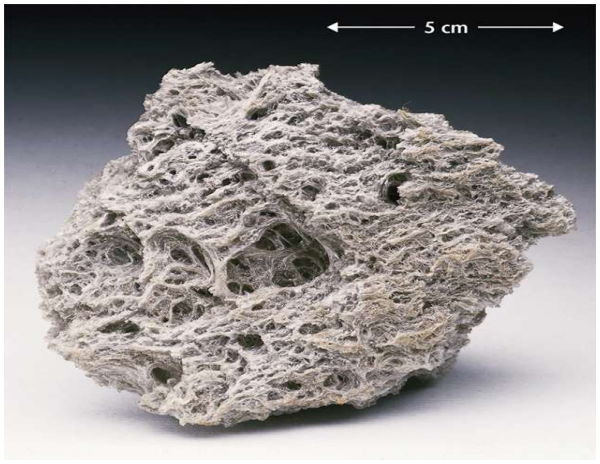
Ch. 3: *Igneous Rocks*



I. **Magma**: The parent material of igneous rocks
   A. Igneous rocks form as molten rock cools and solidifies
   B. General characteristics of magma
      1. Parent material of igneous rocks
      2. Forms by a process called **partial melting** inside the Earth
      3. Magma that reaches the surface is called **lava**
      4. Rocks formed from magma at the surface are classified as **extrusive**, or **volcanic** rocks
      5. Rocks formed from magma that crystallizes at depth are termed **intrusive**, or **plutonic**
   C. The nature of magma
      1. Completely or partly molten material which cools and solidifies to form igneous rock
      2. Consists of three parts:
         a. A liquid portion, called **melt**, composed of mobile ions
         b. **Solids**, if any, are silicate minerals that have already crystallized from the melt
         c. **Volatiles**, gaseous components dissolved within the melt
            1. Water vapor (H_2O)
            2. Carbon dioxide (CO_2)
            3. Sulfur dioxide (SO_2)
   D. **Crystallization** of magma
      1. Generates various silicate minerals
      2. Cooling results in the ions arranging into orderly patterns and various minerals
      3. Size and arrangement of the mineral grains gives an igneous rock its texture
      4. Igneous rocks are most often classified by their
         a. Texture, and
         b. Mineral composition

II. Igneous textures
   A. Used to describe the overall appearance of a rock based on the size, shape, and arrangement of its interlocking mineral crystals
   B. Factors affecting crystal size
      1. Rate of cooling of the magma (most important)
         a. Slow rate promotes the growth of fewer but larger crystals
         b. Fast rate forms many small crystals
         c. Very fast rate forms glass
      2. Amount of silica present
      3. Amount of dissolved gases
   C. Types of igneous textures
      1. **Aphanitic** (fine-grained) texture
         a. Rapid rate of cooling of lava or magma at or near the surface
         b. Microscopic crystals
         c. May contain **vesicles** (voids left by escaping gas as magma or lava solidifies)
      2. **Phaneritic** (coarse-grained) texture
         a. Slow cooling
         b. Crystals can be identified without a microscope
      3. **Porphyritic** texture
         a. Mineral form at different temperatures as well as differing rates
         b. Large crystals, called **phenocrysts**, embedded in a matrix of smaller crystals, called the **groundmass**.
      4. **Glassy** texture
         a. Rapid cooling of molten rock resulting in unordered atoms (non-crystalline)
         b. e.g., obsidian
         c. Mainly from viscous (granitic) magma
      5. **Pyroclastic** texture
         a. Consists of fragments such as blocks, lapilli or ash ejected during a violent eruption
         b. Textures appear to be more similar to sedimentary rocks
      6. **Pegmatitic** texture
         a. Exceptionally coarse grained
         b. Form in the late stages of crystallization
         c. Most have compositions similar to granite

III. Igneous compositions
- A. Mainly silicate minerals
  1. Dark (or **ferromagnesian**) silicates
     - a. Olivine
     - b. Pyroxene
     - c. Amphibole
     - d. Biotite mica
  2. Light (or nonferromagnesian) silicates
     - a. Quartz
     - b. Muscovite mica
     - c. Feldspars
- B. Granitic versus basaltic compositions
  1. **Granitic** composition
     - a. Composed of light-colored silicates
     - b. Referred to as being **felsic** (*fe*ldspar and *si*lica)
     - c. Rich in silica
     - d. Major constituents of the continental crust
  2. **Basaltic** composition
     - a. Composed of dark silicates and calcium-rich feldspar
     - b. Referred to as being **mafic** (*m*agnesium and *f*errum, for iron)
     - c. Darker and denser than granitic rocks
     - d. Make up the ocean floor as well as many volcanic islands
- C. Other compositional groups
  1. Intermediate (or **andesitic**) composition
     - a. Contain at least 25 percent dark silicate minerals
     - b. Associated with volcanic activity
  2. **Ultramafic** - 85% or more mafic minerals
     - a. e.g., peridotite
     - b. Rare
- D. Silica content as an indicator of composition
  1. Silica content in crustal rocks ranges from
     - a. A low of about 45 percent in ultramafic rocks to
     - b. Over 70 percent in felsic rocks
  2. Influences a magma's behavior
     - a. Granitic magma
       1. High silica content
       2. Viscous
       3. Liquid at temperatures as low as 700°C
     - b. Basaltic magma
       1. Low in silica
       2. Fluid
       3. Crystallize at higher temperature

E. Naming igneous rocks
   1. Felsic (granitic) rocks
      a. Granite
         1. Phaneritic
         2. Twenty-five percent quartz, about 65 percent feldspar
         3. May have a porphyritic texture
         4. Often by-products of mountain building
         5. Very abundant
         6. The term *granite* can cover rocks having a wide range of mineral compositions
      b. Rhyolite
         1. Extrusive equivalent of granite
         2. May contain glass fragments and voids
         3. Aphanitic
         4. Less common and less voluminous than granite
      c. Obsidian
         1. Dark colored
         2. Glassy
      d. Pumice
         1. Volcanic
         2. Glassy texture
         3. Frothy mass
   2. Intermediate (andesitic) igneous rocks
      a. Andesite
         1. Fine-grained
         2. Volcanic origin
         3. Often resembles rhyolite
      b. Diorite
         1. Plutonic equivalent of andesite
         2. Coarse grained
         3. Intrusive
         4. Primarily sodium-rich plagioclase feldspar and amphibole
   3. Mafic (basaltic) igneous rocks
      a. Basalt
         1. Fine-grained
         2. Volcanic
         3. Composed primarily of pyroxene and calcium-rich plagioclase feldspar
         4. Most common extrusive igneous rock
      b. Gabbro
         1. Intrusive equivalent of basalt
         2. Composed primarily of pyroxene and calcium-rich plagioclase feldspar
         3. Makes up a significant percentage of the oceanic crust
   4. Pyroclastic rocks
      a. Fragments ejected during a volcanic eruption
      b. Varieties
         1. **Tuff** – ash-sized fragments

2. **Volcanic breccia** – particles larger than ash

IV. Origin of magma
- A. Controversial topic
- B. Generating magma from solid rock
  1. Produced when essentially solid rock in the crust and upper mantle melts
  2. Role of heat
     a. The temperature increase within Earth's upper crust (called the geothermal gradient) averages between 20°C and 30°C per kilometer
     b. Rocks in the lower crust and upper mantle are near their melting points, additional heat to melt the rocks comes from
        1. Friction at subduction zones
        2. Heating as the rocks descend into the mantle
        3. Heat from rising hot mantle rocks
  3. Role of Pressure
     a. An increases in confining pressure causes an increase in a rock's melting temperature; conversely, reducing the pressure lowers the melting temperature
     b. When confining pressure drops, decompression melting occurs
  4. Role of volatiles
     a. Volatiles (primarily water) cause rock to melt at lower temperatures
     b. Important where oceanic lithosphere descends into the mantle

V. How magmas evolve
- A. A single volcano may extrude lavas exhibiting quite different compositions
- B. **Bowen's reaction series** and the composition of igneous rocks
  1. N.L. Bowen demonstrated that as a basaltic magma cools, minerals tend to crystallize in a systematic fashion based on their melting points
  2. During crystallization, the composition of the liquid portion of the magma continually changes
     a. Removal of elements by earlier-forming minerals
     b. Silica component of the melt becomes enriched as the magma evolves
     c. Minerals that remain in the melt can chemically react and change
  3. Bowen's Reaction Series has two branches
     a. **Discontinouous Reaction Series** - at each step a different structure / mineral emerges (ex: olivene, pyroxene, amphibole or biotite)
     b. **Continuous Series** - ions replace each

other within a single plagioclase feldspar structure

4. Ways that magma's composition changes
   a. **Magmatic differentiation**
      1. Minerals crystallize from magma in a systematic fashion
      2. Crystal settling causes a separation of the solid and liquid components
      3. Remaining melt will form a rock with a different chemical composition
      4. The formation of a secondary magma from a single parent magma is called magmatic differentiation
   b. **Assimilation**
      1. Changing a magma's composition by the incorporation of foreign matter
      2. May operate in a near-surface environment where rocks are brittle
   c. **Magma mixing**
      1. One magma body intrudes another
      2. May occur during the ascent of two chemically distinct magma bodies

C. **Partial melting** and magma formation
   1. Incomplete melting of rocks is known as partial melting
   2. Rocks with a granitic composition are composed of minerals with the lowest melting (crystallization) temperatures – namely quartz and potassium feldspar
   3. Partial melting of rock separates the ions from minerals with lower melting temperatures from those with higher melting temperatures

VI. Mineral resources and igneous processes
   A. Many important accumulations of metals are produced by igneous processes
   B. Igneous mineral resources can form from
      1. Magmatic segregation
         a. Heavy minerals that crystallize early in a magma body settle to the lower portion of the magma chamber
         b. Crystallization in the late stages of the magmatic process may produce pegmatites
      2. Hydrothermal solutions
         a. among the best-known and most important ore deposits
         b. Originate from hot, metal-rich fluids that are remnants of the late-stage magmatic process
         c. Cool and produce vein deposits of gold, silver or mercury
         d. May form disseminated deposits where minute quantities are spread throughout an entire rock mass