Environmental Geology
GLG 110 - CHAPTER 3 - MINERALS AND ROCKS

Why are minerals important in Environmental Geology? Let's look at asbestos as an example. There are three minerals from which most commercial **asbestos** (the name for a family of fibrous minerals): **chrysotile** (white asbestos), **amosite** (brown asbestos) and **crocidolite** (blue asbestos). About 95% of the world's commercial asbestos was once chrysotile, which has been demonstrated to be generally safe and non-carcinogenic. This is the type in most commercial buildings (including schools) built in the U.S. in the 1950s and 1960s. Brown and blue asbestos are dangerous, but are largely absent in U.S. facilities. Despite these facts billions of dollars have been needlessly spent and buildings needlessly ripped apart due to misinformed public policies.

Minerals are the building blocks of rocks which are the fundamental building blocks of Earth Rocks and minerals haved a variety of uses. They contain important clues for figuring out the history of Earth. Having a knowledge of minerals and rocks is the first important step to better manage Earth's resources and is important to our health and environment.

To be a mineral, a material must be a naturally occurring, inorganic solid with a definite internal structure (crystalline), and a definite chemical composition.

Minerals have diagnostic properties that we use to identify them, including: color and streak, luster, crystal form, cleavage, hardness and other special properties (taste, smell, feel, tenacity, reaction to acid, magnetism).

Rocks are solid aggregates of minerals, but also include naturally occurring glass, and some organic materials (e.g. coal). There are 3 major types-igneous, metamorphic and sedimentary

Minerals are made up of elements. There are over 100 are known (92 naturally occurring).
Atoms are the smallest particles of matter that retain all the characteristics of an element
Atomic structure – The central region is called the nucleus and it consists of protons (+ charges) and neutrons (zero/neutral charges). Electrons are negatively charged particles that surround the nucleus which are located in discrete energy levels called shells. Electrons orbit in "shells" around the nucleus.

*For each element in the Periodic Table, the atomic number represents t*he unique number of protons in an element's nucleus. Note: The number of electrons is equal to the number of protons in an electrically neutral atom. The a*tomic mass number is the* sum of the number of protons and neutrons.

Isotopes (useful in environmental geology)-atoms of same element with different number of neutrons

Chemical bonding: Atoms want to minimize their "internal" energy. The energy is generally minimized when electron shells are full (outer shell has 8 electrons) and the atom has the same electron configuration as one of the noble gases (e.g. Argon, Krypton).
Example: Fluorine (F) has 2 electrons in the innermost shell (shell 1) and 7 in its outermost shell (shell 2)….so it wants to find another electron to fill its outer shell. It can do this by bonding with another element to form compounds.

Types of bonding:

Ionic bonding - Atoms gain or lose outermost (valence) electrons to form ions. Ionic compounds consist of an orderly arrangement of oppositely charged ions. Example: *Halite (NaCl) aka Salt – Na (Sodium) is positively charged and Cl (Chlorine) is negatively charged so they "stick" together".*

Covalent bonding: Atoms share valence electrons to achieve electrical neutrality. These bonds are generally stronger than ionic bonds. Both ionic and covalent bonds typically occur in the same compound.

Metallic bonding: Valence electrons are free to migrate among atoms. These are weaker and less common than other bonds.

Van der Waals – A weak bond (e.g. graphite-"pencil lead"

Rock-Forming Mineral Groups -More than 4,000 minerals, but a few dozen are common on or near Earth's surface. Common mineral groups are primarily classified by chemical composition.

> **Silicates:** Contain **Si-O tetrahedron** fundamental building unit, including the two most abundant elements oxygen (O) and silicon (Si) in the Earth crust**. This is t<u>he most abundant mineral group.</u>**
> **Carbonates**: contain containing the carbonate ion $\mathbf{CO_3^{2-}}$
> **Oxides:** Contain oxygen atoms bonded to an atom of another element
> **Sulfides:** Contain sulfur atoms bonded to one or more metallic elements
> **Native elements**: Made of single element (e.g. gold and silver)

Igneous Rocks form as molten rock cools and solidifies. Magma is the parent material of igneous rocks which forms from partial melting of rocks.Magma at surface is called lava. Magma has a Liquid portion = melt. Volatiles = dissolved gases in the melt, including water vapor (H_2O), carbon dioxide (CO_2), and sulfur dioxide (SO_2). Solids that crystallize are silicate minerals.

The cooling of magma results in the systematic arrangement of ions into orderly patterns. The silicate minerals resulting from crystallization form in a predictable order.

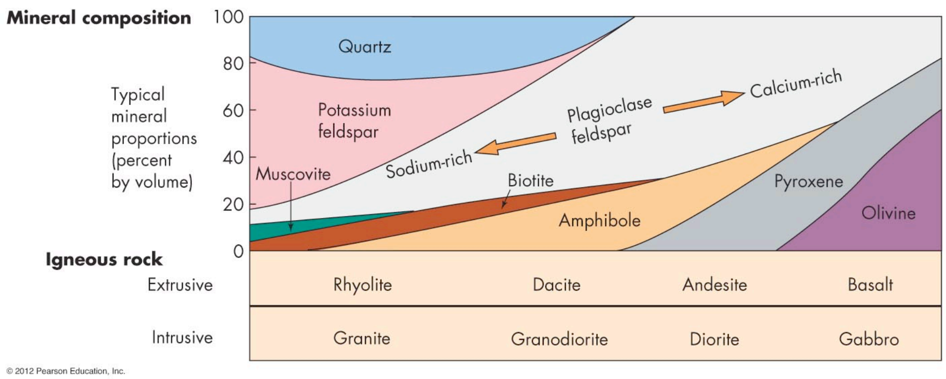
The texture of a rock refers to the size and arrangement of mineral grains.

Rocks formed from lava are called extrusive, or volcanic rocks.
The lava cools rapidly. Because extrusive lava cools rapidly the rocks have smaller microscopic cyrstals. The texture is called aphanitic (fine-grained). These rocks may contain vesicles (holes from gas bubbles).

A glassy texture *is c*ommon in extrusive rocks where the melt cools so rapidly that there is not time for crystals to form.

Rocks formed from magma at depth are called intrusive, or plutonic rocks. Because intrusive magma cools slowly, the rocks have larger crystals, visible to the naked eye. The texture of these rocks is called phaneritic (coarse-grained) texture .

In addition to texture, we classifying igneous rocks based on their composition.



Bowens Reaction Series – The chart below compares rock compositions with characteristics. Bowen demonstrated in a typical basaltic melt that minerals crystallize out at different temperatures. In the column labeled "Dominant Silicate Minerals" the primary minerals in each rock type is shown. The rocks that form at the highest temperatures (ultramafic) are mostly olivine, pyroxene and calcium plagioclase. Olivine crystallizes at the highest temperature. The granites form at the lowest temperatures and are a mixture of biotite, amphiboles, plagioclase, k-feldspar, and muscovite. Quartz is the last mineral to crystallize at the lowest temperature.

Figure 4.1: Igneous Rock Compositions, Magma Characteristics, Volcanism & Plate Tectonic Environments

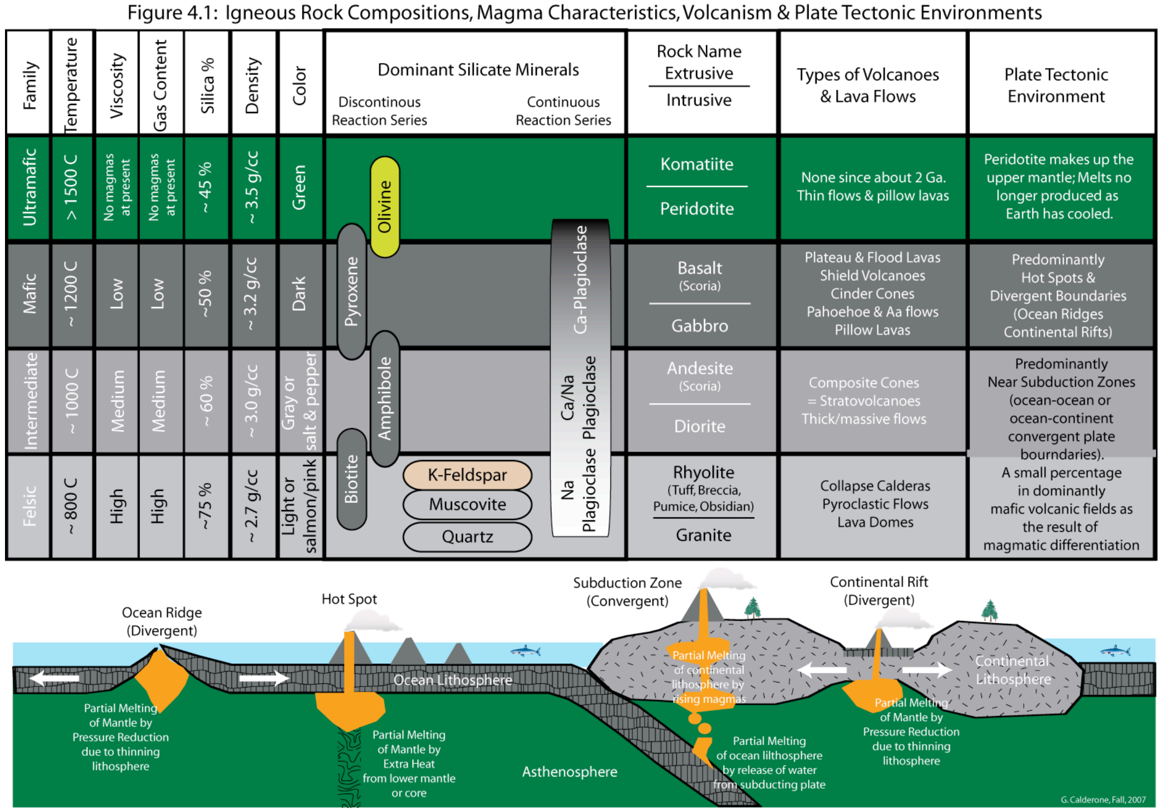


Chart by Gary Calderone

Granitic versus basaltic composition….

Granitic composition: Different mineral types produce different rock colors. These are light-colored silicates. They are termed felsic (*fe*ldspar and *si*lica) in composition. They have high amounts of silica (SiO_2) and are a major constituent of continental crust. The intrusive/phanertic variety is called g*ranite, and the extrusive/aphanitic variety is called rhyolite (Felsic)*

Basaltic composition: These are dark silicates and calcium-rich feldspar. They are termed mafic (*ma*gnesium and *fe*rrum, for iron) in composition, are more dense (heavier) than granitic rocks. These comprise the ocean floor and many volcanic islands. Gabbro is the intrusive/phaneritic variety, and basalt is the extrusive/aphanitic variety.

Rocks that are in between the Felsic and Mafic composition are called intermediate (or andesitic) in composition. They generally contain 25% or more dark silicate minerals. They are associated with explosive volcanic activity. Diorite is the intrusive/phanertic variety, and andesite is the extrusive/aphanitic variety.

Ultramafic composition: These are rocks that are composed entirely of ferromagnesian silicates (high in magnesium and iron). They are found in Earth's Mantle, and are rare in Earth's crust.

*volcanic eruptions: C*haracteristics of a magma determine the "violence" or explosiveness of a volcanic eruption. The composition, temperature and the amount of dissolved gases control the viscosity of a given magma. *nature of volcanic eruptions. V*iscosity is a measure of a material's resistance to flow. Hotter magmas are less viscous (flow more readily). Magmas with a higher silica content (e.g. felsic lava – rhyolite) also have a higher viscosity. Magmas with a lower silica content (e.g. mafic lava – basalt) have a lower viscosity (flow more readily). Gas content also affects magma mobility. Gases expand within a magma as it nears the Earth's surface due to decreasing pressure. The violence of an eruption is related to how easily gases escape from magma.

In summary: Basaltic lavas = mild eruptions AND Rhyolitic or andesitic lavas = explosive eruptions. A typical basaltic lava that flows readily is called a pahoehoe (pa-hoy-hoy) type. Mafic (basaltic) eruptions form shield type volcanoes. The Hawaiian Islands are shield volcanoes. Granitic-andesitic eruptions (e.g. Mount Saint Helens - 1980) are more explosive and form composite volcanoes which are made up of layers of lava flows and volcanic ash. Hot volcanic ash sometimes erupts in a cloud known as a *A nueé ardente (hot gas/ash) on*

Weathering: *Earth's external processes include w*eathering – the physical breakdown (disintegration) and chemical alteration (decomposition) of rock at Earth's surface, mass wasting – the transfer of rock and soil downslope under the influence of gravity and erosion – the physical removal of material by mobile agents such as water, wind, ice, or gravity.

Mechanical weathering – breaking of rocks into smaller pieces. Some of these processes include frost wedging, unloading – release of pressure/fracturing (e.g. exposure of rocks that were once buried deeply), abrasion, thermal expansion and biological activity.

Chemical weathering breaks down rock components and internal structures of minerals. The most important agent is water, which is responsible for transport of ions and molecules involved in chemical processes. Major processes include dissolution (dissolving) which is aided by small amounts of acid in the water, oxidation (e.g. rust)-any reaction when electrons are lost from one element, and hydrolysis, which is the reaction of any substance with water as the hydrogen ion attacks and replaces other ions

Chemical Weathering & Climate: High temperatures and rainfall increases the rate at which rocks weather to form soils. Very warm and wet conditions increase the rate of chemical weathering. Limestones and Marble (made of calcium carbonate) break down much faster in warm/wet condition

Through mechanical weathering that breaks up rock, the exposed surface area. Chemical weathering can act more effectively on the rocks due to this increase in surface area. Rocks like granite often form rounded boulders as mechanical and chemical weathering work together to round the corners of exposed boulders.

Sedimentary Rocks are products of mechanical and chemical weathering. They account for about 5% (by volume) of Earth's outer 10 miles, and about 75 percent of all rocks exposed at the surface. They contain evidence of past environments, and they often contain fossils. Sedimentary rocks are important for economic considerations because they may contain coal, petroleum and natural gas, and sources of iron, aluminum, and manganese.

Sedimentary environments are the places in which sediments can be deposited. The types of sediments we find in areas such as streambeds, beaches, lake bottoms and the ocean floor today can be compared to those in sedimentary rocks to determine the past environments in which those rocks formed.

Sedimentary structures can be used to determine the conditions of wind or water flow when sediments were deposited. Common sedimentary structures include bedding, graded bedding, ripple marks, cross-bedding and mud cracks.

Sedimentary rocks are classified according to the type of material.

Detrital rocks –sediment transported as solid particles. Clay minerals, quartz, feldspars and micas are common constituents of detrial rocks. Particle size is used to distinguish among the various rock types. Common detrital sedimentary rocks:

- Shale - Mud-sized particles in thin layers that are commonly referred to as laminea. This is the most common sedimentary rock
- Sandstone - Composed of sand-sized particles. These forms in a variety of environments. Quartz is the predominant mineral
- Conglomerate and breccia - Both are composed of particles greater than 2mm in diameter. Conglomerate consists largely of rounded gravels. Breccia is composed mainly of large angular particles

Particle shape (how angular or round) is also used to describe sediments. The rounder a particle is, the more it has been abraded, and the farther it is likely to have been transported from the "source region" before being deposited and lithified into sedimentary rock.

Chemical rocks – sediment that was once in solution. Precipitation of material occurs by Inorganic processes, organic processes (biochemical origin). Common chemical sedimentary rocks include:

- Limestone – The most abundant chemical rock, composed chiefly of the mineral calcite. Marine biochemical limestones form as coral reefs, coquina (broken shells), and chalk (microscopic organisms).Inorganic limestones include travertine and oolitic limestone
- Dolostone - Typically formed secondarily from limestone
- Chert - Composed of microcrystalline quartz. Varieties include flint and jasper (banded form is called agate).
- Evaporites - Evaporation triggers deposition of chemical precipitates. Examples include rock salt and rock gypsum

    - Coal - Different from other rocks because it is composed of organic material. Stages in coal formation (in order): 1. Plant material 2. Peat 3. Lignite 4. Bituminous

Metamorphism and Metamorphic Rocks: *Metamorphism is t*he transition of one rock into another by temperatures and/or pressures unlike those in which it formed. Metamorphic rocks are produced from igneous rocks, sedimentary rocks and other metamorphic rocks. Metamorphism progresses incrementally from low-grade to high-grade. During metamorphism the rock must remain essentially solid

Types of metamorphism

- Contact or thermal metamorphism – driven by a rise in temperature within the host rock.
- Hydrothermal metamorphism – chemical alterations from hot, ion-rich water
- Regional metamorphism - Occurs during mountain building. This produces the greatest volume of metamorphic rock. Rocks usually display zones of contact and/or hydrothermal metamorphism.

Agents of metamorphism

- Heat – The most important agent. Recrystallization results in new, stable minerals. There are two sources of heat: Contact metamorphism – heat from magma and An increase in temperature with depth due to the geothermal gradient.

- Hot fluids/water-chemically active fluids

- Pressure and differential stress - This increases with depth. Confining pressure applies forces equally in all directions. Rocks may also be subjected to differential stress which is unequal in different directions. *Foliation resulting from directed stress*

Metamorphism causes a re-crystallization and change from minerals that are out of equilibrium to minerals that are in equilibrium with temperature and pressure conditions. **Crystal size generally increases** with increasing levels of metamorphism.

Heat is the main metamorphic agent in **contact metamorphism**. Contact metamorphism occurs locally in an **aureole** adjacent to cooling magma bodies, where the **country rocks** around the intrusion are baked and altered. Contact metamorphic rocks have a crystalline, **non-foliated** (i.e., non-layered) texture. Common non-foliated rock types include marble and quartzite.

Regional metamorphism produces the greatest quantity of metamorphic rock. It is associated with mountain building. Most metamorphism occurs along convergent plate boundaries as compressional stresses deform the edges of the plate. Foliated rocks form from increased pressure, which is transmitted long distances across convergent boundaries. Pressure is the main metamorphic agent in **regional metamorphism**. The increased pressure associated with deep burial of sediments or sedimentary rocks, particularly along **convergent** plate boundaries, where there is greatly increased pressure produced by the colliding plates, can produce extensive (1000s of km long and 100s of km wide) belts of metamorphic rocks along and adjacent to the major mountain belts of the world.

The pressure in regional metamorphism will gradually align the minerals in these rocks to form a layered or **foliated** texture. The protolith **shale** will be transformed into the metamorphic rock **slate**, in which the pre-existing clay grains will be aligned **perpendicular to** the direction of maximum compression. Clay grains will be transformed into **mica** crystals, which will retain this alignment and grow with increased pressure and time.

Note: Foliation planes are potential zones of weakness & can pose a landslide hazard that can impact roadcuts/homes.

Increasing **metamorphic grade** in regional metamorphism can be seen as mica crystals grow to become visible to the naked eye, and the **foliation** of the rocks becomes coarser. Shale will be transformed into **slate, phyllite,** and **schist** with increased metamorphic grade. At the **highest metamorphic grade**, micas will become unstable and quartz, feldspars and amphibole will crystallize in segregated layers. This light (quartz and feldspars) and dark (amphibole) layered foliated rock is called **gneiss**.

The ROCK CYCLE – This is like a world wide recycling system. The cycle shows how the three rock types and the processes that form them (refer to your text)

Rock Structure – Deformation in Response to Stress

*Brittle deformation creates f*ractures, joints, and faults. These can be Conduits for fluids (mineral deposits….or possibly pollutants. They are also weak surfaces for landslide, earthquake, and failures of infrastructure.
*Ductile deformation creates f*olds (e.g. Anticlines and Synclines) and mountainous terrain. Folds are related to active plate boundaries. Anticlines may be "traps' for oil and gas resources. Folds are caused by compressional stress.

Geologic Time and Dating of Rocks

Three Fundamental Principles or Laws - Help us understand the relationships of rocks and the earth history. We use these for relative dating: determining what is younger and what is older in a sequence of rocks.

1. Crosscutting relationships: Rocks are younger than the ones that it cuts
2. Original horizontality: Sedimentary rock layers nearly horizontal under normal condition
3. Superposition: Rocks become progressively younger towards the top in an undisturbed and undeformed rock sequence.

Unconformity – A geologic time gap in geologic records, ancient erosion surface

- Types of unconformities
    - Angular unconformity – tilted rocks are overlain by flat-lying rocks
    - Disconformity – strata on either side of the unconformity are parallel
    - Nonconformity – metamorphic or igneous rocks in contact with sedimentary strata

***Fossils: Evidence of past life.* Almost all fossils are found in sedimentary rocks**

Types of fossils

- **The remains of relatively recent organisms – teeth, bones, etc.**
- **Entire animals, flesh included**
- **Given enough time, remains may be petrified (literally "turned into stone")**
- **Molds and casts**
- **Carbonization**

***Fossils and correlation:* Correlation** – matching up of two geologic phenomena (fossils, faults, rock layers) in different areas. **Fossils** can be used to correlate rock units across wide areas, by the principle of **fossil succession** and the use of index fossils.

Another important principle: Principle of fossil succession – fossil organisms succeed one another in a definite and determinable order, and therefore any time period can be recognized by its fossil content

- Index fossil – geographically widespread fossil that is limited to a short span of geologic time

Some additional notes about "Rocks" and the Environment: Some rocks are inappropriate to use for construction materials. A knowledge of material properties/strength is critical in choosing the best rock to use in specific situations. A knowledge of geology is critical in the exploration and extraction of fossil fuels and groundwater, and locating and cleaning up contaminants in soil and groundwater. Properties like rock foliation and strength can impact site stability for small and large facilities such as home sites, nuclear power plants, dams, airports, etc.

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