Chapter 4

Igneous Rocks

and Intrusive Igneous Activity

Introduction

- Igneous rocks form by the cooling of magma (or lava).
- Large parts of the continents and all the oceanic crust are composed of Igneous Rocks.



The Properties and Behavior of Magma and Lava

- Molten rock material below the Earth's surface is called magma.
- If the magma reaches the surface it is called lava.
- Magma is erupted as either
  - Lava flows or
  - Pyroclastic materials (ash, etc.)

The Properties and Behavior of Magma and Lava

Composition of Magma

- Silica (SiO_2) is the primary constituent of magmas
- Magmas are differentiated based on the relative proportions of silica, iron, and magnesium.
  - Felsic
  - Intermediate
  - Mafic
  - Ultramafic

The Properties and Behavior of Magma and Lava

Composition of Magma

Table 4.1, p. 89

TABLE 4.1 The Most Common Types of Magmas and Their Characteristics

Type of Magma	Silica Content (%)	Sodium, Potassium, and Aluminum	Calcium, Iron, and Magnesium
Ultramafic	<45	↓	Increase
Mafic	45–52	↓	↑
Intermediate	53–65	↓	↑
Felsic	>65	Increase	↑

The Properties and Behavior of Magma and Lava

How Hot Are Magma and Lava?

- mafic magma has temperatures greater than 1200ºC
- felsic magma has temperatures nearer to 900ºC.

The Properties and Behavior of Magma and Lava

Viscosity – Resistance to Flow

- The viscosity of magma is controlled primarily by temperature and composition (silica and iron content) and also
  - loss of volatiles
  - crystallinity
  - bubble content
  - shear stress during movement

The Properties and Behavior of Magma and Lava

Viscosity – Resistance to Flow

High viscosity – thick, stiff flow.
Examples: Tar, glacial ice, felsic magma

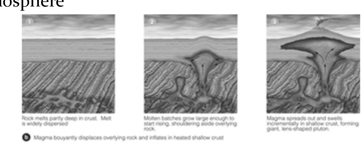
Low viscosity flow – very fluid flow.
Examples: Water, syrup, mafic magma

How Does Magma Originate and Change?

- Some magmas originate at depths of 100 to 300 km.
- Most magmas, however, form at shallower depths in the upper mantle or lower crust.
- Shallow magmas often accumulate in magma chambers.
- Magma chambers beneath spreading ridges may only be a few kilometers below the surface.
- Magma chambers in convergent plate boundaries (subduction zones) are usually at depths of 10s of km.

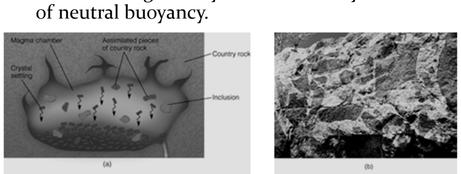
How Does Magma Originate and Change?

- Heat increases the movement of atoms, breaks bonds, and melts rocks to form magmas
- Melting produces expanding magmas that are less dense than the parent rock
- Less dense magmas are buoyant and rise through the lithosphere



How Does Magma Originate and Change?

- Later the magma may stall out and crystallize at a level of neutral buoyancy.

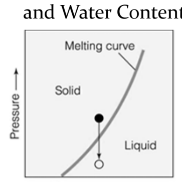


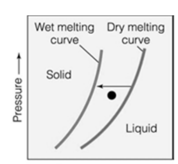
- Stoping - A process where a large body of magma can push aside the overlying crust and assimilate blocks of crust on its way toward the surface.

How Does Magma Originate and Change?

Magma originates at depth due to partial melting.

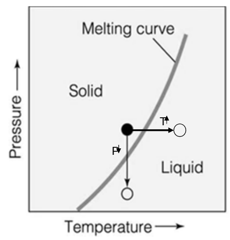
❖ The most important factors are Temperature, Pressure and Water Content





How Does Magma Originate and Change?

Pressure-Temperature (P-T) Diagrams

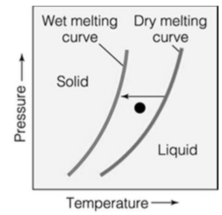


Changes in Temperature

Changes in Pressure

How Does Magma Originate and Change?

Pressure-Temperature (P-T) Diagrams



Changes in Water Content

How Does Magma Originate and Change?

Bowen's reaction series

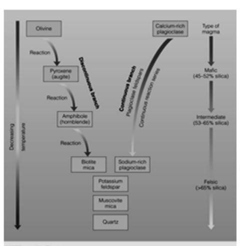
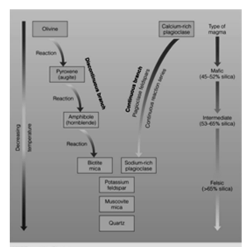


Fig. 4.4, p. 91

- Bowen's reaction series describes the sequence of mineral crystallization in a cooling magma.
- There are two branches in the reaction series.
  - Discontinuous
  - Continuous

How Does Magma Originate and Change?

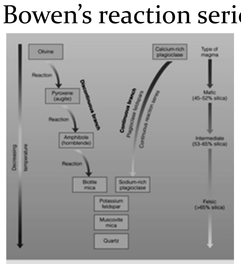
Bowen's reaction series



The **discontinuous branch** produces ferromagnesian silicate minerals.

How Does Magma Originate and Change?

Bowen's reaction series

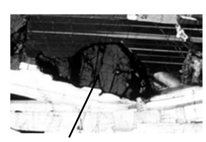


The **continuous branch** produces a variety of plagioclase feldspars

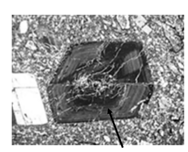
How Does Magma Originate and Change?

Bowen's Reaction Series

Zoned minerals indicate changing conditions during formation.



Rimmed Olivine



Zoned Plagioclase

Images from: http://www.union.edu/PUBLIC/GEODEPT/hollocher/skaergaard/geologic_features/micrographs.htm
And http://www.und.nodak.edu/instruct/mineral/320petrology/opticalmin/plagioclase.htm

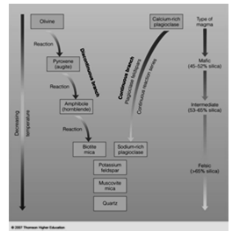
How Does Magma Originate and Change?

Bowen's reaction series

- Bowen's reaction series predicts that:
  - olivine will form first and
  - quartz (SiO_2) will form last

How Does Magma Originate and Change?

Bowen's reaction series

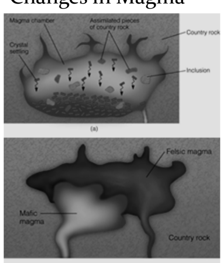


The reverse of Bowen's reaction series describes the melting of rock

Which mineral would melt first?

How Does Magma Originate and Change?

Processes That Bring About Compositional Changes in Magma



1. Crystal settling - During crystallization, the remaining melt becomes progressively more silica-enriched.
2. Assimilation of country rock
3. Magma mixing

Igneous Rocks: Their Characteristics and Classification

Igneous Rock Textures

- Two broad groups based on texture are:
  - volcanic (extrusive) rocks which have an aphanitic texture
  - plutonic (intrusive) rocks which have a phaneritic texture.
  - Rocks with more complex cooling histories are characterized by porphyritic textures.

Igneous Rocks: Their Characteristics and Classification

Igneous Rock Textures

- Rapid cooling typifies volcanic rock and produces aphanitic textures.
- Slow cooling of plutonic magmas produces phaneritic textures with mineral grains that are easily visible without magnification.
- Porphyritic textures are characteristic of rocks with complex cooling histories and contain mineral grains of different sizes.
- Other igneous rock textures include vesicular, glassy, and pyroclastic.

Igneous Rocks: Their Characteristics and Classification

Composition of Igneous Rocks

- Most magma, like most minerals, consists of silicon and oxygen with lesser amounts of other elements, such as magnesium (Mg), iron (Fe), sodium (Na), potassium (K), and aluminum (Al).
- Gabbros and basalts are products of mafic magmas
- Granites and rhyolites are products of felsic magmas
- Diorites and andesites are the products of intermediate magmas
- Peridotites and komatiites are the products of ultramafic magmas

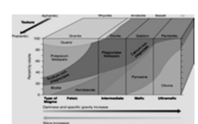
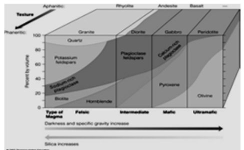


Fig. 4.11, p. 95

Igneous Rocks: Their Characteristics and Classification

Classifying Igneous Rocks

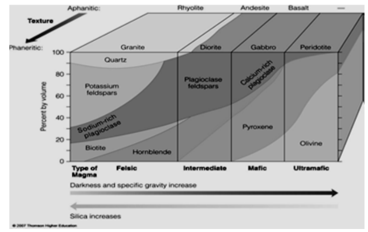
It is best to learn the different kinds of igneous rocks as *pairs* of equivalent plutonic and volcanic compositions; that is, each plutonic rock has its volcanic compositional equivalent, and visa versa.



- For example, gabbro is chemically equivalent to basalt. Gabbro is a plutonic rock. Basalt is a volcanic rock.

Igneous Rocks: Their Characteristics and Classification

Composition of Igneous Rocks



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Igneous Rocks: Their Characteristics and Classification

Classifying Igneous Rocks

Ultramafic Rocks

- Key Mineral - Olivine

Peridotite

Komatiite

Igneous Rocks: Their Characteristics and Classification

Classifying Igneous Rocks

Mafic Rocks

- Key Minerals - Pyroxene and/or Ca-Plagioclase

Gabbro

Basalt

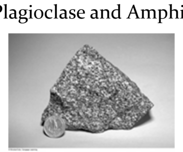
Igneous Rocks: Their Characteristics and Classification

Classifying Igneous Rocks

Intermediate Rocks

- Key Minerals – Na/Ca-Plagioclase and Amphibole

Andesite



Diorite

Igneous Rocks: Their Characteristics and Classification

Classifying Igneous Rocks

Felsic Rocks

- Key Minerals – Quartz, Na-Plagioclase, K-Feldspar

Granite

Rhyloite

Igneous Rocks: Their Characteristics and Classification

Classifying Igneous Rocks – Learn as pairs


Rhyolite porphyry


Andesite


Basalt


Granite


Diorite


Gabbro

Igneous Rocks: Their Characteristics and Classification

Classifying Igneous Rocks

Pegmatite

- Similar to granite in composition
- Contains minerals not ordinarily found in other igneous rocks.
- Contain crystals ≥ 1 cm across.
- Form from water-rich magmas


Pegmatite

Igneous Rocks: Their Characteristics and Classification

Classifying Igneous Rocks

Other igneous rocks:

- Tuff - Composed of volcanic ash.
- Obsidian - Composed of volcanic glass.
- Pumice & Scoria – Vesicular texture

Intrusive Igneous Bodies - Plutons

- Plutons are bodies of igneous rock which have been intruded in country rock or have formed in place far beneath the surface.

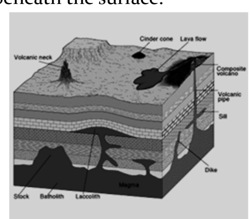


Fig. 4.19, p. 101

- Concordant plutons include sills and laccoliths.
- Discordant plutons include dikes, volcanic necks, batholiths and stocks.

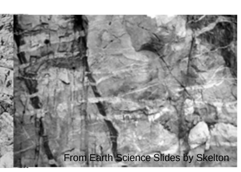
Plutons

Aerial View of a Pluton

Dikes and Sills

Dikes and sills are the most common sheet-like igneous intrusions.

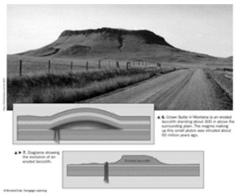

Multiple Sills, California



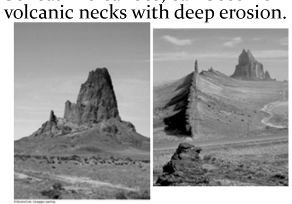
Intersecting Dikes and Veins, California

Laccoliths, Volcanic pipes and necks

Laccoliths are sill-like bodies with inflated cores.



Volcanic pipes are magma-filled, cylindrical feeder channels beneath volcanoes; can become volcanic necks with deep erosion.



Batholiths and Stocks

Batholiths are plutons that have more than 100 km^2 in area of exposure.

Stocks are somewhat smaller plutonic bodies.

Western Batholiths

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