Igneous Rocks and the Rock Cycle

Designed to meet South Carolina Department of Education 2005 Science Academic Standards

Department of Natural Resources
South Carolina Geological Survey

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What are Rocks?

- Most rocks are an aggregate of one or more minerals and a few rocks are composed of non-mineral matter.

- There are three major rock types:
  - 1. **Igneous**
  - 2. **Metamorphic**
  - 3. **Sedimentary**

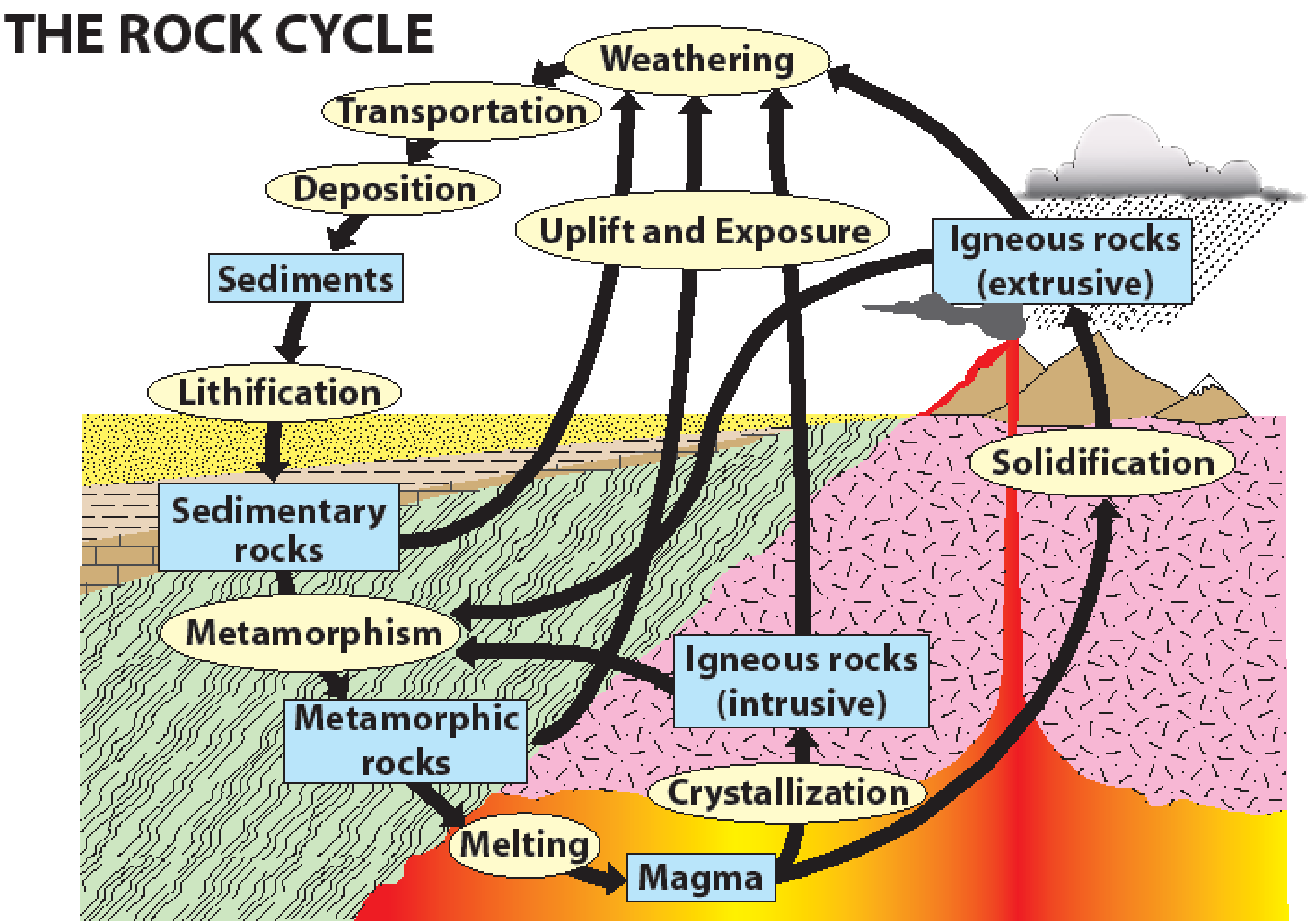
Major Rock Types

- Igneous rocks are formed by the cooling of molten magma or lava near, at, or below the Earth's surface.

- Sedimentary rocks are formed by the lithification of inorganic and organic sediments deposited near or at the Earth's surface.

- Metamorphic rocks are formed when preexisting rocks are transformed into new rocks by heat and pressure, usually below the Earth's surface.

The Rock Cycle



Igneous Rocks -
Rocks that form from the cooling of motlen rock (magma), Example: granite and basalt

Sedimentary Rocks -
Rocks that are fromed from pieces of other rocks, Example: sandstone, or that are deposited from the ocean by chemical processes, Example: limestone

Metamorphic Rocks -
Rocks that are changed by heat and pressure without melting, Example: gneiss

The Rock Cycle graphic is available from the SCGS website: http://www.dnr.sc.gov/geology/images/Rockcycle-pg.pdf

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Igneous Rocks

- Igneous rocks are formed by the cooling of molten rock.
- There are two major states of molten rock: Magma and Lava.
    - Magma is a form of molten rock that exists below the Earth's surface.
    - Lava is the term given to magma once it reaches the Earth's surface, usually in the form of a volcanic eruption.
- There are two major classifications of igneous rocks: Intrusive and Extrusive.
    - Intrusive igneous rocks are formed by magma that cools below the Earth's surface.
    - Extrusive igneous rocks are formed by lava that cools at the Earth's surface.
- Intrusive igneous rocks generally cool very slowly deep below the earth's surface or as the magma is rising to the earth's surface.
- Extrusive igneous rocks generally cool quickly when they reach the earth's surface usually through volcanoes or fissure.

What happens to molten rock as it cools?

- When the temperature of molten rock begins to drop there is a loss of energy that causes ions to slow down. As the ions slow down, they group together and arrange themselves into orderly crystalline structures. This process is referred to as crystallization.

- During crystallization, the silicon and oxygen atoms are the first to link together forming silicon-oxygen tetrahedrons, which are the building block of all silicate minerals.

- As crystallization continues, these individual silicon-oxygen tetrahedrons join with one another, and other ions, to form the basic structure of most minerals and igneous rocks.

- Environmental conditions including temperature and the presence of water or gases during crystallization affect the composition, the size, and the arrangement of the mineral grains.

- The size and arrangement of mineral crystals, also referred to as grains, define the texture of the rock.

- Geologists use mineral and textural classifications to infer information about the environmental setting in which different igneous rocks are formed.

Crystal Size and Cooling Rates

- Slower cooling rates produce larger individual crystals in the rock
  - Intrusive igneous rocks generally cool very slowly and tend to have large crystals that produce a course-grained rock.
  - Phaneritic rocks are coarse-grained rocks which contain individual crystals that are relatively even in size and large enough for scientists to identify the different mineral grains that compose the rock.
- Faster cooling rates produce smaller individual crystals in the rock
  - Extrusive igneous rocks tend to cool quickly and are characterized by smaller grains that produce a fine-grained rock.
  - Aphanitic is the term used to describe very fine grained rocks.
- Porphyritic textured rocks contain both a coarse and fine-grained texture.
  - The coarse grains in a porphyritic rock begin to develop as the magma is cooling below the surface of the earth. Following eruption or exposure to lower temperatures, the remaining magma or lava cools very quickly and forms minerals with fine-grained textures. As a result, porphyritic textures contain both coarse- and fine–grained minerals.

Texture

- Texture is a term used to describe the size, shape, and arrangement of interlocking crystallized mineral grains in an igneous rock.

- Two major factors affect the size of crystal grains in an igneous rock:

  - 1) Rate at which molten rock cools; slow or fast
  - 2) Amount of dissolved gases or fluids in the magma.

Texture

- Igneous minerals vary greatly in grain size. Grain-size classes are similar to the sedimentary scale, but there are fewer divisions with a greater range of size.
- Phenocrysts are grains in an igneous rock that are larger than the other grains that make up the rest of the rock.

Grain Size Categories		Grain Size Divisions
fine grained	=	< 1 mm
medium grained	=	1 mm < 5 mm
coarse grained	=	5 mm < 3 cm
very coarse-grained	=	$\geq$ 3 cm
Phenocrysts Texture		
microphenocrysts	=	0.03 mm – 0.3 mm
phenocrysts	=	0.3 mm – 5 mm
megaphenocrysts	=	> 5 mm

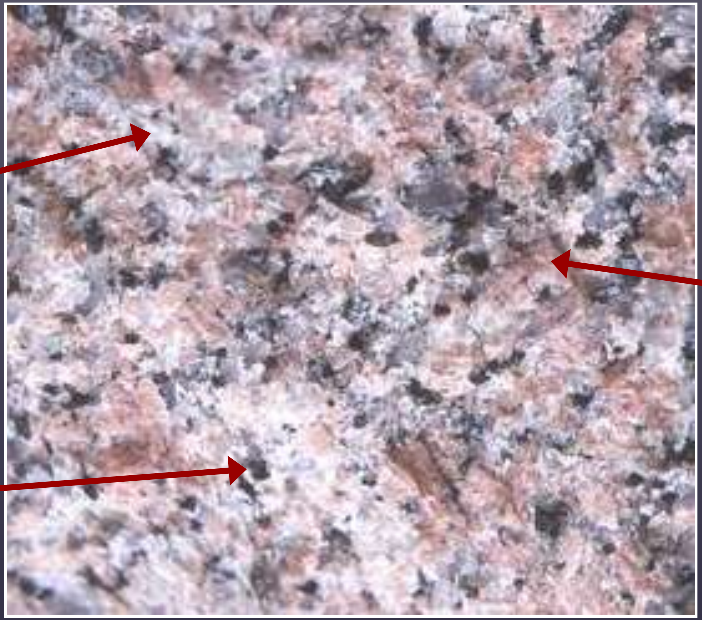
Igneous Rock Textures

- Phaneritic (Intrusive)
- Aphanitic (Extrusive)
- Porphyritic (Intrusive and Extrusive)
- Glassy (Extrusive)
- Pegmatitic (Intrusive)
- Pyroclastic Materials (Extrusive)
- Aa Lava (Extrusive)
- Pahoehoe Lava (Extrusive)

Phaneritic Texture

- Phaneritic (Intrusive)
  - Phaneritic rocks are coarse-grained rocks which form below the Earth's surface.
  - The individual crystals are relatively even-sized and large enough for scientists to identify the different mineral grains that compose the rock.

Granite rock with a phaneritic texture



Quartz Crystals: (White)

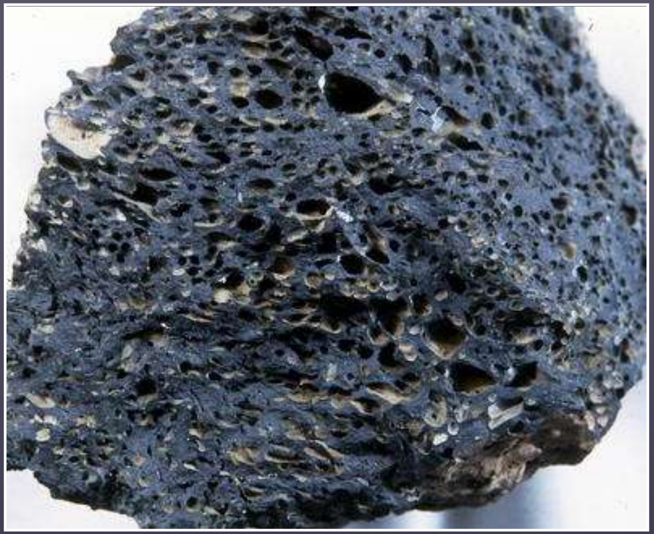
Feldspar Crystals: (Pink)

Biotite Crystals: (Black)

Aphanitic Texture

- Aphanitic (Extrusive)
  - Aphanitic rocks are very fine-grained and contain crystals that are too small to distinguish without the aid of a magnifying lens.
  - Aphanitic rocks are often described by how light or dark the rock appears. Lighter colored aphanitic rocks contain mostly non-ferromagnesian silicate minerals. Darker colored aphanitic rocks contain mostly ferromagnesian silicate minerals.
  - Aphanitic rocks may also contain vesicles of remnant gas that give the rock a vesicular texture. Vesicles form when the rock cools very quickly and preserves the openings formed by the expansion of trapped gas bubbles.

Basalt rock with an aphanitic and vesicular texture



Porphyritic Texture

- **Porphyritic (Intrusive and Extrusive)**
  - Porphyritic rocks contain both coarse- and fine-grained textures indicating different environmental conditions which formed the rock.
  - The coarse grains in a porphyritic rock develop as the magma is cooling below the surface of the earth.
  - The fine-grained component of a porphyriic rocks forms when the magma or lava cools faster.
  - The large coarse-grained crystals are referred to as phenocrysts.
  - The small fine-grained crystals are referred to as groundmass.

Rhyolite rock with porphyritic texture containing phenocrysts of olivine and pyroxene and a gabbro groundmass.

Glassy Texture

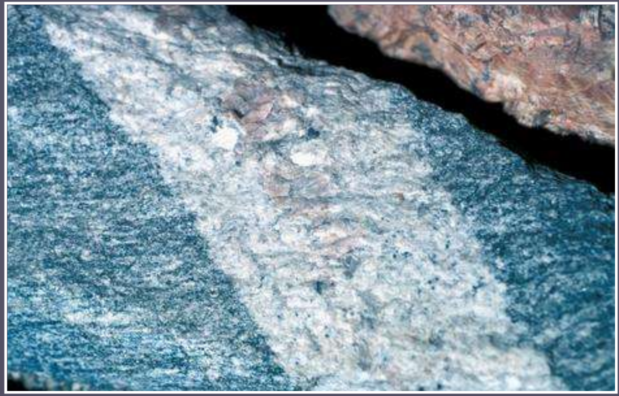
- Glassy (Extrusive)
  - Glassy textured rocks are formed by very rapid cooling of magma.
  - Glassy rocks often form from magmas with high silica content that arranges into long chainlike structures before crystallization occurs. These silica chains increase the viscosity of the magma and it once it eventually cools it forms a glassy textured rock.
  - Glassy rocks can be considered amorphous because they have no crystalline structure.
  - Glassy rocks are classified by the amount of glass contained by the rock:
    - Glass-bearing: 0-20% glass
    - Glass-rich: 20-50% glass
    - Glassy: 50 – 100% glass
  - Obsidian is a common glassy rock.

Obsidian rock with a glassy texture and conchoidal fractures

Pegmatitic Texture

- Pegmatitic (Intrusive)
  - Pegmatitic rocks contain large interlocking crystalline grains > 1-2 centimeter in diameter.
  - Pegmatites are commonly composed of quartz, feldspar, and mica minerals.
  - Pegmatities form from a combination of hydrothermal and igneous processes; and is dependant on the presence of fluids and volatiles such as water, chlorine, bromine, sulfur, and fluorine.
  - Pegmatites form late in the crystallization process when there are a lot of fluids present in the molten rock. The fluids enable individual ions to move around more freely, ultimately bonding to form very large and sometimes exotic crystals.
  - Pegmatitic dikes form around the margins of intrusive plutons, or occasionally as veins of rock which extend into the pluton.

Examples of pegmatitic veins extending through rock



Pyroclastic Materials

- Pyroclastic (Extrusive)
  - Pyroclastic materials form when individual rock fragments are ejected during a violent volcanic eruption and consolidate into larger rock composites when they deposit on the surface.
  - Pyroclastic rocks contain at least 75% pyroclastic fragments with the remainder consisting of other inorganic sediments or organic materials.
  - Pyroclastic rocks contain a mixture of different types of particles that are not cohesively joined by interlocking crystals, but instead are consolidated masses of multiple rock fragments.
  - Tephra is the term used to describe pyroclastic sediments.

Tuff rock with pyroclastic material.

Pyroclastic Fragments

- Pyroclastic materials do not conform well to igneous grain size classifications. Instead, geologists use the following terms to describe pyroclastic fragments:
  - Juvenile fragments: volcanic rocks formed from cooled magma before it is deposited.
  - Cognate fragments: volcanic rocks which formed during previous volcanic activity and are ejected by a later eruption.
  - Accidental fragments: rocks which are disrupted, dislodged, and possibly even ejected by the volcano, but are not of volcanic origin (although they may be igneous).
  - Bombs: fragments with a mean diameter > 64 mm, and a rounded shape.
  - Blocks: fragments with a mean diameter > 64 mm, and a blocky, angular shape.
  - Lapilli: fragments in any shape with a mean diameter of 2-64 mm.
  - Ash: grains of pyroclastic fragments with a mean diameter < 2 mm. This includes coarse ash grains (0.032 -2 mm) and fine ash grains (< 0.032 mm).

Aa Lava

- Aa Lava (Extrusive)
  - Aa is a basaltic lava flow that has a rough surface, characterized by sharp, jagged blocks and protruding spines of volcanic rock.
  - Aa flows move slowly (5-50 meters per hour) and are often several meters thick.
  - As aa lava flows, the outer surface and advancing edge cools first. The molten material pushes through the cooled rocks and breaks the fragments even more. As a result the lava flow appears more like a mass of advancing rubble as apposed to a viscous flow.
  - Aa lava flows are common on the Hawaiian Islands. The aa flows move so slowly that tourists can walk up to them and take pictures.

Aa lava in Hawaii's Volcanoes National Park.

Photo Courtesy USGS Hawaiian Volcano Observatory

Pahoehoe Lava

- Pahoehoe Lava (Extrusive)
  - Pahoehoe (pronounced pah-hoy-hoy) is a basaltic lava flow that has a smooth and twisty, rope-like surface.
  - The characteristic ropy texture forms as the surface lava cools while the molten material beneath it is still moving. The tension formed by the cooling lava causes it to wrinkle as the subsurface lava continues to flow. As a result the surface cools in a series of overlapping, ropy lobes.
  - Pahoehoe lava flows move slow enough (5-50 meters per hour) for observers to watch the cooling lava as it advances forward.

Pahoehoe lava flows in Hawaii.

Photo Courtesy USGS

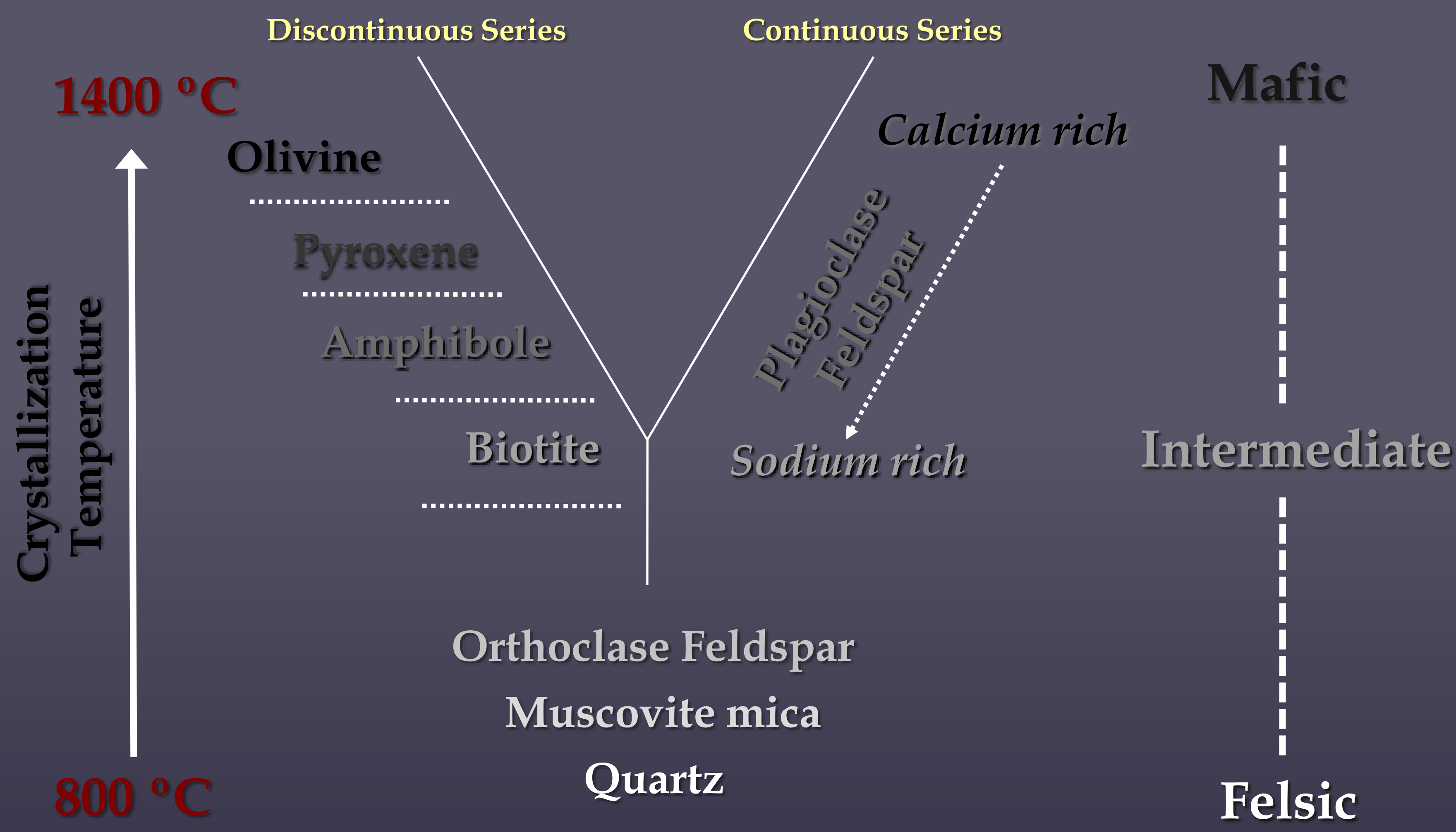
Igneous Rocks Mineral Composition

- The chemical composition of the magma during cooling determines the mineral composition of the crystallized rocks.
- 98% of all magma is composed primarily of silicate (SiO_2) ions joined with aluminum (Al), calcium (Ca), sodium (Na), potassium (K), magnesium (Mg), and iron (Fe) ions.
- Magma may also contain trace amounts of other elements such as titanium (Ti), manganese (Mn), gold (Au), silver (Ag), and uranium (U).
- During crystallization the minerals combine to form two major groups of silicate minerals, these include the dark-colored ferromagnesian silicates which crystallize at high temperatures and the light-colored nonferromagnesian silicates which crystallize at lower temperatures.

Bowen's Reaction Series

- In the early 1900's N.L. Bowen and other geologists conducted a series of experiments to determine the order at which different silicate minerals crystallize from magma. Their results produced a generalized mineral crystallization model that is recognized as Bowen's Reaction Series, and it states that mineral crystallization will occur in a predictable manner.
- Bowen's Reaction Series is a model that describes the formation of igneous rocks with an emphasis on the effect of temperature changes, melting points, and cooling rates, on the types of minerals crystallizing and their resultant rock compositions.
- Once crystallization begins, the composition of the liquid magma changes.
  Minerals with higher melting points will begin to solidify leaving behind a liquid from which minerals with lower melting temperatures will eventually solidify.
- An ideal discontinuous crystallizing series progresses from the minerals olivine - pyroxenes - amphiboles – biotite.
- An ideal continuous series progresses from calcium to sodium-rich plagioclase feldspar.
- Both series merge and are followed by orthoclase feldspar, muscovite, and quartz, with quartz exhibiting the lowest crystallization temperature.

Bowen’s Reaction Series



Classification of Igneous Rocks by Mineral Composition and Texture

<table>
<tr><th colspan="2">Chemical Composition</th><th>Felsic (Granitic)</th><th>Intermediate (Andesitic)</th><th>Mafic (Basaltic)</th><th>Ultramafic</th></tr>
<tr><td colspan="2">Dominant Minerals</td><td>Quartz, Potassium Feldspar, Sodium-rich plagioclase feldspar</td><td>Amphibole, Sodium-and calcium-rich plagioclase feldspar</td><td>Pyroxene, Calcium-rich plagioclase feldspar</td><td>Olivine, Pyroxene</td></tr>
<tr><td colspan="2">Accessory Minerals</td><td>Amphibole, Muscovite, Biotite</td><td>Pyroxene, Biotite</td><td>Amphibole, Olivine</td><td>Calcium-rich plagioclase feldspar</td></tr>
<tr><td colspan="2">Rock Color (% of dark minerals)</td><td>0-25 %</td><td>25 – 45 %</td><td>45 – 85 %</td><td>85 – 100 %</td></tr>
<tr><td rowspan="5">Texture</td><td>Phaneritic (coarse-grained)</td><td>Granite</td><td>Diorite</td><td>Gabbro</td><td>Peridotite</td></tr>
<tr><td>Aphanitic (fine- grained)</td><td>Rhyolite</td><td>Andesite</td><td>Basalt</td><td>Komatiite</td></tr>
<tr><td>Porphyritic</td><td colspan="3">Porphyritic used to describe abundant presence of phenocrysts in Granite, Diorite, Gabbro, Peridotite, Rhyolite, Andesite, and Basalt</td><td rowspan="3">Uncommon</td></tr>
<tr><td>Glassy</td><td colspan="3">Obsidian (compact) and Pumice (frothy-like)</td></tr>
<tr><td>Pyroclastic</td><td colspan="3">Tuff (fine grained) and Volcanic Breccia (coarse grained)</td></tr>
</table>

Modified from Lutgens and Tarbuck 2003

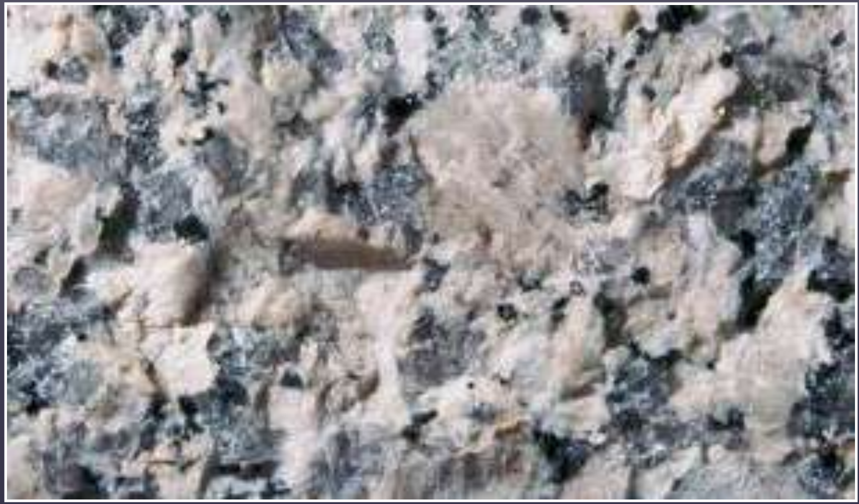
Ferromagnesian Silicates

- Ferromagnesian silicates crystallize at higher temperatures than non-ferromagnesian silicates.
- Ferromagnesian silicates contain greater amounts of iron (Fe) and magnesium (Mg) and less silica ($Si O_2$) than non-ferromagnesian silicates .
- Ferromagnesian minerals are generally dark in color and can be greenish, black, or dark grey.
- Common ferromagnesian silicate minerals include olivine, pyroxene, amphibole, biotite, hornblende, augite, and peridote.

Gabbro rock with olivine (yellowish crystals) and Pyroxene (darker crystals) phenocrysts

Non-Ferromagnesian Silicates

- Non-ferromagnesian silicates crystallize at lower temperatures that ferromagnesian silicates.
- Non-ferromagnesian silicates contain greater amounts of potassium (K), sodium (Na), and calcium (Ca) in combination with more silica ($Si\ O_2$) than ferromagnesian silicates.
- Non-ferromagnesian minerals are generally light colored, and may be white, pink, or light grey.
- Common non-ferromagnesian silicate minerals include quartz, muscovite, and feldspars.



Granite composed of non-ferromagnesian silicates including feldspar (pink crystals) and quartz (white crystals).

Igneous Rock Categories: Felsic to Mafic

Felsic

Mafic

- Igneous rocks are divided into three broad groups Granitic, Basaltic, and Andesitic depending on their proportion of felsic (light-colored) to mafic (dark-colored) minerals.
- Granitic rocks contain more light-colored feldspars and silica than dark- colored minerals. Because of the high feldspar and silica content of Granitic rocks, geologists refer to them as being felsic (*fel* for *fel*dspar and *si* for *si*lica).
  - The primary minerals in granitic rocks include quartz, feldspar, biotite, and amphibole.
  - Granitic rocks make up about 70% of the Earth's crust.
- Basaltic rocks contain mostly darker silicate minerals and calcium-rich plagioclase feldspar and little quartz. Because of the high percentage of ferrromagnesian minerals in basaltic rocks, geologist refer to them as mafic (*ma* for *ma*gnesium and *f* for *f*errum).
  - Basaltic rocks are dark colored and tend to be more dense than granitic rocks.
- Andesitic rocks have a composition between granites and basalts.
  - They generally contain about 25% dark silicate minerals (amphibole, pyroxene, and biotite mica) with the remaining 75% consisting of plagioclase feldspar.

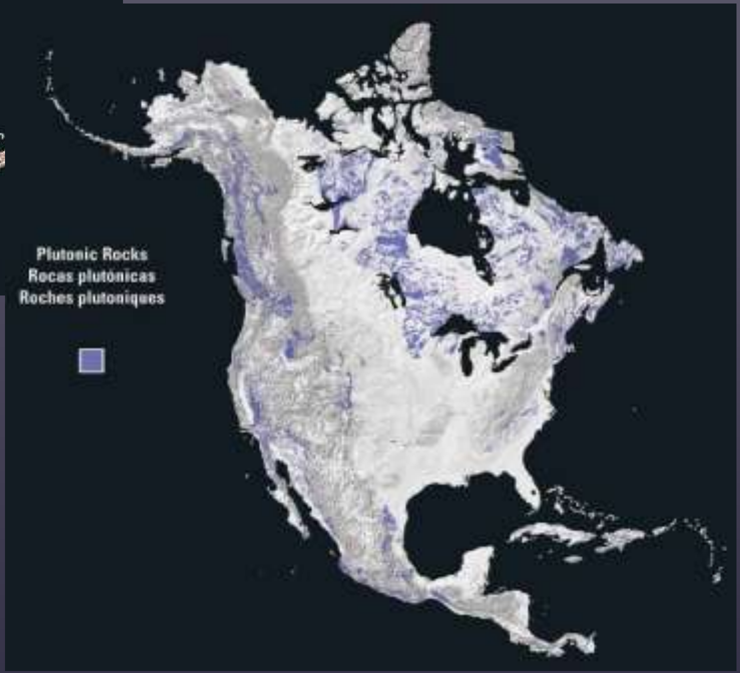
Igneous Rocks

- Granite
- Rhyollite
- Pumice
- Obsidian
- Gabbro
- Basalt
- Diabase
- Andesite
- Diorite
- Tuff

Extrusive Igneous Rocks in North America

www.usgs.gov

Intrusive Igneous Rocks
in North America

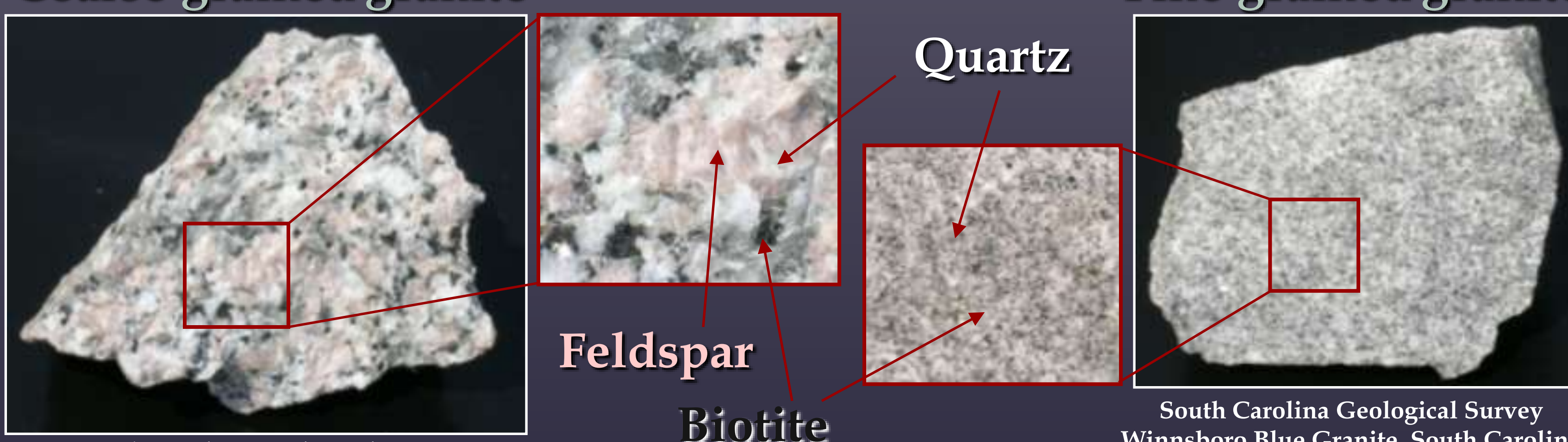


www.usgs.gov

Granite

- Granite is a felsic intrusive igneous rock and has either a phaneritic or porphyritic texture.
  - Granite cools very slowly and often forms large masses of rock that are referred to as plutons or batholiths.
- Granite usually contains about 20-50% quartz, 30-60% feldspar, and the remaining 5-10% darker minerals such as biotite.
  - The quartz grains are usually spherical in shape and are a white to grayish color.
  - The feldspars grains are mostly potassium and sodium rich varieties with individual rectangular shaped grains. The feldspars are often white, grey, or pinkish in color depending on the chemical composition.
  - The remaining darker minerals usually consist of muscovite, biotite and amphibole and are generally black.

Coarse-grained granite **Fine-grained granite**



South Carolina Geological Survey
Kershaw Pink Granite, South Carolina

South Carolina Geological Survey
Winnsboro Blue Granite, South Carolina

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Rhyolite

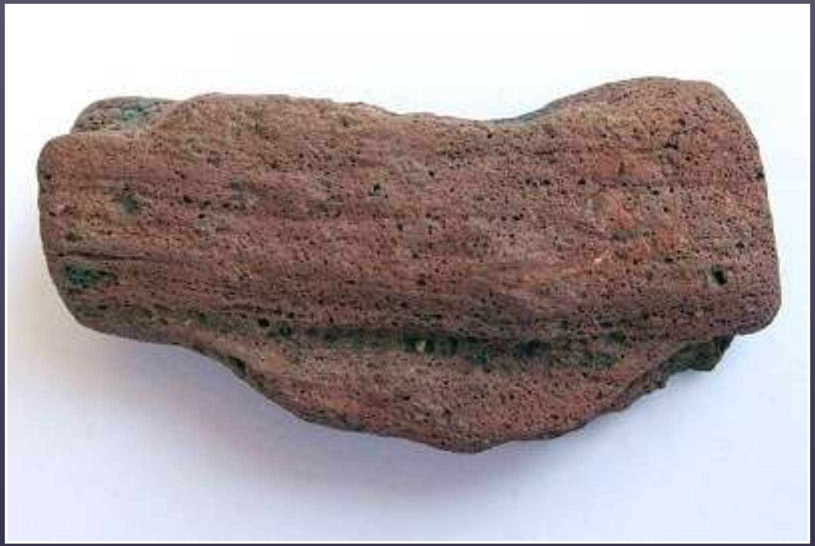
- Rhyolite is a felsic, extrusive igneous rock and usually has an aphanitic texture with glassy fragments and phenocrysts depending on the rate of cooling. Glassy fragments form from rapid cooling and phenocrysts form from slower cooling rates.
- Rhyolite forms very rapidly from lava flows on the Earth’s surface.
- Rhyolite contains mostly light colored quartz and feldspar minerals.
- These minerals generally give the rock a pink or grayish color.

Fine-grained rhyolite

Pumice

- Pumice is a felsic, extrusive igneous rock with a glassy, vesicular texture formed from a combination of rapid cooling and a high gas content.
- Pumice forms in similar condition as obsidian, and the two can often be found in close proximity.
- Pumice is so light from the presence of lots of gas bubbles pockets that it often floats when placed in water.

Pumice with a vesicular texture



Obsidian

- Obsidian is a felsic, extrusive igneous rock with a glassy texture.
- Obsidian forms very quickly from the rapid cooling of silica-rich lava.
- Unlike other minerals and rocks, the ions that form obsidian are unordered, or amorphous, meaning they have no structure, and as a result it produces a conchoidal fracture when broken.
- Thin sections of obsidian appear translucent and it is the presence of various metallic ions that give it an overall dark appearance.

Obsidian

Gabbro

- Gabbro is a mafic, intrusive medium to coarse-grained igneous rock with a phaneritic texture.
- Gabbro is composed primarily of pyroxene, with calcium-rich plagioclase feldspar and small amounts of olivine and amphibole.
- Large gabbro intrusions are often sources of economically valuable nickel, chromium, and platinum.

Medium-grained gabbro

Basalt

- Basalt is a mafic, extrusive fine-grained dark green to black volcanic rock with a porphyritic texture.
- Basalt is composed primarily of pyroxene, and calcium-rich plagioclase with small amounts of olivine and amphibole.

Diabase

- Diabase is a medium to fine-grained mafic, intrusive igneous rock.
- Diabase consists primarily of iron-rich pyroxenes and plagioclase labradorite.
- It is often very dark colored, but can be mottled with lighter colors.
- Diabase dikes are tabular intrusions of diabase that fill fractures below the Earth's surface.

commons.wikimedia.org/wiki/Image:Diabas_1.jpg

Andesite

- Andesite is an intermediate, extrusive igneous rock with a predominantly fine-grained porphyritic texture that forms during volcanic eruptions.
- Andesite main contain phenocrysts which are usually large-grained feldspar or amphibole minerals.

Andesite with amphibole phenocrysts

Diorite

- Diorite is an intermediate, intrusive igneous rock with a predominantly coarse-grained phaneritic texture .
- Diorite is composed of quartz, sodium-rich plagioclase, and amphibole or biotite.
- The composition of diorite looks similar to granite, except that diorite contains a greater concentration of darker mafic minerals.

http://www.mii.org/index.html

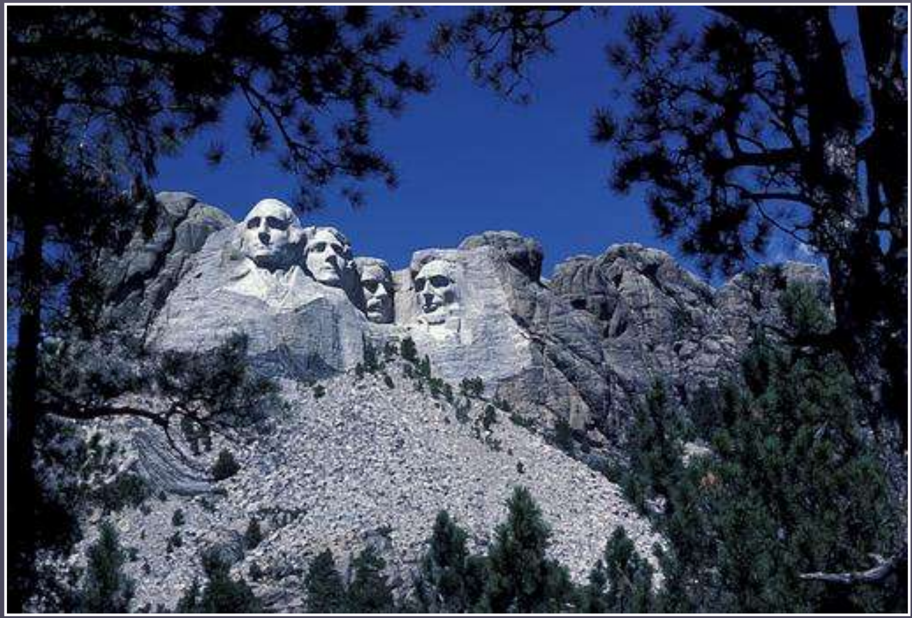
Tuff

- Tuff is an extrusive, pyroclastic rock composed of an aggregate of tiny ash fragments ejected during volcanic eruption.
- A mixture of various other extrusive rock fragments may weld with tuff making a cemented mass of ash and other rock/mineral fragments.
- Tuff may also be used as a descriptor along side other rocks depending on the relative concentration of rock to ash ratio, for example a rhyolite tuff.

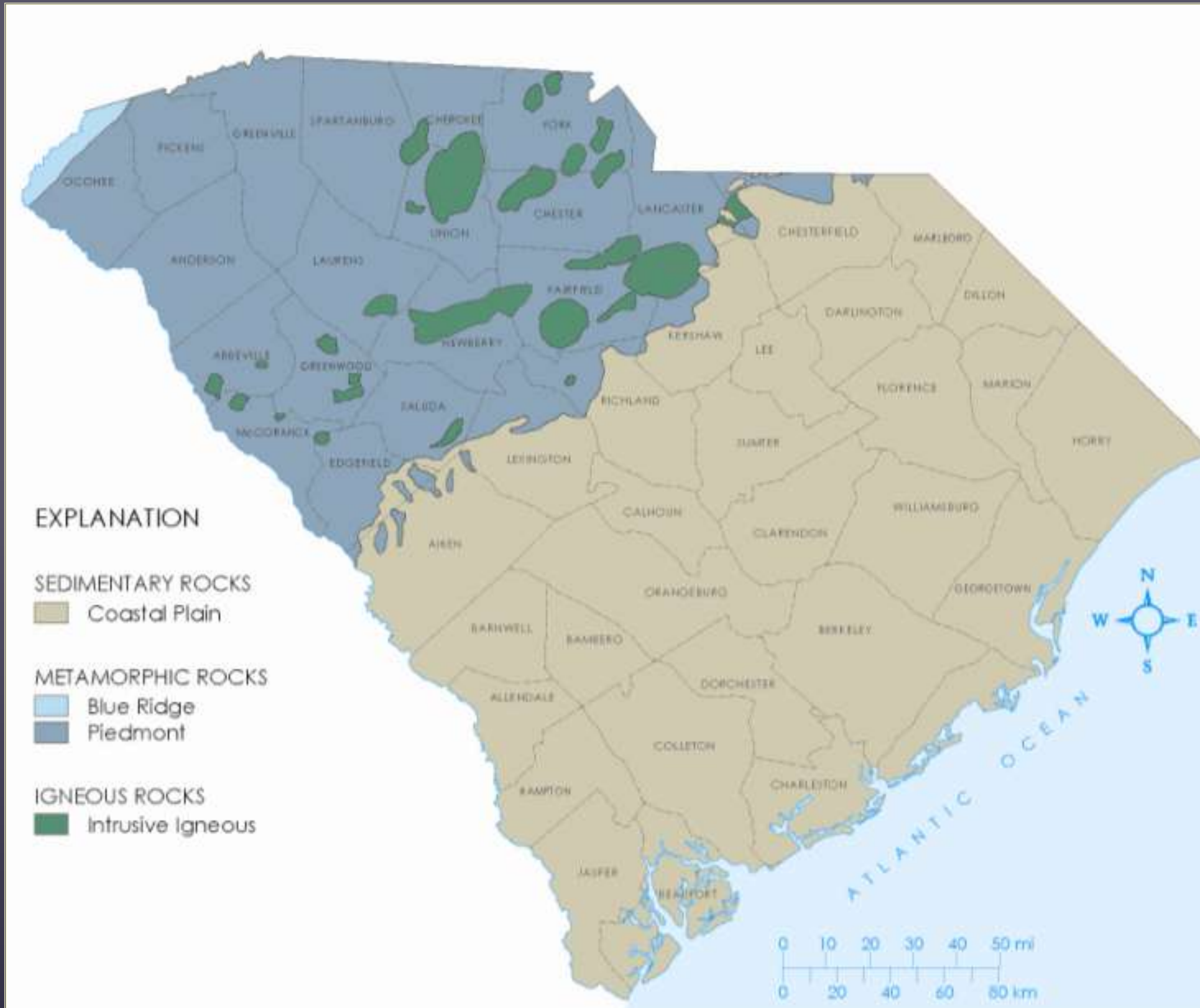
Igneous Rocks in the Landscape

Devils Tower at Devils Tower National Monument in Wyoming is an intrusive igneous rock formation that is exposed from millions of years of weathering and erosion of the surrounding landscape.

Mount Rushmore in the Black Hills of South Dakota is a Precambrian igneous, granitic batholith.



Igneous Rocks in South Carolina



South Carolina Science Academic Standards: Grade 3

1) Earth's Materials and Changes:

Standard 3-3:

The student will demonstrate an understanding of Earth's composition and the changes that occur to the features of Earth's surface. (Earth Science).

Indicators:

3-3.1: Classify rocks (including sedimentary, igneous, and metamorphic). (slides: 3-26)

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Resources and References

Christopherson, R. W. ,2002, Geosystems (4th ed.): Upper Saddle River, New Jersey, Prentice Hall.

Christopherson, R. W., 2004, Elemental Geosystems (4th ed.): Upper Saddle River, New Jersey, Prentice Hall.

Gillespie, M. R., 1999, BGS Rock Classification Scheme, Volume 1, classification of igneous rocks: British Geological Survey Research Report (2nd Edition) RR 99-06.

Keller, E. A., 2000, Environmental Geology (8th ed.): Upper Saddle River, New Jersey, Prentice Hall.

Lutgens, F. K., and Tarbuck, E. J., 2003, Essentials of Geology (8th ed.): Upper Saddle River, New Jersey, Prentice Hall.