Chapter 2 – Rocks and Minerals

Outline:
I. Minerals - Rocks and minerals provide tangible evidence of past events because they formed within a specific range of physical and chemical conditions.
   A. Common Rock-forming minerals - A mineral is a naturally occurring element or compound formed by inorganic processes that has a definite chemical composition or range of composition as well as distinctive properties and form that reflect its internal atomic structure.

Cleavage - the tendency of some minerals to break smoothly along certain planes of weakness. 3000 minerals have been discovered, we will only consider those minerals that compose the bulk of common minerals.

1. Silicate minerals
   - Oxygen (O) and silicon (Si) compose about 75% of the Earth's crust
   - O and Si occur in combination with aluminum, iron, calcium, sodium, potassium, and magnesium
   - They form a group of minerals called the silicates
   - A single family of silicates, the feldspars, comprises 50% of the material of the crust
   - A single mineral species, called quartz represents a sizable portion of the remainder.
   a. Quartz - Most important of all the silicate minerals
      - glassy, colorless or gray
      - relatively hard and will easily scratch glass
      - may form hexagonal crystals
      - sedimentary varieties
      - Chert -
         - dense, hard white microcrystalline variety forms as a result of the precipitation of silicon dioxide by either biologic or chemical means
         - different varieties are formed by different processes
   b. The Feldspars - The most abundant constituent of rocks
      - 60% of the total weight of the Earth's crust
      Two major families of feldspars
      - potassium feldspar group comprises the potassium aluminosilicates
      - plagioclase group: comprises the aluminosilicates of sodium and calcium
      Feldspar characteristics
      - hardness of 6
      - range in color from white or pink to bluish gray
      - good cleavage in 2 directions
      - sodium plagioclase and potassium feldspar tend to occur in silica-rich rocks, calcium plagioclase occur in basalts
   c. Mica
      - characterize by perfect cleavage in one direction
      - Common constituents of igneous and metamorphic rocks
      - Muscovite - colorless, pale-colored hydrous potassium aluminum silicate
      - Biotite - dark-colored mica containing magnesium and iron
   d. Hornblende - vitreous black or very dark green mineral
      - most common member of a family of minerals called amphiboles
      - ferromagnesanic or mafic minera
      - iron and magnesium content
      - crystals tend to be long and narrow
      - 2 good clavages parallel to the long axis that intersect each other at 56° and 124°
   e. Augite
      - member of the pyroxene family
      - dark colored ferromagnesian mineral
• crystal typically stumpy in shape
• good cleavages developed along 2 planes at ~90°
f. **Olivine** - olive green colored iron and magnesium silicate
  • common in dark mafic rocks and an important constituent of stony meteorites
  • gemstone - peridot
g. Clay minerals - silicates of hydrogen and aluminum
  • submicroscopic flakes
  • formed as a result of weathering of other aluminum silicates
  • amorphous form, softness, low density and ability to behave plastically when wet
2. Nonsilicate minerals - Compose about 8% of the Earth's crust
a. Carbonates - most important nonsilicate mineral group
1. Calcite is the main constituent of limestone and marble
  • formed in a variety of ways

II. Rocks
A. Rock Conversions
   **Rock cycle** - no rock is immutable (dynamic Earth - Hutton)
   1. the conversion of one rock type into another by melting, deformation, and weathering and erosion. For rock identification it is necessary to know general appearance as well as mineral composition and physical properties.
   2. Texture: size, shape, and arrangement of constituent minerals. Inferences regarding the origin of the rock are based on geologic observations and experimentation.
B. **Igneous** Rocks - Ignis (Latin for fire) Constitute >90% by volume of the Earth’s crust. Develop from cooling masses of molten material (magma) derived from hot parts of the Earth’s interior; magma that reaches the Earth’s surface is termed lava.
1. Cooling history of Igneous Rocks
a. **Intrusive** igneous rocks
   • formed from magma that had penetrated into other rocks and solidified before reaching the surface.
   • **pluton**: very large masses
   • Magma
   - high energy sufficient to break the bonds of the molecules that form the crystalline structure.
   - Pressure effects - increased pressure requires more energy (temperature to break the bonds - boiling water at SL and mtn top; pressure cooker); ice skating example
   - temperatures within the earth are high enough that without P, the earth would be molten; it is solid for the most part.
   - Volatile effects - dissolved water and gases (O, CO2, H2S etc.) lower the melting temperature of silicate minerals.
   - Once molten the magma tends to flow away from the melt (Upwards); cools; crystallization;
   - Bowen’s Reaction Series- some minerals tend to crystallize first.
b. **Extrusive** igneous rocks:
   • form from melts that have reached the surface
   • includes rocks formed from lava erupted from volcanoes or lava that has welled out of fissures
c. **Grain size** is an index to the history of cooling of an igneous rock
   • magma cools slowly and retains water, inhibiting formation of crystal nuclei
   • allows time and space for growth of large crystals around a few nuclei
   • intergrown crystals large enough to be seen readily without magnification - diorite, granite, and gabbro
• in extrusive rocks, the water is lost and many small crystals are formed, producing a fine texture in which crystals are too small to be seen with the unaided eye - basalt
• obsidian cooled so rapidly there are no crystals, just glass
• cooling history of a rock with large crystals immersed in a very fine grained matrix: large crystals (phenocrysts) formed slowly at depth and were then swept on the surface - produces a porphyritic texture

2. Composition of Igneous Rocks
a. The minerals reflect the proportions of elements present in the melt from which the rock was formed.
• eight common elements: silicon, oxygen, aluminum, calcium, iron, magnesium, sodium, and potassium
• elements combine to form the constituent minerals of igneous rocks
• intrusive igneous rocks tend to be richer in silica than extrusive rocks - silica increase the magma viscosity - highly viscous magmas cannot work its way to the surface
b. Granite
• a silica-rich, relatively light colored intrusive rock composed primarily of potassium feldspar, quartz, sodium plagioclase, hornblende and mica
• derived from silica-rich magma, forming quartz
c. Granodiorite
• related to granite except that plagioclase is the dominant feldspar, quartz still common
d. Basalt
• fine-grained extrusive rock derived from a low-silica melt that is rich in iron and magnesium
• low viscosity melt
• quartz grains are rare
e. Relationship in the chemistry of magmas and lavas
• silica-rich melts also tend to include ample quantities of potassium and sodium in addition to quartz
• low-silica melts are rich in calcium, magnesium, and iron

3. Volcanic Activity
a. Volcanoes are vents in the Earth’s surface through which hot gases and molten rock flow from the Earth’s interior.
b. Hawaiian volcanoes
• quiet, outpouring of low-viscosity lava
c. Explosive volcanoes
• due to the sudden release of molten rock driven upward by pockets of compressed gases
• Krakatoa, 1883
d. Fissure Eruptions
• great outpouring of lava
e. Most abundant kind of volcanic rock is basalt
• originates from molten pockets of upper mantle material, the low velocity zone
• mechanism by which basaltic magmas develop is called partial melting
  - liquid component is moved to another location
  - some minerals melt at lower temperature than others, molten faction is less dense
  -tends to separate from the parent mass an rise towards the surface
f. Factors that control partial melting
• heat in excess of 1500•C
• pressure: increased pressure increase melting temperature
• water content: tends to lower melting temperature
g. **Andesite**
• intermediate in silica content
• originate by fractional crystallization or form the melting of basaltic oceanic crust and siliceous marine sediments
  - fractional crystallization refers to the settling out of early formed minerals from a basaltic melt producing a more silica-rich magma

### C. Sedimentary Rocks

Rocks composed of consolidated sediment—particles that are the product of weathering and erosion of any previously existing rock or soil

Components range from large boulders to molecules dissolved in water

Sediment is deposited by wind, water, ice, or mineral-secreting organisms

Loose sediment is lithified (converted into solid rock)

• precipitation of a cementing material around individual grains
• compaction
• crystallization
• stratification
  - the occurrence of sedimentary rocks in beds or layers
  - the result of changes in the conditions of deposition such as velocity of a stream or changes in type of material being deposited

**Most abundant sedimentary rocks**

- sandstone: composed of grains of quartz, feldspar, and other particles cemented together
- shale: consists of very fine particles of quartz and clay
- carbonates: formed when carbon dioxide combines with oxides of calcium and magnesium

1. **Derivation of Sedimentary Rocks**
   **Example: granodiorite**
   • quartz is chemically stable and will remain unchanged during weathering, it will accumulate as sand
   • feldspars weather more readily releasing potassium, sodium, and calcium into solution deposited either as limestone or evaporites, halite or gypsum
   • biotite decomposition yields soluble potassium and magnesium carbonates, silica, and iron oxides; iron oxides serve to color sedimentary rocks in shades of red and brown

2. **Variety among Sedimentary Rocks**

   Classified according to composition and **texture**
   - the size and shape of the individual grains and to their arrangement in the rock
   - clastic texture: composed of grains and broken fragments (clasts) of pre-existing minerals, rocks, and fossils
   - crystalline texture: a network of intergrown crystals

   **a. Clastic Rocks**
   - Classified according to particle size
     1. **Conglomerate**
        - composed of water-worn, rounded particles >2 mm in diameter
     2. **Breccia**
        - angular fragments >2 mm in diameter
     3. **Sandstone**
        - grains range in size 1/16 mm-2 mm, varieties are subdivided according to composition
     4. **Siltstones**
        - grains range in size 1/16 mm-1/256 mm
     5. **Shales**
        - grains <1/256 mm
        - fissile: split into thin slabs parallel to bedding planes
b. Carbonate Rocks

Minerals that compose carbonate rocks

1. Calcite (CaCO$_3$)
   - crystallizes in the hexagonal system
   - predominant mineral in limestone

2. Aragonite (CaCO$_3$)
   - crystallizes in the orthorhombic system
   - relatively unstable, converts to calcite

3. Dolomite (CaMg(CO$_3$)$_2$
   - predominant mineral in dolomite

4. Limestones
   Origin
   - marine
   - formed as a result of precipitation of calcite or aragonite by organisms and incorporated in skeletons in sedimentary deposits
   - inorganic: direct chemical precipitation
   - Lithification by the accumulation of calcium carbonate or recrystallized or consolidated into rock
   - highly fossiliferous
     - range in texture from coarsely granular to very fine-grained and aphanitic

Textural components
- micrite: exceptionally fine-grained carbonate mud
- carbonate clasts: sand- or gravel-sized clasts of carbonate
- bioclasts: skeletal fragments of marine invertebrates
- oolites: spherical grains formed by the precipitation of carbonate around a nucleus
- carbonate spar: a clear crystalline carbonate that is deposited between the clasts as a cement

Varieties
- chalk: a soft, porous variety composed largely of extremely minute calcareous skeletal elements (cocoliths)
- lithographic limestone: a dense, micritic limestone consisting almost entirely as skeletal remains of reef corals and other skeletonized marine invertebrates

Dolomite
- A rock composed of the calcium-magnesium mineral dolomite
  - Origin not entirely understood
  - result from the partial replacement of calcium by magnesium in the original calcareous sediment

c. Other Sedimentary Rocks

Chert: A microcrystalline form of quartz

Occurrence
- nodules in limestone
- bedded cherts: areally extensive layers formed of the siliceous remains of diatoms and radiolaria; found in association with ash beds and submarine lava flows

Evaporites
- Chemically precipitated rocks that are formed as a result of evaporation of saline water bodies composed chiefly of gypsum, anhydrite, halite and associated celeite and dolomite

Deposits of evaporites
- Michigan, Kansas, Texas, New Mexico, Germany and Israel

Conditions required for precipitation
- warm, relatively arid climates
• physiographic situation that would provide periodic additions of sea water to the evaporating marine basin.

Coal
A carbonaceous rock resulting from the accumulation of plant matter in a swampy environment combined with alteration of that plant tissue by both biochemical and physical processes until it converts to a consolidated carbon-rich material. 

Formation of coal
• peat-lignite-bituminous-anthracite
• underwater accumulation or quick burial of plant tissue to retain carbon

D. Metamorphic Rocks

Metamorphism: change of form
• alterations in any pre-existing rocks brought about by physical/chemical changes in the environment
• intermediate between melting and formation of sedimentary rock (diagenesis)
• recrystallization of minerals in the solid state
• variations in temperature and pressure may result in different kinds of metamorphic rocks, even from the same parent material

Foliation: layering resulting from the parallel alignment of mineral grains
• may be fine or coarse, depending upon size and shapes of the constituent minerals

1. Metamorphism
   a. Contact metamorphism
      • alterations of rock immediately adjacent to igneous intrusions
      • changes are mainly the result of high temperature and chemically active fluids
      • amount of change related to the size of the magmatic body, composition, fluidity and nature of the intruded rock
      • related to the formation of ore deposits
   b. Regional metamorphism
      • areally extensive and occurs under the conditions of great confining pressures and heat
      • related to deep burial and mountain building
      • Geothermal Gradient (30°C/km)
   c. Metamorphic index minerals
      • known to form under specific pressure and temperature conditions
      • used to decipher the history of growth of mountainous regions

2. Kinds of Metamorphic Rocks
   a. Foliated Metamorphic Rocks
      • Slate
         - foliation is microscopic, smooth, causing rock to split along planes
         - derived from the regional metamorphism of shale
      • Phyllite
         - texture fine, grains of mica, chlorite, garnet or quartz may be visible
         - surfaces often develop a wrinkled aspect and are lustrous
         - represent an intermediate degree of metamorphism
      • Schist
         - consists of platy or needle-like minerals segregated into distinct layers
         - named according to the most conspicuous mineral present
         - derived from shales or fine-grained volcanic rocks
      • Gneiss
         - coarse-grained, evenly granular rock
         - coarse foliation results from segregation of minerals in bands
         - derived from high-silica igneous and sandstones
   b. Nonfoliated Metamorphic Rocks
      • Marble
- fine-coarsely crystalline rock
- composed of calcite or dolomite, soft
- derived from limestone or dolostone

Quartzite
- fine-grained, sugary textured rock
- composed of intergrown quartz, hard
- derived from quartz sandstone

c. Historical significance of Metamorphic Rocks

- Reconstruction of conditions under which rocks were altered
  - mineral composition

- Inferences
  - directions of compressional forces
  - pressure
  - temperature
  - nature of the parent rock

- Metamorphic facies
  - zones of rocks that formed under specific conditions
  - additional factors that influence the kinds of mineral produced include: nature and depth of metamorphism; mineralogic composition of parent material; amount of water present during metamorphism