Earth's Magnetic poles

On average, these poles approximate the position of the Earth's current rotation axis.

Ancient rocks show different positions (Apparent Polar Wander) posing a problem with two possible hypotheses:

- (1) the magnetic field has really wandered through time; OR
- (2) the continents have drifted through time.

Comparison of paleomagnetic poles from different continents (T&L Figure 2.11) strongly favors hypothesis #2 causing scientists to again consider Continental Drift.

### **The Discovery of a Layered Earth- a theory**

Observations of earthquake wave behavior, gravity, the magnetic field, in conjunction with astronomical considerations allow us to make the following theory of what's inside the Earth

•**The Layered Earth- Know T & L Figure 1.14 INTIMATELY (except exact thicknesses)**

*There are 2 ways to describe the Earth's interior: by composition and by its mechanical properties. This often creates confusion for students so study this well.*

#### **The Compositional Earth Layers**

- Core:** Probably iron and nickel in composition.
- Mantle-** greatest volume of Earth- probably compounds of silicon, aluminum, iron, magnesium, and oxygen
- Crust-** thin scum on top of mantle
  - Oceanic crust-** crust under deep oceans; also made up of silicon compounds similar to those in mantle; denser and thinner than continental crust; made up of volcanic rocks much like those at Sunset Crater by Flagstaff.
  - Continental Crust-** thick and relatively light- also made up of silicon compounds but less iron and magnesium; overall made up of rocks that have compositions similar to the granite used in making landscape rocks.

#### **The Mechanical Earth Layers**

- Inner Core:** Solid: Probably iron and nickel in composition.
- Outer Core:** Liquid: Also most likely iron and nickel in composition.
- Mesosphere:** Solid: The bulk of the mantle. Sometimes called the lower mantle.
- Asthenosphere:** Gooley: upper mantle that is at or very near melting point. May be partially molten to behave like a fluid much like peanut butter in consistency
- Lithosphere-** Solid: Everything above the asthenosphere. Includes uppermost solid mantle AND crusts
- Hydrosphere & Atmosphere-** Liquid and Gas: oxygen, nitrogen, carbon dioxide etc.

## Sea Floor Exploration and the Sea Floor Spreading Hypothesis (Chapter 13).

### Plate Tectonics- the current fundamental theory accounting our observations on the Earth

- **Basic Premise of Plate Tectonics-** lithosphere broken up into plates "floating" on asthenosphere in relative motion with respect to one another. Plates are basically rigid. Most action (earthquakes, volcanoes and mountain building) occurs at or near the boundaries of plates.
- **The Plates Themselves-** Basic plate map (see Figure 2.19)
- **Plate Boundaries (see Chapter 2 in T & L)**
- **Divergent:** Plates pull apart. Continental rifts and mid-ocean ridges; new lithosphere created; volcanism and earthquakes
- **Convergent:** Plates collide or push together.
  - **Oceanic-Oceanic:** Subduction zones, oceanic trenches, old lithosphere consumed back into the asthenosphere; volcanism (island arcs) and earthquakes. **Example:** Marianas Trench- Pacific and Philippine plate converge.
  - **Oceanic-Continental:** Subduction zones, oceanic trenches, old lithosphere consumed back into the asthenosphere; volcanism (volcanic arcs) and earthquakes. **Example 1:** (Nazca-South America plate converge creating the Peru-Chile Trench and the Andes Mountains. **Example 2:** The Juan de Fuca and the North American plates converge in the Pacific Northwest of USA forming the Cascade Mountains and Volcanoes.
  - **Continental-Continental:** No subduction and no volcanoes. Great earthquakes and mountain belts. **Example:** India and Asia converge creating the Himalayan Mountains.
- **Transform:** Plates slide past one another. Forms fracture zones in ocean floor. Lithosphere is neither created nor destroyed; Earthquakes but no volcanism. **Example:** San Andreas Fault of California. Everything west of it is on the Pacific Plate sliding northwest relative to the rest of North America.

### Testing the Plate Tectonic Theory

Geomagnetic Field Reversals & the Geomagnetic Polarity Time Scale

Sea Floor Magnetic Anomalies and the Vine-Matthews Hypothesis

Calculating plate velocities using magnetic anomalies (KNOW HOW TO DO THIS- IT'S USUALLY ON THE TEST)

### Earth's Internal Heat Engine - The Driving Mechanism of Plate Motion

- Heat within the Earth- **temperature increases with depth** (=Geothermal gradient)  
Primordial heat- leftover from early formation of Earth. Rocks lose heat very slowly.  
Heat from decay of radioactive materials
- **Thermal Convection** (Drives plate motion, causing earthquakes, volcanoes, and mountain building; produces igneous and metamorphic rocks)
- **Hot Spots:** create chain of inactive volcanoes with the oldest in direction of plate motion. The active volcano indicates the position of the hot spot. Can also calculate plate velocities using hot spot tracks as well.

### Earth's External Solar Powered Heat Engine and the Hydrologic Cycle

- The **Hydrologic (Water) Cycle** (Know Figure 1.11 in Tarbuck & Lutgens intimately)  
**Evaporation-Condensation-Precipitation-Runoff**
- **Role of Hydrologic Cycle in geology-** weathering and erosion act to level topography; produces sedimentary rocks

### HOW THE EARTH WORKS IN A NUTSHELL

- The Earth's internal heat engine causes plate motions, mountain building and creation of new continental crust. The external solar engine drives the hydrologic cycle that erodes mountains and changes landscapes. The landscapes and features that we see on Earth today are result of the interaction between these two engines. This is sometimes referred to as a Dynamic Equilibrium system because both engines are in constant motion. The Earth's internal heat is slowly being lost, however, so eventually new mountains will cease to form and erosion will level the landscape.

**Rocks-** solid aggregates of crystals (xls) with a couple of exceptions (glass). Crystals are minerals, the natural chemicals of the Earth. Rocks are classified primarily on how they formed based on the Principle of Uniformitarianism (present is the key to the past/ past is key to future). There are three major categories: igneous, sedimentary and metamorphic.

- **Igneous Rocks:** formed from cooling of molten material (magma/lava) Texture is interlocking xls or glass. Associated with convergent and divergent plate boundaries  
**Volcanic = extrusive** are formed by rapid cooling at or near the surface  
**Plutonic = intrusive** are formed by slow cooling beneath the Earth's surface

- **Sedimentary Rocks:** formed at Earth's surface; Layered rocks deposited *horizontally with the oldest layer on the bottom*. Can form anywhere but are typically preserved when deposited in large basins such as near or in oceans. Tell us about ancient geography
  - Detrital** = made up of detritus (bits or **clasts** of other rocks, or crystals weathered from other rocks. Clasts are cemented together by crystals grown from chemical precipitation in empty space between clasts.
  - Chemical/Biochemical** = xls formed by chemical precipitation due to chemical environment or biological activity
  - Organic** = compacted and altered organic material- coal
  
- **Metamorphic:** changed form of any other rock type (igneous, sedimentary AND other metamorphic rocks. Crystal growth and changes induced by changes in the *pressure, temperature or both*. Change is solid state.
  - Although metamorphic rocks occur in a variety of places, large continuous regional belts are typically associated with convergent plate boundaries

### Geologic Time

- Most geologic processes occur very very very sloooooowwly.
- Rocks can be dated relatively using principles of superposition and faunal succession
- Geologic Time Scale
- Earth is very old- about 4.6 Ga. ("Ga." stands for Giga annum or billion years)

### • Summary films (all available in media center library)

Continental Drift and Plate Tectonics (Atwater);

Rocks that originate underground- Britannica Films

Rocks that originate on the Earth's Surface- Britannica Films

**GLG101: Minerals Lectures****Minerals versus rocks.**

**Rock definition:** A solid aggregate of one or more minerals (some exceptions)

**Mineral definition:**

- Naturally occurring (Dupont diamonds- NOT)
- Inorganic (Amber-Not)
- Crystalline
  - definite internal structure (Glass- NOT)
  - definite chemical composition (within limits)
- Solid

**Physical Properties of Minerals (how we can tell one mineral from another)**

**Crystal Form-** external expression of internal structure. Geometrically symmetrical **shape** that mineral will attain if it has the space & time to grow.

**Cleavage/Fracture** = the way a mineral breaks and is dependent on internal structure.

**Hardness** (Tarbuck & Lutgens Figure 3.13 Mohs Hardness scale-) = resistance to abrasion = "scratchability".

(1 = Talc-Gypsum-Calcite-Fluorite-Apatite-Feldspar-Quartz-Topaz-Corundum-Diamond = 10)

The Geology Class Failed, Apparently From Quizzes That Calderone Delivered

**Specific Gravity** = similar to density but specific to Earth. *S.G.* = Weight in air /difference between weight in air and weight in water. Sufficient to think of *S.G.* as "heaviness" of mineral.

**Color** = self-explanatory

**Luster** = the quality and intensity by which a mineral reflects light (metallic or nonmetallic).

**Streak** = color of a pulverized mineral on an unglazed porcelain streak plate (good test for metallic or earth minerals)

**Taste** = how a mineral "tastes" = its flavor; good for identifying halite (salt)

**Smell** = how a mineral smells- either by itself or when scratched; good for sulfur

**Double Refraction** = the ability of a mineral to split light

**Magnetism** = the ability of a mineral to "act a magnet" (i.e. to have a magnetic moment in the absence of an external magnetic field. In the simplest terms consistent with your experience, it is the ability to attract other magnets).

**Acid reaction** = the reaction of a mineral when exposed to a weak hydrochloric acid

**Radioactivity** = the emission of radiation- useful in that it radiometric clocks allow us to fix the age of formation of minerals and the rocks in which they are found.

**Piezoelectricity** = the ability of a mineral to emit an electric current when stressed

**Fluorescence** in ultraviolet light = mineral glows or emits different colors in UV light

**Melting point** = temperature at which the mineral will melt.

## Atomic Structure and Chemical Bonding

Some basic definitions- Intro to chemistry [see P. 80, Tarbuck & Lutgens]

**Element**- a substance that cannot be broken down further by ordinary chemical means

**Compounds** are substances that can be broken down chemically into elements

Introduce NaCl as a compound and our chief example of how atoms behave and what that can tell us about mineral and crystal formation.

**Atoms**- the smallest particle of an element that retains the properties of that element.

**Molecules** are two or more atoms combined with a chemical bond to form a substance.

An **element** occurs when the atoms are the same. A **compound** occurs when the atoms are different types. Atoms are made up of still smaller particles:

- Protons** (positive electrical charge, contributes mass)

- Neutrons** (no electrical charge, contributes mass)

- Electrons** (negative electrical charge, contributes almost no mass)

Protons and neutrons form the **nucleus** of the atom and give the atom its **mass**.

Electrons surround the nucleus at predictable distances and give the atom its **size**.

**Atomic number** = the number of protons in an atom. Na has an atomic number of 11. Cl has an atomic number of 17.

**Atomic mass number** = the number of protons + the number of neutrons.

**Isotopes** = atoms of an element that contain the same number of protons as the element but a different number of neutrons. Isotopes are important because many are naturally radioactive and allow us to "tell geologic time" by their rate of radioactive decay into isotopes of other elements. Uranium 238 (we write this  $^{238}\text{U}$ ) for example decays into Lead 206 ( $^{206}\text{Pb}$ ). This decay is a function of time. Thus by measuring the amount of U and Pb in a mineral we can tell how old it is. This process is called radiometric dating, or isotopic dating.

**Atomic weight** = the average weight of an atom of an element in atomic mass units where one atomic mass unit is equal to 1/12 the weight of the carbon isotope  $^{12}\text{C}$ . Not exactly equal to the mass number due to the existence of isotopes. The atomic weight or atomic mass number of an element is important in that we can predict some of the physical properties of minerals. Example: compounds containing lead (Pb) such as

galena will be heavier, or have a higher specific gravity, than compounds containing carbon (C) such as graphite.

### The Quantum Mechanics model of an atom

- Atom consists of a nucleus surrounded by a "cloud" of electrons moving around with specific levels of energy (roughly corresponding to distances from the nucleus).
- Electron configuration of the atom determines the ability of the atom to combine with other atoms and make new substances.
- We can sum up atomic behavior as the equilibrium between two basic processes: Atoms want to:
  - (1) minimize their "internal" energy- generally minimized when outermost electron shell (the **valence** shell) has 8 electrons and the atom has the same electron configuration as one of the noble gases (Argon, Krypton, Neon etc). To fulfill this requirement, atoms will want to lose or gain electrons to form **ions**. **Ions are atoms that have an electric charge**. Positive ions are called **cations**, whereas negative ions are called **anions**.
  - (2) neutralize their net electrical charge. This requirement is what causes ions to combine with other ions.

### Chemical bonding

**Ionic** - Bond between ions. Compounds formed in this manner are grouped according to the anion type. NaCl is a **chloride**. Named for the chlorine anion. Other geologically important ionic mineral groups are the **Sulfides** and the **Oxides**.

**Covalent**- adjacent atoms share outer electrons. Each atom thinks it owns one or more of the outer electrons of the adjacent atom. Very strong bonds. Isolated purely covalent bonds are rare in nature but include some important minerals. Carbon, for example will bond covalently with other carbon atoms to produce the minerals diamond and graphite- **native elements**.

**Metallic** - usually occurs in heavier metals near the center of the periodic table.

Nucleuses of atoms pack together closely and clusters of nuclei share the net cloud of valence electrons. Tight packing accounts for "heaviness" metals and their ability to conduct electricity as well as their malleability, and ductility. Elements that can form metallic bonds often occur naturally as native elements. Example Gold, silver, copper.

**van der Waals Bond** - weak bond between atoms with leftover nuclear forces. Example: Graphite- Carbon atoms bonded covalently in sheets. Sheets held together with van der Waals bonds. Weakness contributes to the ability of graphite to cleave along

planes between sheets giving graphite a cleavage allowing it easily write down these words.

**Mixed (hybrid) bonds** - usually occurs in compounds but can occur in elements. Consider Si and O. Si has a +4 ion,  $\text{Si}^{+4}$ , whereas O likes to form  $\text{O}^{-2}$ . Because of their relative sizes they can fit together in a tetrahedral form where 4  $\text{O}^{-2}$  ions gather around the  $\text{Si}^{+4}$  ion. The combination creates a compound or molecule with the formula  $\text{SiO}_4$ . The positively charged silicon ion is balanced by one electron from each of the Oxygen ions (an ionic bond). Each of the Oxygen ions touch and share their remaining electron with each other (a covalent bond) But notice that the molecule itself is not neutrally charged. There is an excess negative charge of -4. This molecule is called the silica tetrahedron and would like to find some other cation or cations to neutralize the charge- to form another ionic bond. If the silica tetrahedron can find say a couple of magnesium ions around ( $\text{Mg}^{+2}$ ) they can ionically bond to form a compound that we call the a **silicate**. A silicate compound is one in which something combines with the Silica molecular ion. Many compounds in nature like to do this. These form some of the fundamental mineral groups. **Silicates**, **carbonates** ( $\text{CO}_3^{-2}$ ), and **sulfates** ( $\text{SO}_4^{-2}$ )

As natural chemicals, the common minerals fall into distinct chemical groups on the basis of their composition. Because of the relative abundance of elements in the Earth's crust, there are only about 7 common mineral groups: the **silicates** ( $\text{Z}_x\text{SiO}_x$ ), the **carbonates** ( $\text{Z}_x\text{CO}_3$ ), the **sulfates** ( $\text{Z}_x\text{SO}_4$ ), the **sulfides** ( $\text{Z}_x\text{S}_x$ ), the **oxides** ( $\text{Z}_x\text{O}_x$ ), the **chlorides** ( $\text{Z}_x\text{Cl}_x$ ), and the **native elements** (Z) themselves.

**Factors governing formation of minerals** Minerals that form are dependent on:

- What elements are around- the chemical composition of the environment and the sizes of those elements.
- The pressure and temperature conditions- the physical environment

Diamond-Graphite example- **CRITICALLY IMPORTANT CONCEPT** a mineral that forms under one set of P/T conditions may not be stable at other P/T conditions. Changes in the environment (brought about by plate tectonic and solar engine processes) may force a mineral to be out of equilibrium with its surroundings. But it may be metastable, that is, it may require a certain amount of energy or activity to cause it to come to equilibrium with it's new surroundings.

- The presence/absence of volatiles or the activity of organisms that produce chemical reactions
- Time for formation of crystals and for chemical reactions to take place.

### Processes of crystallization- the formation of minerals

- Cooling from melt**- Igneous rocks- high temperature silicates through lower temperature silicates (Quartz)
- Chemical precipitation from evaporation** or change in concentration in a solution-  
Sedimentary Rocks- carbonates, sulfates, oxides
- Chemical precipitation from reaction**- (like clams making their shells by secreting fluid into seawater)  
Sedimentary rocks- Clay minerals, carbonates.  
Metamorphic rocks- If high temperatures and pressures are present then also can create higher temp/pressure silicates.  
Igneous rocks- Chemical reactions also take place during the formation of igneous rocks (will discuss later).

### Composition of Earth's Crust (know Figure 3.18 Tarbuck & Lutgens- top 4)

Oxygen: 60.5% by numbers of atoms

Silicon: 20.5%

- 80% of all atoms in Earth's crust are silicon and oxygen

Aluminum: 6.2%

Iron: 1.9%

Calcium: 1.9%, Sodium: 2.5%, Potassium: 1.8%, Magnesium: 1.4%

- ~97% of all crustal atoms are made up of only 8 elements  
All other elements are only ~3%

<h3>Common Minerals of the Earth's Crust</h3>
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#### Mineral categories

**Rock-forming mineral**- minerals that make up common rocks. No other value except as aggregates for building, landscaping etc.

**Ore-forming mineral**- minerals that can be profitably mined for one of their chemical constituents (e.g. sphalerite (PbS) can be mined for extraction of lead (Pb))

**Industrial minerals-** minerals that are used for their properties if not chemistry. E.g. gypsum is used as a whole mineral for the production of drywall.

**Accessory Minerals-** minerals that occur in rocks that although they may make up only a small percentage of the rock's composition, they nonetheless can provide important clues to the rock's origin; or may be concentrated by other processes to provide valuable chemicals to soil.

**Gemstones-** minerals valued for their intrinsic beauty.

**Note:** some minerals can fall into more than one category. (e.g quartz)

### SILICATE MINERAL GROUP ( $ZSi_xO_x$ ) SEE FIGURE 3.22

Recall that silicon and oxygen can bond together to make a substance called **silica**-  $SiO_4$ .

Geometrically, the representation of  $SiO_4$  is that of a tetrahedron- the **silica tetrahedron**, which is the basic building block of all the silicate minerals. Silica tetrahedrons have a -4 charge deficiency and so would like to get a few positively charged cations to achieve electrical neutrality. The addition of a little iron or magnesium, aluminum sodium, calcium, and potassium to the silica generates different minerals that make up a class called **the silicates** and make up about 95% of all the minerals in the crust!!! And of those silicates, we need learn only around 10 or so to help us identify most of the kinds of rocks we will need to interpret the history and evolution of the planet.

### Isolated Silica Tetrahedrons (Nesosilicates)

Silica tetrahedra are isolated from one another & held together by ionic bonds with other elements such as Fe, Mg, Al, Ca, etc. They are typically relatively high temperature minerals because the isolated structure is usually not stable at lower temperatures.

Mineral: **OLIVINE** (most commonly an iron-magnesium (= ferromagnesian) silicate; actually a group of minerals)

Formula:  $(Mg,Fe)_2SiO_4$

Diagnostic Physical Properties: "Coke-bottle" or olive green to dark green granular ("sugary") masses of glassy crystals. No cleavage,  $H \sim 7$ . Specific gravity  $\sim 3.5$ .

P/T Environment & Modes of Occurrence: Stable at high temperatures ( $\sim 1200^\circ - 1800^\circ C$ ).

Usually associated with very high temperature igneous rocks. Probably a major component of the upper mantle. Metastable at surface conditions. Weathers easily to red-brown clay (iddingsite). At high temperatures will react with free silica to produce pyroxene.

Uses: a common rock-forming and accessory mineral; forms a gem called **peridot**.

Mineral: **GARNET** (occurs as an iron-magnesium aluminum silicate; actually a group of minerals)

Formula:  $(Ca, Mg, Fe, Mn)_3(Al, Fe, Cr)_2(SiO_4)_3$  quite variable.

Diagnostic Physical Properties: Typically forms dark red or green 12 sided crystals (dodecahedrons). No cleavage,  $H \sim 7$ . Specific gravity  $\sim 3.7$ .

P/T Environment & Modes of Occurrence: Stable at relatively high temperatures ( $\sim 500^\circ - 1000^\circ C$ ) and moderate to high pressures. Usually associated with medium and high grade metamorphic rocks in addition to some igneous rocks. Metastable at surface conditions. Weathers easily to a greenish clay or clay-like mineral.

Uses: a common rock-forming and accessory mineral; may have gem form. Industrial abrasives.

### Single Chain & Double Chain Silicates (Inosilicates)

Silica tetrahedra are chained together and the chains are held together by ionic bonds with other elements such as Fe, Mg, Al, Ca, etc. They are typically moderate to high temperature minerals because the chain structures are usually not stable at lower temperatures.

Mineral: **PYROXENE** (most commonly a complex calcium/sodium iron-magnesium-aluminum (= ferromagnesian) silicate; actually a group of minerals of which the most common is **Augite**)

Formula:  $(Ca, Na)(Mg, Fe, Al)(Si, Al)_2O_6$  **Single Chains**

Diagnostic Physical Properties: Usually black or greenish black. Hardness around 6. 2 directions cleavage at  $90^\circ$

P/T Environment & Modes of Occurrence: Stable at high temperatures ( $\sim 1200^\circ - 1500^\circ C$ ). Usually associated with high temperature, dark colored igneous rocks. Metastable at surface conditions. Weathers easily to clay. At moderate temperatures will react with free silica to produce amphiboles.

Uses: a common rock-forming mineral; no common uses.

Mineral: **AMPHIBOLE** (most commonly a complex calcium/sodium iron-magnesium-aluminum (= ferromagnesian) silicate; actually a group of minerals of which the most common is **Hornblende**)

Formula:  $(Ca, Na)_{2-3}(Mg, Fe, Al)_5Si_6(Si, Al)_2O_{22}(OH)_2$  **Double Chains**

Diagnostic Physical Properties: Usually black or greenish black. Hardness around 6. 2 directions cleavage at  $60^\circ$  and  $120^\circ$ . Tends to form long pencil-like crystals

P/T Environment & Modes of Occurrence: Stable at moderate temperatures (~1000° - 1200°C).

Usually associated with moderate temperature, grayish igneous rocks or darker metamorphic rocks. Metastable at surface conditions. Weathers easily to clay. At low to moderate temperatures will react with free silica to produce micas.

Uses: a common rock-forming mineral; no common uses.

### Sheet Silicates (Phyllosilicates)

Silica chains bond together into continuous sheets. Sheets are held together by ionic or van der Waals bonds with other elements such as Fe, Mg, Al, Ca, Na, K, etc. They are typically low temperature minerals.

Mineral: **MICAS** (most commonly a complex calcium/sodium/potassium iron-magnesium-aluminum silicate; actually a group of minerals of which the most common are **Biotite and Muscovite**)

Formula:  $K(Al,Fe,Mg)_{2-3}(AlSi_3O_{10})(OH)_2$  **Sheets**

Diagnostic Physical Properties: Both Biotite and Muscovite have one cleavage, elastic tenacity, and a cellophane-like luster. Hardness around 2.5-3. **Biotite** is dark colored whereas **muscovite** is a mottled silvery brown color. Thin sheets of muscovite are almost colorless.

P/T Environment & Modes of Occurrence: Stable at lower temperatures (~800° - 1000°C).

Usually associated with low temperature, light colored igneous and metamorphic rocks. Metastable at surface conditions. Weathers easily to clay.

Uses: a common rock forming mineral; with its high dielectric and insulating properties, it is used as an insulating material in electrical apparatus; "isinglass" is large sheets of mica used in furnace doors; ground mica is used in: wallpaper (shiny); as a lubricant when mixed with oils; fireproofing material..

Mineral: **CLAYS** (most commonly a complex calcium/sodium/potassium iron-magnesium-aluminum silicate; actually a group of minerals of which the most common are **Biotite and Muscovite**)

Formula: Quite variable with some combination of  $(Al_2Si_2O_5)(OH)_4$  **Sheets**

Diagnostic Physical Properties: Most clays have a dull/earthy luster and various colors.

Hardness around 2. One cleavage. Most clays will also expand in water

P/T Environment & Modes of Occurrence: Stable at surface. A constituent of mud and a common sedimentary rock material.

Uses: a common rock forming mineral; used in ceramic materials; building materials (Portland cement); expansive varieties are utilized as engineering sealants (may also cause structural problems to buildings and highways); their absorbent properties make them useful in some

pharmaceuticals (Kaopectate contains kaolinite clay); used as fillers in food products ("shakes" at some fast food restaurants); fillers for paper, rubber and paint; drilling mud.

### **Framework Silicates (Tectosilicates)**

Silica tetrahedrons bond together three dimensionally (each oxygen is shared). Other elements such as Ca, Na, and K can be accommodated in this crystal structure. These are the most common minerals in the world.

Mineral: **POTASSIUM FELDSPAR** (actually a group of minerals of which the most common is **orthoclase**)

Formula:  $KAlSi_3O_8$  **Framework**

Diagnostic Physical Properties: Hardness = 6; two cleavages at  $90^\circ$ ; glassy to waxy luster; pink to milky white to light bluish; lacks striations

P/T Environment & Modes of Occurrence: Stable at low to moderate temperatures and pressures. A constituent of some sand. Also a common constituent in igneous and metamorphic rocks. Metastable at surface conditions- weathers to clay.

Uses: a common rock forming mineral; weathers to form clays; used in the manufacture of glass and ceramics.

Mineral: **PLAGIOCLASE FELDSPAR** (actually a group of minerals ranging from a Na-rich variety to a Ca-rich variety)

Formula:  $NaAlSi_3O_8$  to  $CaAl_2Si_2O_6$  **Framework**

Diagnostic Physical Properties: Hardness = 6; two cleavages at  $90^\circ$ ; glassy to waxy luster; milky white to grayish black; has striations on cleavage planes

P/T Environment & Modes of Occurrence: Na-rich variety is stable at low to moderate temperatures and pressures. Ca rich variety is stable at high temperatures and pressures. A constituent of some sand. Also a common constituent in igneous and metamorphic rocks. Metastable at surface conditions- weathers to clay.

Uses: a common rock forming mineral; weathers to form clays; used in the manufacture of glass and ceramics.

Mineral: **QUARTZ** includes a variety of crystalline forms including amethyst (purple); rose quartz (pink); citrine (orangish-yellow); smokey quartz (gray). Also includes microcrystalline forms such as agate, carnelian, onyx, chalcedony, petrified wood, bloodstone, jasper, flint, and chert.

Formula:  $SiO_2$  **Framework**

**Diagnostic Physical Properties:** Hardness = 7; conchoidal fracture; can form 6 sided crystals; glassy to waxy luster; any color; transparent to translucent; piezoelectric.

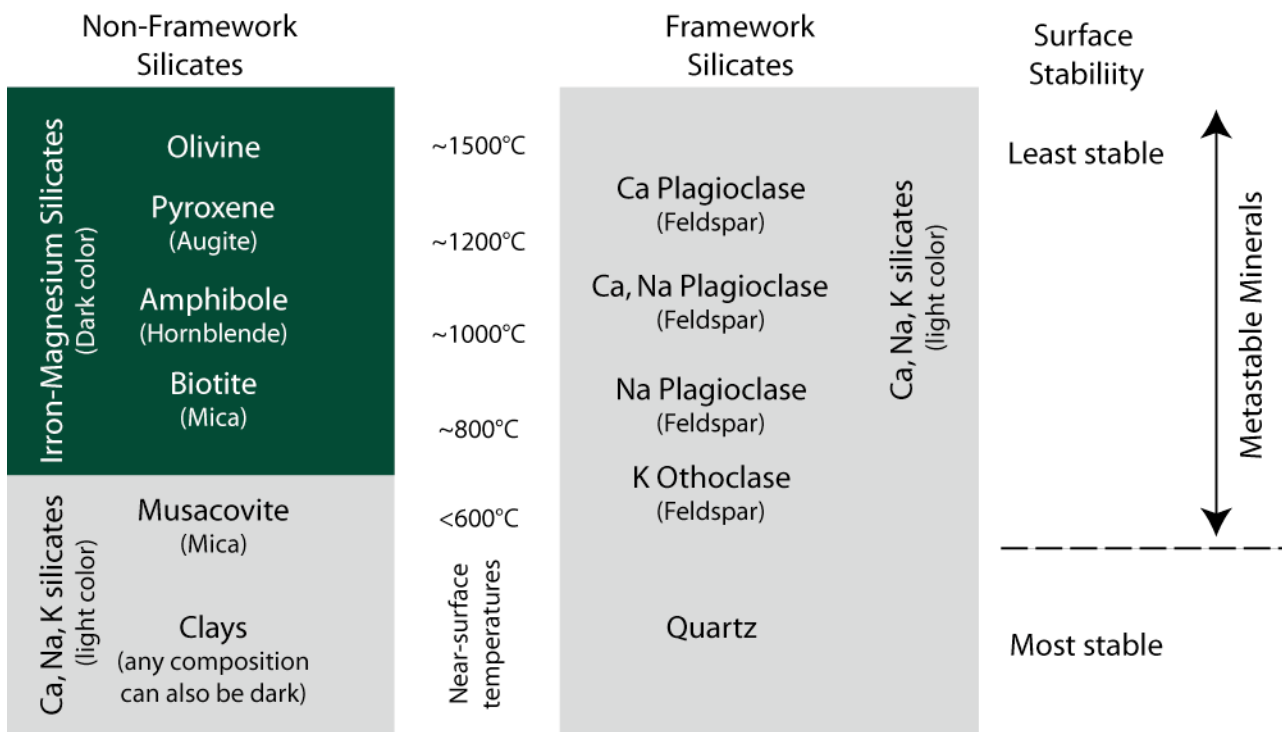
**P/T Environment & Modes of Occurrence:** Stable at surface and moderate temperatures and pressures. A constituent of sand and a common sedimentary rock material. Also a common constituent in igneous and metamorphic rocks.

**Uses:** a common rock forming mineral; very resistant to weathering; quartz crystal has piezoelectric properties that allows for its use in frequency control and filtration in electronic circuitry; a common abrasive in sandpaper; used to make glass; often collected by "rockhounds"; some varieties (such as amethyst and citrine) have gem value. Quartz comes in many varieties.

**Summary of the silicates- the most common rock-forming minerals.**

The following diagram depicts the temperature stability and other attributes of the silicate mineral family.

Bowen's Reaction Series- Temperature Stability of the common silicates



**CARBONATE MINERAL GROUP ( $Z_xCO_3$ )**

**Carbonates**-- Minerals containing the  $CO_3$  ion (the carbonate ion) are called carbonates. By far the most important carbonate minerals are: **calcite** ( $CaCO_3$ ) and **dolomite**  $CaMg(CO_3)_2$ . Stable through a wide range of temperatures and pressures. Dissolves relatively easily though.

CALCITE - common in many rock types; most abundant in sedimentary rocks (esp. as limestone which is nearly pure calcite); primary use is for the manufacture of cements and lime for mortars (Portland cement); chemical industry; fertilizer; whitewash; flux for smelting various metal ores; aggregate in concrete; building stone; "Iceland spar" (variety of crystalline calcite) is used in optical instruments.

**SULFATE MINERAL GROUP ( $Z_xSO_4$ )**

**Sulfates**-- Minerals containing the sulfate ion( $SO_4$ ) are called the sulfates. Of these the most important/common is **gypsum**. Stable through a wide range of temperatures. Dissolves relatively easily though.

GYPSUM - used in production of plaster of Paris; wallboard; soil conditioner in arid areas.

**CHLORIDE ( $Z_xCl_x$ ) AND FLUORIDE ( $Z_xF_x$ ) MINERAL GROUPS**

**Chlorides**-- Minerals containing the chloride ion( $O^{-2}$ ) are called the chloride. The most important chloride is **halite**. Halite is the substance we know as ordinary table salt. Dissolves easily. Can be stable up to fairly high pressures. Will flow though.

FLUORITE - an ore of fluorine; used in steel production as a slag thinner; ceramics as a flux; fluorocarbon chemicals that are used in: refrigerants, plastics, solvents, aerosols, lubricants, coolants, surfactants, rocket fuels, medicinals, and many other industrial products.

HALITE - common table salt; commercial source of chlorine; used in the manufacture of hydrochloric acid; tanning hides; fertilizers; in stock feeds; and as weed killer; food preparation and preservation; used to de-ice roads in winter which causes environmental problems, such as corrosion of metals and concrete, and contamination of both surface and groundwater.

### OXIDE MINERAL GROUP ( $Z_xO_x$ )

**Oxides**-- Minerals containing the oxide ion(O) are called the oxides. The most important oxides are **magnetite** and **hematite**. Magnetite is strongly magnetic, hematite is only very weakly magnetic (it takes very sensitive instruments to measure the magnetic properties of hematite. Stable through a wide range of temperatures and pressures. Dissolves relatively easily though. Magnetite often oxidizes further to hematite at surface conditions. These minerals record the Earth's magnetic field. Allow us to do paleomagnetism and fix the position of the continents through time.

HEMATITE - a major ore of iron; alloyed to make steel, iron is "the cheapest and most abundant, useful, and important of all metals" - Handbook of Chemistry and Physics

LIMONITE - often an indicator of an ore body below the surface; very minor ore of iron.

MAGNETITE - a very minor ore of iron (see Hematite); can play havoc on compasses.

### SULFIDE MINERAL GROUP ( $Z_xS_x$ )

#### **Sulfides**

Minerals containing the sulfide ion( $S^{-2}$ ) are called the sulfides. Some sulfides are important economically. These include **chalcopyrite** (copper-iron sulfide), a major ore of copper; **galena** (lead sulfide) a major ore of lead; and **sphalerite** (zinc sulfide), a major ore of zinc. Another common sulfide is **pyrite** (iron sulfide). Although not commercially valuable, it can act as an indicator for other more valuable minerals. In addition, weathering at the surface causes acid mine drainage.

GALENA - a major ore of lead; toxic element (cumulative poison); alloyed to make solder (lead); used in storage batteries (lead); lead is also used in plumbing, ammunition, anti-knock compounds in gasoline, radiation shields around x-ray and nuclear equipment, paint pigments, glass additive "lead crystal".

CHALCOPYRITE - a major ore of copper; (see Native Copper)

PYRITE - "Fools Gold", common accessory mineral in all rock types, its abundance in many ore deposits is the cause of "acid mine drainage" and high iron content in water, a source of sulfur emissions from smelter "smoke" forming sulfuric acid which causes "Acid Rain".

SPHALERITE - a major ore of zinc; zinc is used to galvanize iron; alloyed with copper to make brass; electric batteries; dyes; medicinal.

## NATIVE ELEMENT GROUP (Z)

### Native elements

A elements occur naturally in their native state. Native element minerals are usually important economically for their value. These include **gold**, **diamond/graphite** (both are pure carbon), **silver** and **copper**.

DIAMOND Stable at range of temperatures but needs high pressure.; H = 10; 4 Cleavages; Clear to yellowish in color; Igneous/Metamorphic Rock Mineral; Uses: Cutting devices; Gem: popular when cleaved

GRAPHITE - a source of carbon; dry lubricant; electrical components; carbon steel; foundry facings to prevent molten metals and alloys from sticking to molds; high temperature refractory uses (crucibles); pencils; batteries; paints; inks; brake linings.

NATIVE COPPER - a minor ore of copper; copper is used in electrical applications (second only to silver in electrical conductivity), structural uses; decorative uses. Alloyed with zinc to make brass and with tin to make bronze.

GOLD Stable at range of temperatures. H = 3-4; No Cleavages

Yellow gold color; Hydrothermal Rock Mineral; Uses: Principle ore of gold for electronics, currency base. Gem: yes

SILVER Stable at range of temperatures. H = 3-4; No Cleavages; Silver color; Hydrothermal Rock Mineral; Uses: Principle ore of silver for electronics, currency base. Gem: jewelry

Sources - "Handbook of Chemistry and Physics", 66th Ed., C.R.C. Press, 1985;

"Mineral Facts and Problems", 1970 Ed., Bureau of Mines, U.S. Dept. of Interior, 1970;

"Dana's Manual of Mineralogy", 18th Ed., Cornelius S. Hurlbut, Jr., John Wiley and Sons, 1971

- Summary diagrams- none
- Summary films -Minerals: Materials of the Earth (Earth Revealed) available in media center library