Essentials of Geology, 11e

Igneous Rocks and Intrusive Activity
Chapter 3

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Characteristics of Magma

- Igneous rocks form as molten rock cools and solidifies
- General Characteristic of magma
  - Parent material of igneous rocks
  - Forms from partial melting of rocks inside Earth
  - Magma that reaches the surface is called lava

Characteristics of Magma

- General Characteristic of magma
  - Rocks formed from lava at the surface are classified as extrusive, or volcanic rocks
  - Rocks formed from magma that crystallizes at depth are termed intrusive, or plutonic rocks

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Characteristics of Magma

- The nature of magma
  - Consists of three components:
    - A liquid portion, called melt, that is composed of mobile ions
    - Solids, if any, are silicate minerals that have already crystallized from the melt
    - Volatiles, which are gases dissolved in the melt, including water vapor (H_2O), carbon dioxide (CO_2), and sulfur dioxide (SO_2)

Characteristics of Magma

- Crystallization of magma
  - Texture in igneous rocks is determined by the size and arrangement of mineral grains
  - Igneous rocks are typically classified by their overall-
    - Texture (dictated by cooling rate and environment…where it cooled)
    - Mineral composition

Igneous Textures

Texture is used to describe the overall appearance of a rock based on the size, shape, and arrangement of interlocking minerals or grains.

Figure 3.15

Igneous Textures

- Factors affecting crystal size
  - Rate of cooling
    - Slow rate promotes the growth of fewer but larger crystals
    - Fast rate forms many small crystals
    - Very fast rate forms glass
  - Amount of silica (SiO_2) present
  - Amount of dissolved gases

Igneous Textures

- Types of igneous textures
  - Aphanitic (fine-grained) texture
    - Rapid rate of cooling of lava or magma
    - Microscopic crystals
    - May contain vesicles (holes from gas bubbles)
  - Phaneritic (coarse-grained) texture
    - Slow cooling
    - Crystals can be identified without a microscope

Fine-grained Texture

Figure 3.1 and 3.11

Coarse-grained Texture

Figure 3.11 and 3.12

Igneous Textures

- Types of igneous textures
  - Porphyritic texture
    - Minerals form at different temperatures as well as differing rates
    - Large crystals, called phenocrysts, are embedded in a matrix of smaller crystals, called the groundmass
  - Glassy texture
    - Very rapid cooling of molten rock
    - Resulting rock is called obsidian

Porphyritic Texture

Figure 3.11 porphyritic

Glassy

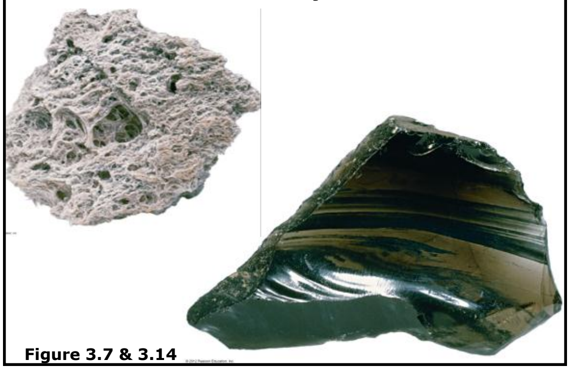


Figure 3.7 & 3.14

An Obsidian Flow in Oregon

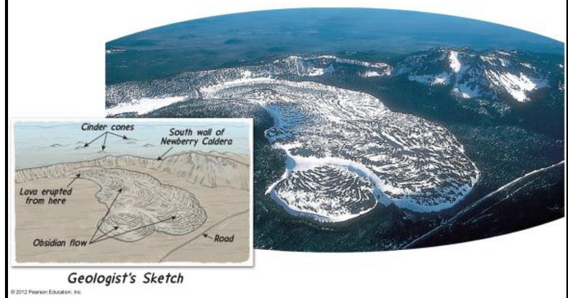


Figure 3.8

Igneous Textures

- Types of igneous textures
  - **Pyroclastic** texture
    - Various fragments ejected during a violent volcanic eruption
    - Textures often appear to more similar to sedimentary rocks
  - **Pegmatitic** texture
    - Exceptionally coarse grained
    - Form in late stages of crystallization of granitic magmas

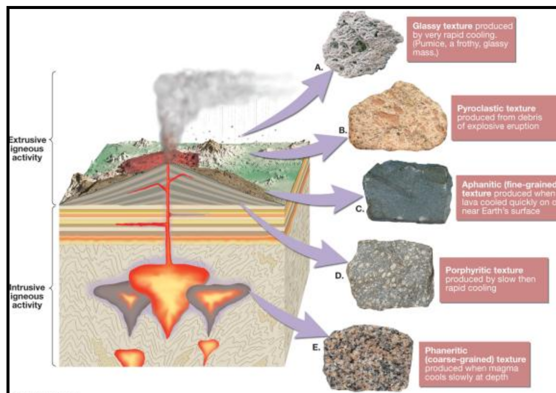


Figure 3.4

Igneous Compositions

- Igneous rocks are composed primarily of silicate minerals
  - Dark (or **ferromagnesian**) silicates
    - Olivine
    - Pyroxene
    - Amphibole
    - Biotite mica
  - Light (or **nonferromagnesian**) silicates
    - Quartz
    - Muscovite mica
    - Feldspars

Igneous Compositions

- There are 4 basic compositional groups
  1. Felsic (granitic)
     - Granite, rhyolite, obsidian, and pumice
  2. Intermediate (andesitic)
     - Diorite and andesite
  3. Mafic (basaltic)
     - Gabbro and basalt
  4. Ultramafic (upper mantle rock)
     - Peridotite and komatiite

Igneous Compositions

- **Granitic versus basaltic compositions**
  - **Granitic composition**
    - **Composed of light-colored silicates**
    - **Designated as being felsic (*fe*ldspar and *si*lica) in composition**
    - **Contains high amounts of silica (SiO_2)**
    - **Major constituents of continental crust**

Igneous Compositions

- **Granitic versus basaltic compositions**
  - **Basaltic composition**
    - **Composed of dark silicates and calcium-rich feldspar**
    - **Designated as being mafic (*ma*gnesium and *f*errum, for iron) in composition**
    - **More dense than granitic rocks**
    - **Comprise the ocean floor as well as many volcanic islands**

Igneous Compositions

- **Other compositional groups**
  - **Intermediate (or andesitic) composition**
    - **Contain at least 25 percent dark silicate minerals**
    - **Associated with explosive volcanic activity**
  - **Ultramafic composition**
    - **Rare composition that is high in magnesium and iron**
    - **Composed entirely of ferromagnesian silicates**

Mineralogy of Common Igneous Rocks

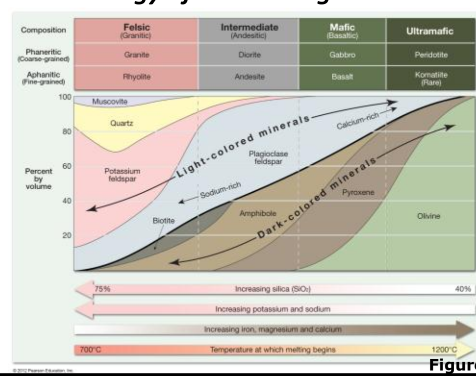


Figure 3.3

Igneous Compositions

- **Silica content as an indicator of composition**
  - **Silica content in crustal rocks exhibits a considerable range**
    - **A low of 45 percent in ultramafic rocks**
    - **Over 70 percent in felsic rocks**

Igneous Compositions

- **Silica content influences a magma's behavior**
  - **Granitic magma**
    - **High silica content**
    - **Extremely viscous**
    - **Liquid exists at temperatures as low as 700°C**
  - **Basaltic magma**
    - **Much lower silica content**
    - **Fluid-like behavior**
    - **Crystallizes at higher temperatures**

Igneous Compositions

- Naming igneous rocks – felsic rocks
  - Granite
    - Phaneritic, course grained
    - Over 25 percent quartz, about 65 percent or more feldspar
    - May exhibit a porphyritic texture
    - Very abundant as it is often associated with mountain building
    - The term granite covers a wide range of mineral compositions

Granite

Figure 3.11

Igneous Compositions

- Naming igneous rocks – felsic rocks
  - Rhyolite
    - Extrusive equivalent of granite
    - May contain glass fragments and vesicles
    - Aphanitic texture, fine grained
    - Less common and less voluminous than granite

Rhyolite

Figure 3.11

Igneous Compositions

- Naming igneous rocks – felsic rocks
  - Obsidian
    - Dark colored
    - Glassy texture
  - Pumice
    - Volcanic
    - Glassy texture
    - Frothy appearance with numerous voids

Obsidian

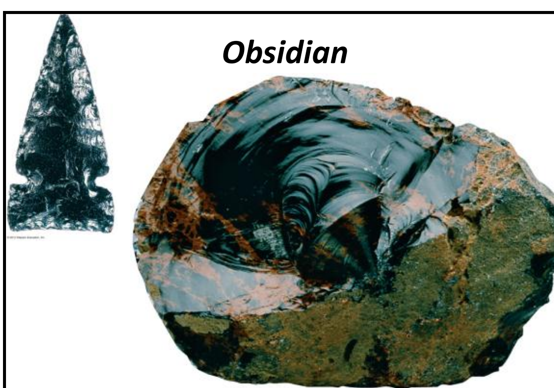


Figure 3.13 B

B. Hand sample of obsidan.

Pumice

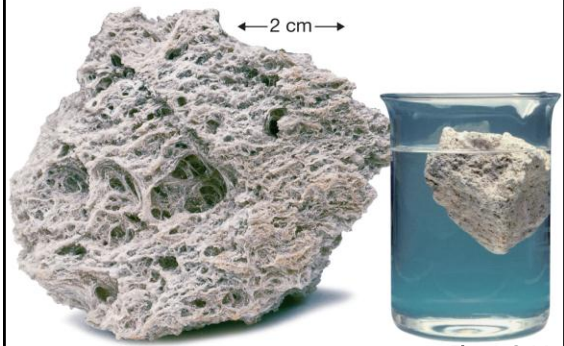


Figure 3.14

Igneous Compositions

- Naming igneous rocks – intermediate rocks
  - Andesite
    - Volcanic origin
    - Aphanitic texture
    - Often resembles rhyolite
    - Light to dark shades of grey color

Andesite

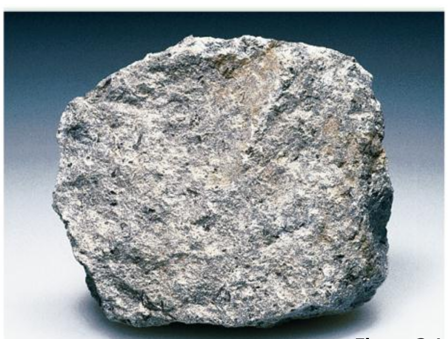


Figure 3.11

Igneous Compositions

- Naming igneous rocks – intermediate rocks
  - Diorite
    - Plutonic equivalent of andesite
    - Coarse grained
    - Intrusive
    - Composed mainly of intermediate feldspar and amphibole
    - "salt and pepper" color

Diorite

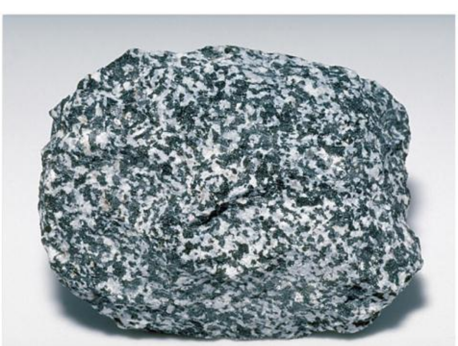


Figure 3.11

Igneous Compositions

- Naming igneous rocks – mafic rocks
  - Basalt
    - Volcanic origin
    - Aphanitic texture
    - Composed mainly of pyroxene and calcium-rich plagioclase feldspar
    - Most common extrusive igneous rock
    - May contain vesicules

Basalt

Figure 3.11

Igneous Compositions

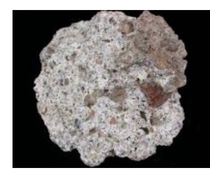
- Naming igneous rocks –mafic rocks
  - Gabbro
    - Intrusive equivalent of basalt
    - Phaneritic texture consisting of pyroxene and calcium-rich plagioclase
    - Makes up a significant percentage of the oceanic crust

Gabbro

Figure 3.11

Igneous Compositions

- Naming igneous rocks – pyroclastic rocks
  - Composed of fragments ejected during a volcanic eruption
  - Varieties
    - Tuff – ash-sized fragments
    - Volcanic breccia – particles larger than ash



Origin of Magma

- Highly debated topic
- Generating magma from solid rock
  - Produced from partial melting of rocks in the crust and upper mantle
- Consider the-
  - Role of heat
  - Role of pressure
  - Role of volatiles

Origin of Magma

- Role of heat
  - Temperature increases within Earth's upper crust (called the geothermal gradient) average between 20°C to 30°C per kilometer
  - Rocks in the lower crust and upper mantle are near their melting points
  - Any additional heat (from rocks descending into the mantle or rising heat from the mantle) may induce melting

Origin of Magma

– Role of **pressure**
  - An increase in confining pressure causes an increase in a rock's melting temperature or conversely, reducing the pressure lowers the melting temperature
  - When confining pressures drop, ***decompression melting*** occurs

Decompression Melting

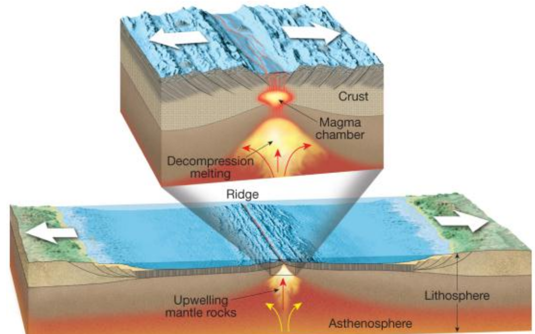


Figure 3.18

Origin of Magma

– Role of **volatiles**
  - Volatiles (primarily ***water***) cause rocks to melt at lower temperatures
  - This is particularly important where oceanic lithosphere descends into the mantle
  - Common at convergent plate boundaries

Volatile Melting

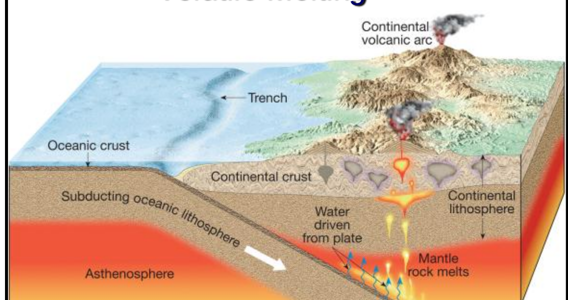


Figure 3.19

Evolution of Magmas

- A single volcano may extrude lavas exhibiting very different compositions
- **Bowen's reaction series** and the composition of igneous rocks
  - N.L. Bowen demonstrated that as a magma cools, minerals crystallize in a systematic fashion based on their melting points

Bowen's Reaction Series

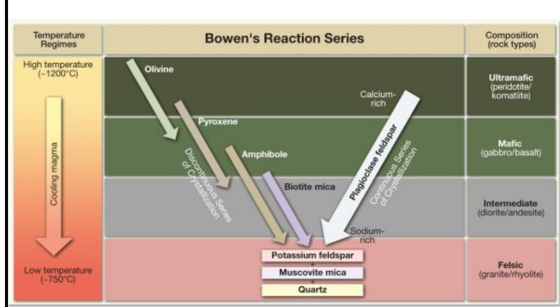


Figure 3.20

Evolution of Magmas

- Bowen's reaction series
  - During crystallization, the composition of the liquid portion of the magma continually changes
    - Composition changes due to ***removal of elements*** by earlier-forming minerals
    - The silica component of the melt becomes enriched as crystallization proceeds
    - Minerals in the melt can chemically react and change

Evolution of Magmas

- Processes responsible for changing a magma's composition:
  - Magmatic differentiation
    - Separation of a melt from earlier formed crystals to form a different composition of magma
  - Assimilation
    - Changing a magma's composition by the incorporation of foreign matter (surrounding rock bodies) into a magma
  - Magma mixing
    - Involves two bodies of magma intruding one another
    - Two chemically distinct magmas may produce a composition quite different from either original magma

Assimilation, Mixing, and Magmatic Differentiation

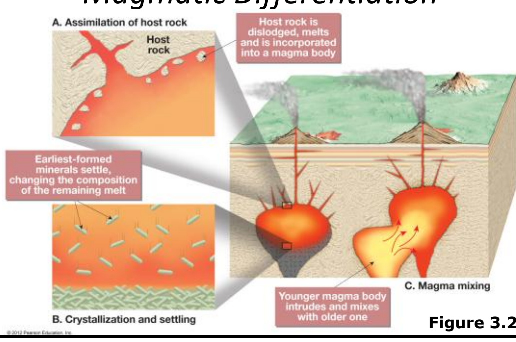


Figure 3.22

Evolution of Magmas

- Partial melting and magma formation
  - Incomplete melting of rocks is known as partial melting
  - Most melting is not complete
  - This process produces most, if not all, magma

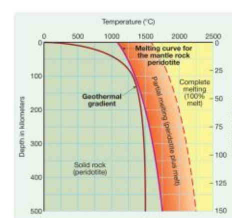


Figure 3.17

Evolution of Magmas

- Partial melting and magma formation
  - Formation of basaltic magmas
    - Most originate from partial melting of ultramafic rock in the mantle
    - Basaltic magmas form at mid-ocean ridges by decompression melting or at subduction zones
      - As basaltic magmas migrate upward, confining pressure decreases which reduces the melting temp.
    - Large outpourings of basaltic magma are common at Earth's surface (CRB's)

Evolution of Magmas

- Partial melting and magma formation
  - Formation of intermediate magmas
    - Interactions between mantle-derived basaltic magmas and more silica-rich rocks in the crust generate magma of andesitic composition
    - Common at convergent plate boundaries
    - Andesitic magma may also evolve by magmatic differentiation

Evolution of Magmas

- Partial melting and magma formation
  - Formation of felsic magmas
    - Most likely form as the end product of crystallization of andesitic magma
    - Granitic magmas are higher in silica… therefore more viscous than others
    - Because of their viscosity, they lose their mobility before reaching the surface
    - Tend to produce large plutonic structures

Plutonic Igneous Activity

- Most magma is emplaced at depth
- An underground igneous body, once cooled and solidified, is called a pluton
- Classification of plutons:
  - Shape
    - Tabular (sheet-like)
    - Massive (bulb-like)
  - Orientation with respect to the host rock
    - Discordant – cuts across sedimentary rock
    - Concordant – parallel to sedimentary rock

Plutonic Igneous Activity

- Types of intrusive igneous features
  - Dike – a tabular, discordant pluton
  - Sill – a tabular, concordant pluton (e.g., Palisades Sill in New York)
  - Laccolith
    - Similar to a sill
    - Lens or mushroom-shaped mass
    - Arches overlying strata upward

Intrusive Igneous Structures

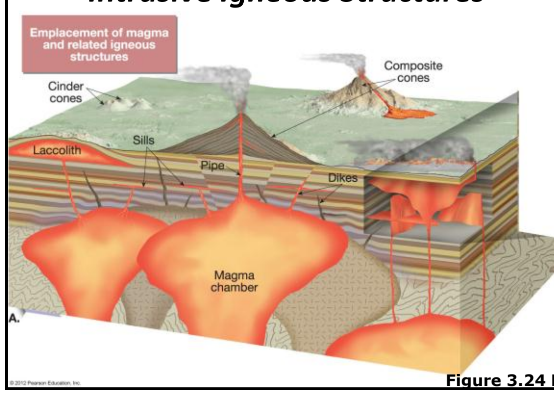


Figure 3.24 B

A Sill in the Salt River Canyon, Arizona

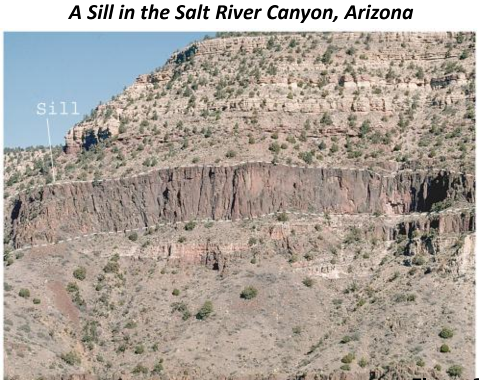


Figure 3.25

Plutonic Igneous Activity

- Types of intrusive igneous features
  - Batholith
    - Largest intrusive body
    - Surface exposure of over 100 square kilometers (smaller bodies – 'stocks')
    - Bulb-like shape
    - Frequently form the cores of mountains

A Batholith Exposed by Erosion

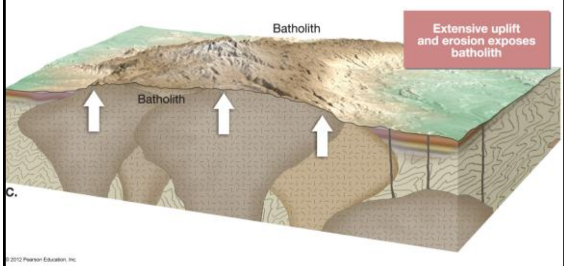


Figure 3.24 C

Mineral Resources and Igneous Processes

- Many important accumulations of metals are produced by igneous processes
- Igneous mineral resources can form from:
  - Magmatic segregation – separation of heavy minerals in a magma chamber
  - Hydrothermal solutions - Originate from hot, metal-rich fluids that are remnants of the late-stage magmatic process

Origin of Hydrothermal Deposits

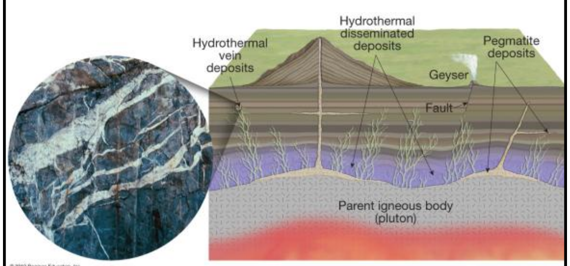


Figure 3.31

End of Chapter 3