Rocks: the structure of the planet

A ***rock*** is any naturally formed solid that is made up (mixture) of an aggregate of one or more minerals, mineraloids, volcanic glass, organic matter, and/or other materials. *Rocks are divided into three groups* based on how they formed: **igneous, sedimentary,** and **metamorphic**. Most rocks are polymineralic (made of more than one mineral), but some are monomineralic (made of only one type of mineral). Some monomineralic rocks can also be considered minerals. In addition to minerals, sedimentary rocks may contain organic materials or pieces of other types of rocks. Sedimentary rocks are the most common rocks, due to there location near the Earth's surface, even though they are not the majority of the rocks that make up the Earth's crust. The *majority* of Earth's crust is made of igneous rocks, which are rocks that formed as a result of the cooling and solidification of molten rock. Molten rock is rock that is in a liquid state. Molten rock inside Earth is known as **magma**, while molten rock found on Earth's surface is referred to as **lava**. As molten rock cools and hardens, the atoms in the rock usually arrange themselves into ordered patterns to form crystals; this process is called **crystallization**.

The Rock Cycle

Recall that the three main types of rocks are igneous, sedimentary, and metamorphic. Rocks are categorized and placed in these groups based on the way they formed. **The Rock Cycle** in Earth's Crust can be used to help remind you how each class of rock forms, and how rocks can be transformed from one type to another. The **Rock Cycle** is a process that shows how rocks slowly continuously change through time and remaking of rocks. These transformations are driven by sunlight (which drives the water cycle that causes erosion), heat from Earth's core (which drives plate movements), and gravity (which drives erosion and causes compaction). These factors cause uplift, weathering, erosion, pressure, and melting that are responsible for rock formation.

You should remember that the *rock cycle is a continuous process with no definite beginning or end, and that all rock types can be changed into all other rock types over time*. By following the arrows, you can see that one way igneous rocks form is when metamorphic rocks are melted into magma, which then solidifies to form igneous rock. A sedimentary rock may be exposed to heat and/or pressure, creating a metamorphic rock. This rock can then be weathered and eroded back into sediments that can then be compacted and cemented, creating yet another sedimentary rock. Follow the other arrows in the figure to see how each of the other types of rocks can form. Be sure to note the many alternative pathways that may be taken through the middle of the diagram, in addition to those around the outside.

Rock Cycle in Earth's Crust

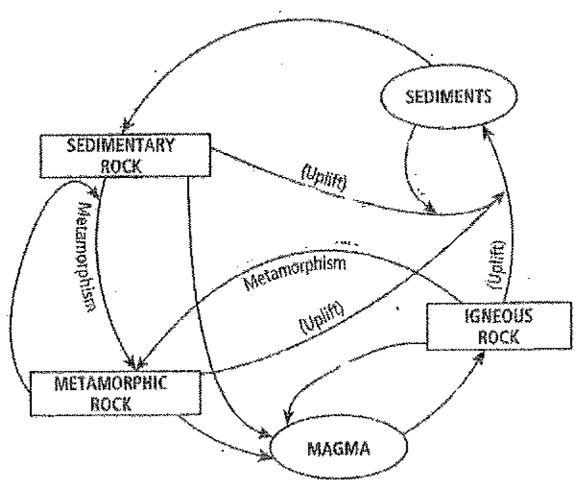


Figure 12-7 Diagram of the rock cycle.

"SUBTOPIC A"
WHAT ARE IGNEOUS ROCKS

Characteristics of Igneous Rocks

Igneous rocks can be recognized by their texture. To a geologist, the texture of a rock refers to the size, shape, and arrangement of the materials that make up the rock. Thus, a rock with a coarse texture has large, visible crystals, even though it may not actually feel rough or coarse. A rock with a fine texture has very small crystals. The cores of the continents are made mostly of a light-colored, coarse-grained igneous rock called granite. In contrast, the ocean floor is made almost entirely of basalt, a dark, fine-grained igneous rock. Some igneous rocks lack crystals; these rocks may have a glassy appearance and may contain bubbles.

Intrusive Igneous Rocks (Phaneritic)

Igneous rocks formed from magma cooling inside Earth are called **intrusive** or **plutonic**. Extremely high temperatures and pressures inside Earth allow magma to cool slowly, which allows the growth of large crystals. The greater the amount of time that is allowed for cooling, the larger are the crystals that form and the coarser the texture is.

Extrusive Igneous Rocks (Aphanitic)

Igneous rocks formed from lava cooling on Earth's surface are called **extrusive** or **volcanic**. Lava cools very quickly as a result of the lower temperatures and decreased pressure on Earth's surface. Rapid, cooling results in rocks with small crystals that may be visible only under a magnifying glass or microscope. Such rocks have a fine texture and may appear to contain sparkles when viewed with the naked eye; these sparkles are the very small mineral crystals present in the rocks. The more rapidly the lava cools, the smaller the crystals are.

When lava cools very quickly, it solidifies before any crystals can form, producing noncrystalline igneous rocks. Some noncrystalline igneous rocks, such as obsidian, have a *glassy texture*. *Obsidian* is very smooth and shiny. It is also easily identified by its conchoidal fracture. Some noncrystalline igneous rocks also contain bubbles and are therefore said to have a *vesicular texture*. The bubbles were produced by gases that became trapped in the lava when it solidified. *Pumice* has a vesicular texture and often contains so many bubbles that it can float in water. Rocks that do not contain bubbles have a nonvesicular texture.

Uses of Igneous Rocks

The properties of igneous rocks, including their strength, texture, and mineral content, allow humans to use igneous rocks in a variety of ways. The interlocking crystals of igneous rocks such as granite make such rocks strong and therefore excellent building materials. In addition, many of the minerals present in igneous rocks are very resistant to weathering, which helps structures made from these rocks last for extended periods of time.

The presence of granite or other strong igneous rocks in bedrock allows large, heavy structures such as skyscrapers to be built with minimal risk of compressing the bedrock. Another strong igneous rock, basalt, is often used in the beds of roads and railroad tracks to increase stability.

Many valuable mineral and metal deposits have been found in or near layers of igneous rocks. Sometimes these deposits occur in veins or pegmatites and may include exquisitely formed crystals used for jewelry and museum exhibits. Gems such as diamonds and deposits of rare elements such as lithium are often mined from igneous intrusions.

Obsidian's conchoidal fracture and glassy texture allow it to be sharpened to a very fine point. Early humans used this rock to make cutting tools, and obsidian is still used today to make extremely sharp scalpels used for cosmetic surgery. Another useful igneous rock is pumice; its vesicular texture makes it useful as an abrasive and for polishing hard materials. In fact, dentists use pumice for polishing teeth.

"SUBTOPIC B"
CLASSIFYING IGNEOUS ROCKS

Recall that igneous rocks are classified as intrusive or extrusive based on the conditions under which they formed. Geologists further classify igneous rocks based on their mineral composition, density, color, texture, and grain size. The distribution of these characteristics among different types of igneous rocks is shown in Figure 11-1 and in Scheme for Igneous Rock Identification in the Earth Science Tables and Charts. Observe that the middle section of Figure 11-1, labeled "Characteristics," consists of three double-headed arrows that show the ranges for color, density, and composition of igneous rocks. Light-colored, low-density rocks are listed above the left side of the arrows; dark-colored, high-density rocks are listed above the right side of the arrows; and rocks with intermediate color and density are listed above the middle of the arrows.

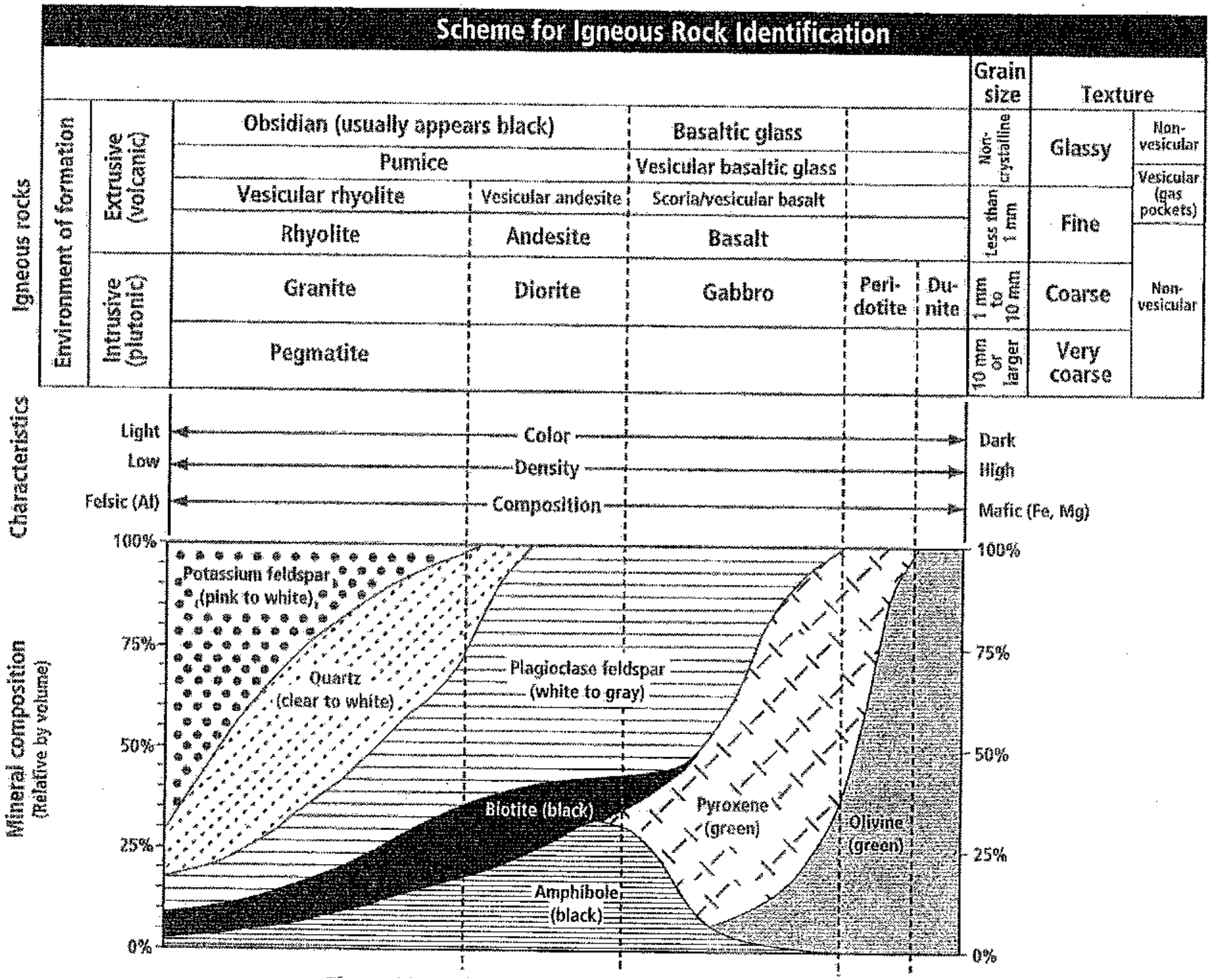


Figure 11-1 Scheme for identifying igneous rocks.

Mineral Composition, Density, and Color

Igneous rocks are classified as felsic, mafic, or intermediate based on their mineral composition. A rock's mineral composition, in turn, determines the rock's density and color.

Felsic Rocks

Felsic rocks are composed largely of feldspars; they also contain a high proportion of silica and aluminum. Felsic rocks tend to be light-colored and to have a relatively low density. In Figure 11-1, felsic rocks are listed on the left side of the left dashed line. Notice in Figure 11-1 that the minerals most commonly found in felsic rocks are potassium feldspar, quartz, and plagioclase feldspar, all of which are light colored. Smaller amounts of the dark minerals biotite (a type of mica) and hornblende (a type of amphi-bole) are also found in felsic rocks. Felsic rocks include granite, rhyolite, pumice, and most types of obsidian. These rocks form from rhyolytic (also called felsic) magma or lava, which is 70 percent silica. The silica content of magma or lava affects its melting temperature and the rate at which it flows. Magma or lava with a high silica content usually is thick (highly viscous) and flows slowly. **Viscosity** *is the resistant to flow.* Thus a *High viscosity* would have a slow flow and a *Low viscosity* would have a fast flow like water.

Mafic Rocks

Mafic rocks, such as basalt, are made mostly of minerals high in magnesium (Mg) and iron (Fe). Mafic rocks tend to be dark and have a relatively high density. In Figure 11-1, mafic rocks are listed on the right side of the second dashed line from the left. Notice in Figure 11-1 that the minerals commonly found in mafic rocks includes pyroxene and olivine, along with smaller amounts of biotite, amphi-bole, and plagioclase feldspar. Mafic rocks include basalt, gabbro, and scoria, which typically form from basaltic (also called mafic) magma or lava, which is only 50 percent silica. The lower silica content of this magma or lava makes it thinner (less viscous) and faster flowing than felsic magma. Two rocks listed in Figure 11-1 have a composition referred to as ultramafic: peridotite and Dunite. Ultramafic rocks appear very dark and tend to be the densest igneous rocks. Peridotite is made primarily of dark pyroxene and olivine, while Dunite is made exclusively of dark green olivine.

Intermediate Rocks

Rocks with an intermediate composition are made of a combination of light and dark minerals. In Figure 11-1, intermediate rocks are listed between the two dashed lines that are farthest to the left. These rocks are usually made of plagioclase feldspar with smaller amounts of biotite, amphi-bole, quartz, and pyroxene. Plagioclase feldspar is usually gray, so most intermediate rocks take on this color. As Figure 11-1 shows, intermediate rocks include andesite, diorite, and some types of pumice and obsidian. Intermediate rocks form from Andesitic magma, which is about 60 percent silica.

Texture and Grain Size

Recall that the texture of an igneous rock refers to the rock's grain size and is determined by the environment in which the rock formed. As Figure 11-1 shows, the intrusive rocks granite, diorite, gabbro, peridotite, and Dunite have a coarse texture, with crystals ranging from 1 mm to 10 mm in diameter. Mineral grains in coarse-textured igneous rocks are often so large that you can easily identify them as a particular mineral. Although minerals forced to grow in tight spaces often cannot take on their usual crystal shapes, you can use other

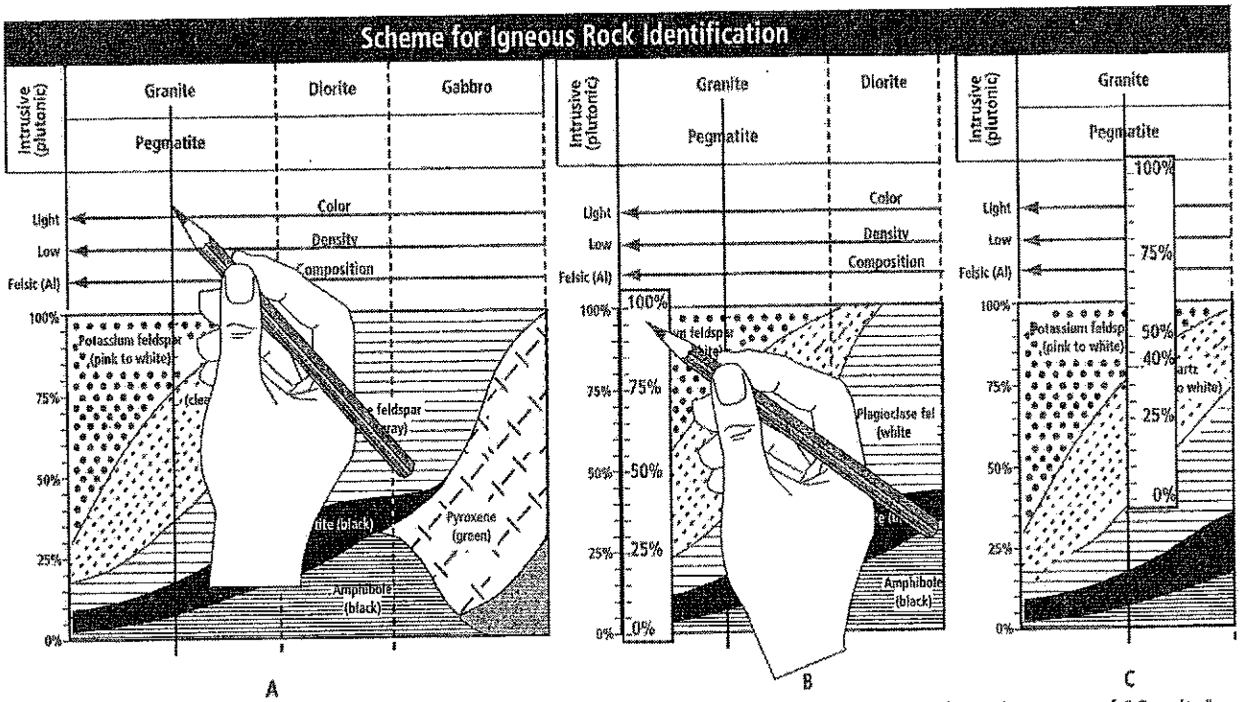


Figure 11-2 To estimate the percentage of quartz in a typical piece of granite, draw a vertical line from the center of "Granite" in the chart titled *Scheme for Igneous Rock Identification* in the *Earth Science Tables and Charts.* Extend the line to the bottom of the chart (A). Then copy the percentage scale at the left side of the chart onto a strip of paper (B). Finally, position the strip of paper alongside the line you drew in the first step. The 0% mark on the strip should line up with the bottom of the stippled section representing quartz on the chart. The mark that lines up with the top of the stippled section (40%) indicates the percentage of quartz in granite.

characteristics to identify minerals within igneous rocks. The most useful tests for this purpose are tests for color, streak, cleavage, and luster.

Intrusive rocks with extremely large crystals (10 mm or larger in diameter) are referred to as pegmatites in Figure 11-1, and their texture is very coarse. Pegmatites cooled from magma deep in the ground over a very long time. The minerals in this type of rock often take on their usual crystal shapes because the crystals grow very slowly in fractures and veins around the margins of large plutons. Coarse and very coarse rocks can never have a vesicular texture because bubbles form only when molten rock cools very quickly.

Extrusive igneous rocks often have a fine texture, with crystals generally less than 1 mm in diameter, as shown in Figure 11-1. Igneous rocks can be fine-grained and vesicular (such as vesicular rhyolite), or they can be fine-grained and non-vesicular (such as rhyolite). As explained in subtopic A, rocks that cool extremely quickly do not develop crystals at all. Noncrystalline rocks can be glassy and vesicular, like vesicular basaltic glass, or glassy and nonvesicular like obsidian.

One texture not included in Figure 11-1 is **porphyritic**. Rocks with a porphyritic texture have large crystals surrounded by finer crystals, often of the same mineral. Such rocks form when slowly cooling magma or lava suddenly begins to cool quickly. This often happens when magma inside a volcano is thrust to Earth's surface during an eruption. The large crystals that have already formed in the magma are incorporated into the fine-grained rocks that form on or near the surface.

Using the Scheme for Igneous Rock Identification

The Scheme for Igneous Rock Identification (Figure 11-1) can be used to answer many types of questions about igneous rocks. You have already learned that you can read vertically down this chart to determine the color, density, and composition of igneous rocks. You have also learned that you can read across this chart to see which igneous rocks are intrusive or extrusive and to determine rock texture and grain size.

The Scheme for Igneous Rock Identification can also be used to *classify igneous* rocks based on just their *color and texture*. For example, suppose you found a rock that has a color midway between light and dark and it has a coarse texture. First, locate the column on the chart that includes the middle of the double-headed "Color" arrow. Then locate the row that lists rocks with a coarse texture. The place where that column and row intersect shows the name of the rock you found: *diorite*.

Finally, the Scheme for Igneous Rock Identification can be used to determine the percentage composition of any mineral shown on the chart in any igneous rock. As an example, Figure 11-2 explains how to estimate the percentage of quartz in a typical piece of granite.

"SUBTOPIC C"
COMPOSITION & ORIGIN OF MAGMA

MAGMA is molten, liquid material (rock) that forms inside Earth. It is often a slushy mix of molten rock, gases, and mineral crystals. The elements found in magma are the same major 8 elements found in the Earth's crust. Which are O, Si, Al, Fe, Ca, Na, K, & Mg. Of all the compounds found in magma, **silica** (SiO_2) is the most abundant. Magmas are classified according to silica content. They can be Basaltic (50%), Andesitic (60%), or Rhyolitic (70%). This affects melting temperature and how magma flows. Since most rocks must be heated to temperatures of 800° C (1,472° F) to 1200° C (2,192° F) this temperatures, is found in nature, DEEP inside the Earth is around 60 Km (37 miles) to 1200 Km (746 miles) below the surface. Rocks at this depth are under great pressure, which may causes some of the overlying rocks to melt to form **MAGMA.** Also heat from the Earth's core helps in melting rocks. Why even some radioactive elements can generate thermal energy and melt rocks... to form magma.

Factors that affect Magma Formation

There are several main factors that affect the formation of magma. They are Temperature, Pressure, Water content, & Mineral composition.

Temperature is generally increases with depth. This is known as **geothermal gradient.** Deep oil-well drilling have been know to exceed temperatures in the 200° C (392° F). *Pressure* increases with depth. This is due to the overlying rock above it. A rock melts at Earth's surface at around a temperature of 1100° C (2,012° F) BUT the same rock will melt at 1400° C (2,552° F) under the intense pressure found at a depth or 100 Km (62 miles). *Water content* also affects the formation of magma. Rocks & minerals often contain small percentages of water, which changed the melting point of the rock. When water content increases, the melting point decreases. *Mineral content* also impacts how magma is formed. The different minerals have different melting points. Rocks formed of Olivine, Calcium Feldspar, & Pyroxene melt at higher temperatures than rocks formed of Quartz, & Potassium Feldspar.

Oceanic crust (rich in Iron & Magnesium) called **Basaltic rock** melt at high temperatures while Continental crust (rich in Silicon and Aluminum) called **Granitic (Rhyolitic) rock** melts at lower temperatures due to its water content.

How ROCKS melt

So how do rocks melt? Rocks melt at different temperatures. For example if you froze bits of candle wax & water in an ice-cube tray, then you remove it from the freezer and left it at room temperature the ice would melt but the candle wax would not due to the different melting point. Some rocks go through a process called **Partial Melting.** Since different minerals melt at different temperatures, not all parts of a rock melt at the same time. This explains why magma is often a slushy mix of crystals & molten rock. This process whereby some minerals melt at low temperatures while other minerals remain solid is called **partial melting.** As minerals melt, different elements are added to the magma "stew", thereby changing its composition. If temperatures are not great enough to melt the entire rock, the resulting magma will have a different chemistry from that of the original (**protolith**) parent rock.

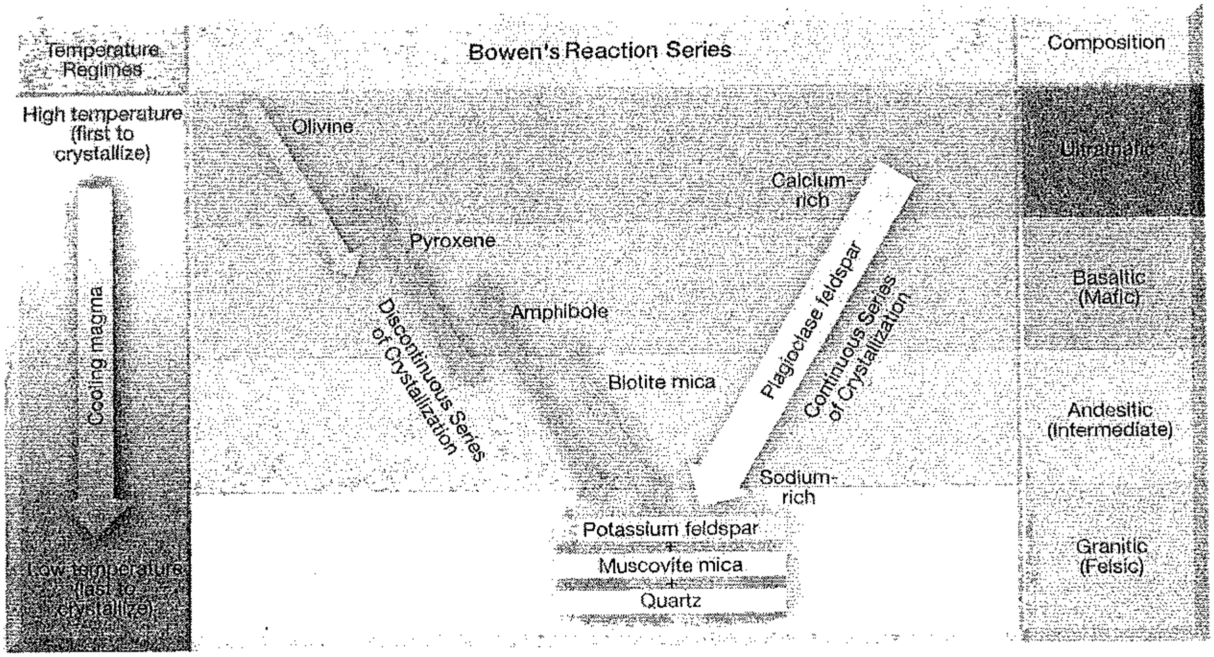
Magma and/or lava can eventually cool & solidified. This process, called **fractional crystallization** may occur either beneath the surface or, following a volcanic eruption, at the surface. The crystallization is in the reverse order of partial melting.

First minerals to crystallize from magma are the last minerals to melt during partial melting. This was discovered in the 1900's by a Canadian geologist who studied magma as it cooled. **NORMAN L. BOWEN (N. L. Bowen)** demonstrated that as magma cools, minerals from in predictable patterns. He then determined that specific minerals formed at specific temperature as magma cools. This predictable pattern is called the Bowen's Reaction Series. It illustrates the relationship between cooling magma & mineral formation

Bowen's Reaction Series is a sequence in which minerals crystallize within a cooling magma. Crystallization occurs simultaneously on two branches if lithification rates are slow enough. Minerals found at the top of the chart (both left and right columns) form first during cooling. Other minerals form in progression (down the table) as temperature cools. Bowen discovered 2 main patterns or branches of crystallization.

First pattern is called the **Discontinuous Branch.** Olivine-Pyroxene-Amphibole-Biotite (all **ferro-magnesium** minerals) takes turns forming at specific temperatures on this branch. As the temperature progressively decreases, each takes elements remaining in the melt and steals from previously formed minerals to make new minerals. Biotite is the last to form in this group, after which all iron and magnesium remaining in the melt are used up. Obviously, the available amount of iron and magnesium in the melt determines the amount of ferro-magnesium minerals formed. Characterized by an abrupt change of mineral type in the iron-magnesium groups left branch represents the Fe-rich minerals, which these minerals undergo abrupt changes during fractional crystallization. Magma rich in Iron and Magnesium cools around 1800° C (3,272° F). Olivine begins to crystallize first till the temperature drops to 1,557° C (2,835° F). Then Pyroxene begins to form, followed by amphiboles & then biotite. Finally the remaining melt, enriched with silica & oxygen, crystallize, quartz forms.

Second pattern is called the **Continuous Branch.** Here two flavor of Plagioclase minerals (containing calcium and sodium) form on this branch at the same temperature range as the Discontinuous Branch (Plagioclase is a mixture of Anorthite: $CaAl_2Si_2O_8$ and Albite:



Bowen's reaction series shows the sequence in which minerals crystallize from a magma.

$NaAlSi_3O_8$). Characterized by a continuous, gradual change of mineral compositions the feldspar group (the right branch) represents the feldspar minerals, which undergo this continuous change of composition. Magma cools the first feldspar to form are rich in calcium. Calcium-rich plagioclase minerals (anorthite) form first, robbing the melt of this element. As cooling continues, Calcium-rich feldspar change to Sodium-rich feldspar. As less calcium remains within the melt more sodium elements are used to form a sodium-rich plagioclase (Albite). Plagioclase is formed until all calcium and sodium is used up in the melt. The remaining minerals are formed at lower temperatures (Fe/Mg/Ca/Na all used up by this time). Magma is now rich in silica, aluminum and potassium. Orthoclase (potassium-aluminum) ($KAlSi_3O_8$) feldspar is now formed. If water is present, muscovite may form. Otherwise the remaining melt contains only silica, all other elements have been depleted, and finally forms quartz: SiO_3. Geologists hypothesize that under certain conditions, newly formed crystals are separated from magma, & the chemical reactions between the magma and the minerals stop. **Crystal separation** can occur when crystal settle to the bottom of the magma body, & when liquid magma is squeezed from the crystal mush to form 2 distinct igneous bodies with different compositions. In some magma bodies, the minerals form into distinct bands in the order in Bowen's reaction series. This results in a **layered intrusion.** Not sure how they form, scientist think that settling of crystals, flowing currents in the magma, & temperatures gradients within the magma chambers all play a part. **Layered intrusion** can be a valuable source of raw metals. Some contain very high concentrations of elements such as platinum, chromium, nickel, & gold. Stillwater Complex in Montana is the only source of platinum in the United States. Platinum is a critical component in catalytic converters, which reduce the amount of pollutants that vehicles emit. Rocks formed from this molten material are called: IGNEOUS ROCKS.