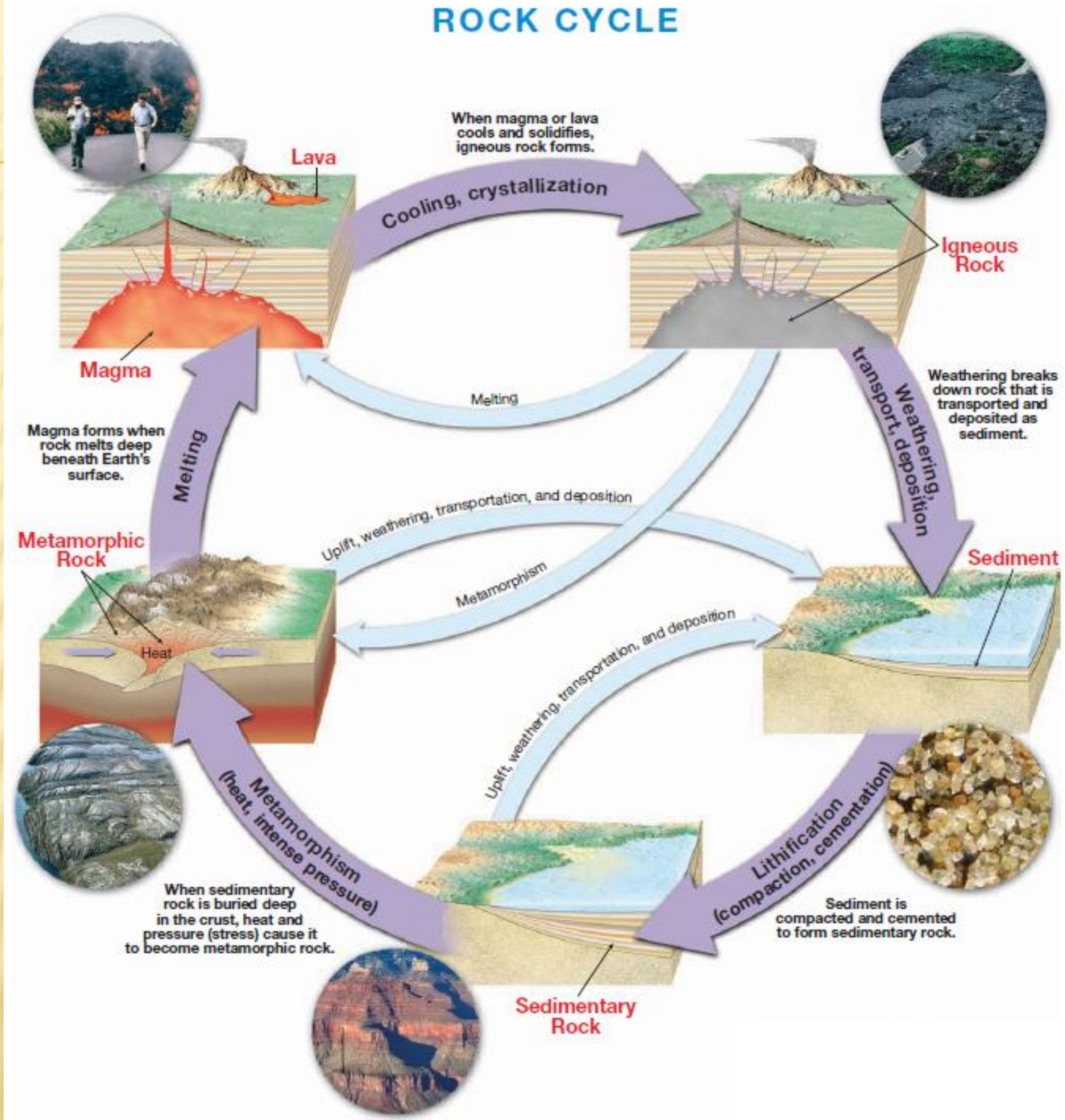
UNIT 3

IGNEOUS ROCKS

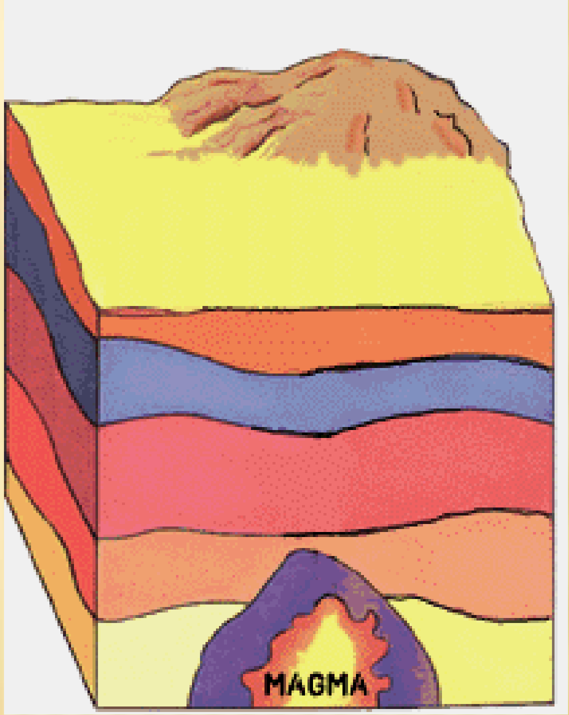

ROCK CYCLE
Lava
When magma or lava cools and solidifies, igneous rock forms.
Cooling, crystallization
Igneous Rock
Magma
Melting
Weathering breaks down rock that is transported and deposited as sediment.
Weathering, transport, deposition
Magma forms when rock melts deep beneath Earth's surface.
Melting
Uplift, weathering, transportation, and deposition
Metamorphic Rock
Sediment
Metamorphism
Heat
Uplift, weathering, transportation, and deposition
Metamorphism (heat, intense pressure)
Lithification (compaction, cementation)
When sedimentary rock is buried deep in the crust, heat and pressure (stress) cause it to become metamorphic rock.
Sediment is compacted and cemented to form sedimentary rock.
Sedimentary Rock

ROCK TYPES

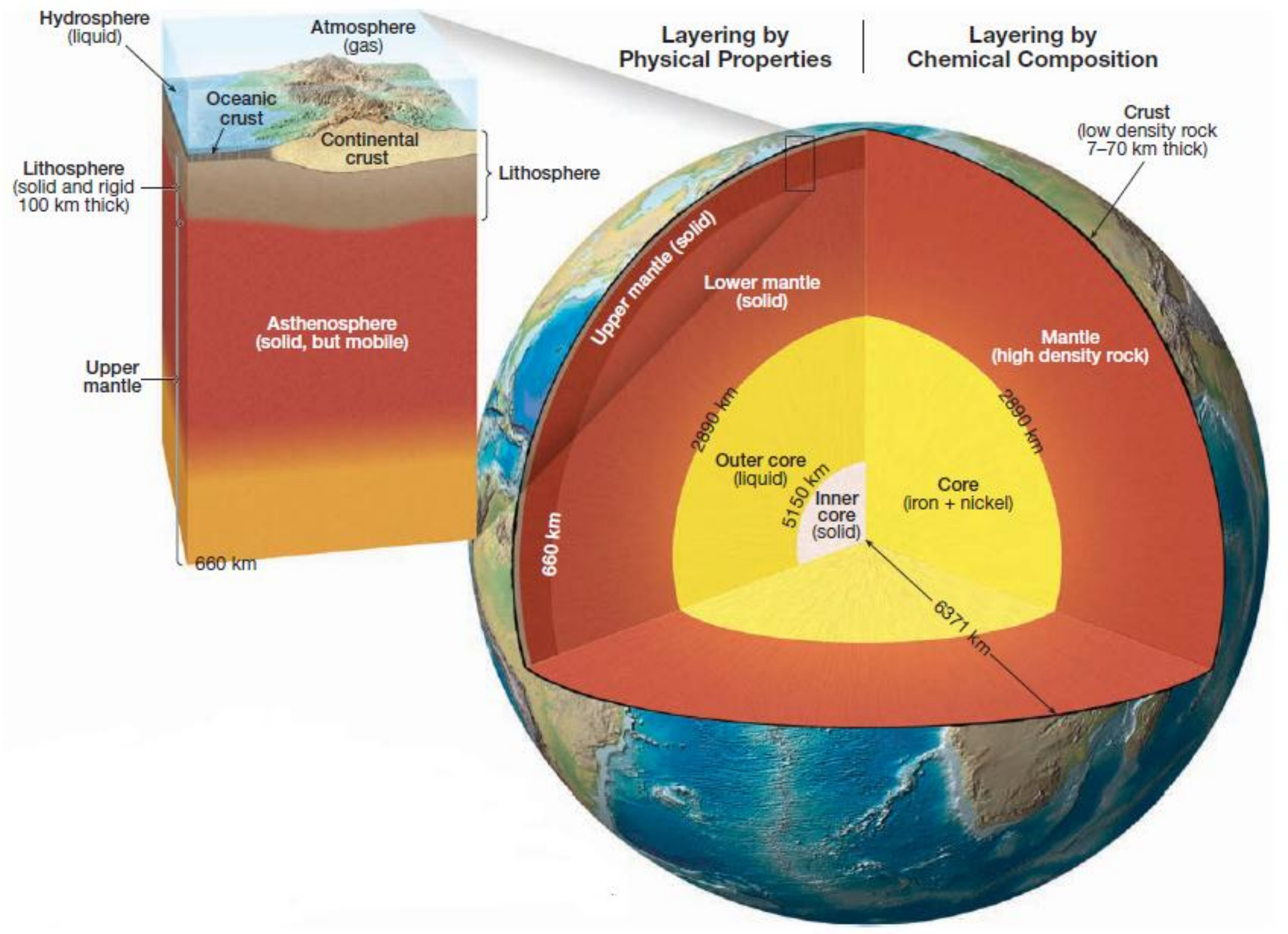
- The Earth is almost entirely rock to a depth of 2900 kilometers, where the solid mantle gives way to the liquid outer core.

- Geologists group rocks into three categories on the basis of how they form:

- Igneous rocks,
- Sedimentary rocks, and
- Metamorphic rocks



ORIGIN OF THE MAGMA



- In the asthenosphere (between depths of about 100 to 350 kilometers), the temperature is so high that rocks melt in certain environments to form magma

FORMATION OF MAGMA

- Under certain conditions, rocks of the upper mantle and lower crust melt, forming a hot liquid called magma.
- An igneous rock forms when magma solidifies.
- About 95 percent of the Earth's crust consists of igneous rock and metamorphosed igneous rock.
- Granite and basalt are two common and familiar igneous rocks.

FORMATION OF MAGMA

- Three different processes melt the asthenosphere:

1. **rising temperature,**
2. **decreasing pressure** and
3. **addition of water**

FORMATION OF MAGMA

- Rising Temperature
- A solid melts when it becomes hot enough. Therefore an increase in temperature melts a hot rock.
- Most magma originates when essentially solid rock, located in the crust and upper mantle, melts. The most obvious way to generate magma from solid rock is to raise the temperature above the rock's melting point.
- The temperatures gets higher as we go deeper inside the earth. Although the rate of temperature change varies considerably from place to place, it averages about 25 °C per kilometer in the upper crust.
- This increase in temperature with depth, known as the geothermal gradient, is somewhat higher beneath the oceans than beneath the continents.
- Tectonic processes exist that can increase the geothermal gradient sufficiently to trigger melting.

FORMATION OF MAGMA

- Decreasing Pressure
- If temperature were the only factor that determined whether or not rock melts, our planet would be a molten ball covered with a thin, solid outer shell.
- This, of course, is not the case. The reason is that pressure also increases with depth.
- Melting, which is accompanied by an increase in volume, occurs at higher temperatures at depth because of greater confining pressure.
- Consequently, an increase in confining pressure causes an increase in the rock’s melting temperature. Conversely, reducing confining pressure lowers a rock’s melting temperature. When confining pressure drops sufficiently, decompression melting is triggered.

FORMATION OF MAGMA

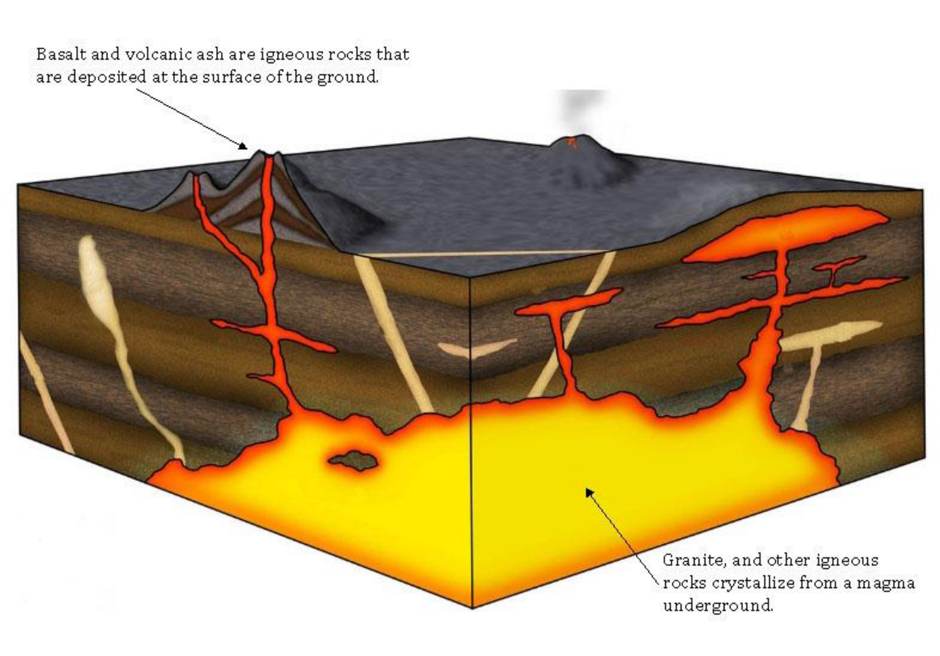
- Addition of Water
- Another important factor affecting the melting temperature of rock is its water content.
- Volatiles cause rock to melt at lower temperatures. Further, the effect of volatiles is magnified by increased pressure.
- Deeply buried "wet" rock has a much lower melting temperature than "dry" rock of the same composition.
- Therefore, in addition to a rock's composition, its temperature, depth (confining pressure), and water content determine whether it exists as a solid or liquid.

NATURE OF MAGMA

- Magma is the completely or partially molten material, which on cooling solidifies to form an igneous rock.

- Once a magma is formed it rises towards the surface as its is less dense than the surrounding rocks.

- Sometimes these magma may reach the earth's surface in the form of volcanoes. Magma that reaches the earth's surface is known as Lava.



COMPONENTS OF THE MAGMA

- Most magma consists of 3 distinct parts: a liquid component, a solid component and a gaseous phase.

- The melt is mostly made up of the ions of Silicon and Oxygen which readily combines to form Silica (SiO_2). Less amounts of Aluminum, Potassium, Calcium, Sodium, Iron and Magnesium are also found.

- The solid component if any are silicate minerals that have already crystallized from the melt. As the magma cools, the size and the number of crystals increase. During the last stage of cooling, the magma body is mostly a crystalline solid with only minor amounts of melt.

- Water (H_2O), carbon dioxide (CO_2) and Sulfur Dioxide (SO_2) are the most common gases found in the magma. Theses gaseous components also known as the volatiles are dissolved within the melt.

- Volatiles remain a part of the magma until the magma body crystallizes or it moves near the surface (low pressure), at which time any remaining volatile freely moves away.

CHARACTERISTICS OF THE MAGMA

- Temperature: The temperature of magma varies from about 600ºC to 1400ºC, depending on its chemical composition and the depth at which it forms.
- Generally, basaltic magma forms at great depth and has a temperature near the high end of this scale.
- Granitic magmas, which form at shallower depths, tend to lie near the cooler end of the scale.

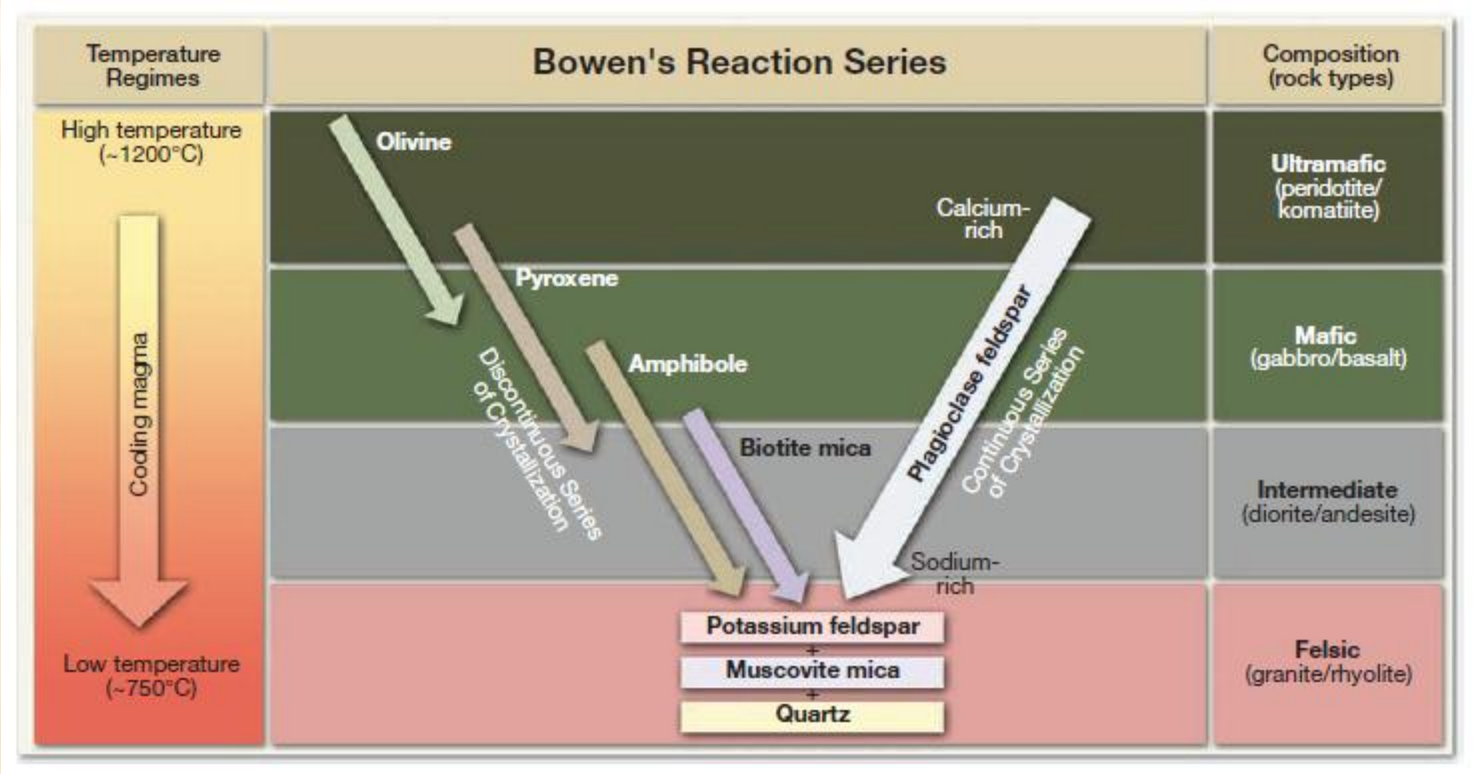
Composition	Source Material	Viscosity	Temperature
Basaltic Magma	Upper Mantle	Low	1200 °C
Andesitic Magma	Oceanic Crust	Inetermediate	800-1000 °C
Granitic Magma	Continental Crust	High	750-850 °C

CHARACTERISTICS OF THE MAGMA

- Chemical Composition: Because oxygen and silicon are the two most abundant elements in the crust and mantle, nearly all magmas are silicate magmas.
- In addition to oxygen and silicon, they also contain lesser amounts of the six other common elements of the Earth's crust: aluminum, iron, magnesium, calcium, potassium, and sodium.
- The main variations among different types of magmas are differences in the relative proportions of these eight elements.
- For example, basaltic magma contains more iron and magnesium than granitic magma, but granitic magma is richer in silicon, potassium, and sodium. A few rare magmas are of carbonate composition.

EVOLUTION OF MAGMA

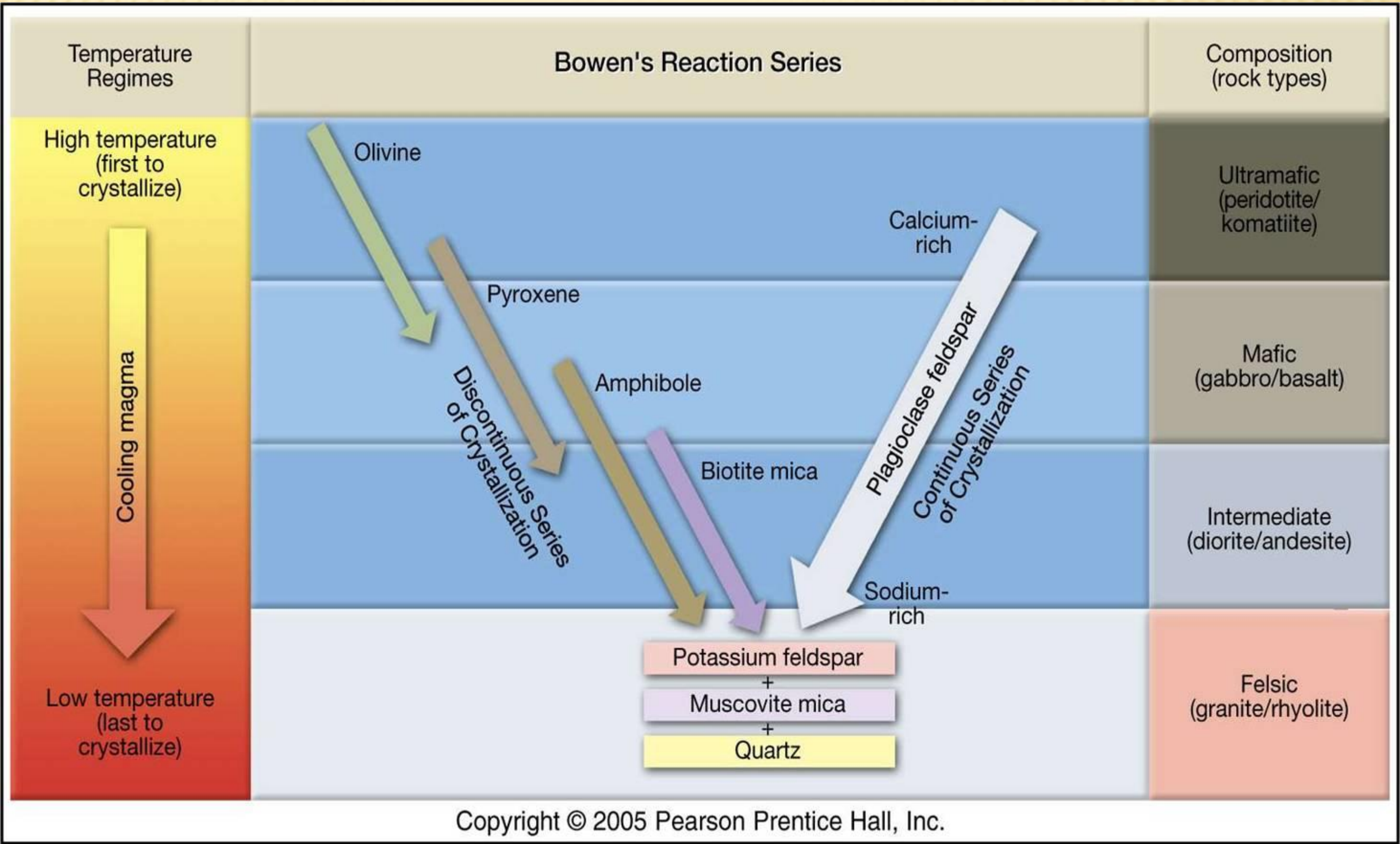
- A large variety of Igneous rocks are found on the earth but a single magma can lead to the formation of different types of igneous rocks.
- This idea was first investigated by geologist Norman L. Bowen (1887–1956).
- The order of crystallization of the different minerals from the magma came to be known as the Bowen Reaction series which allows geologists to predict chemical composition and texture based upon the temperature of a cooling magma.



EVOLUTION OF MAGMA

- Bowen's reaction series is usually diagramed as a "Y" with horizontal lines drawn across the "Y
- The horizontal temperature lines divide the "Y" into four compositional sections.
- Mineral formation is not possible above 1800°C.
- Between 1100°C and 1800°C, rocks are ultramafic in composition.
- Between 900°C and 1100°C, rocks are mafic in composition.
- Between 600°C and 900°C, rocks are intermediate in composition. Below 600°C, felsic rocks form.
- The upper arms of the "Y" represent two different series. By convention, the left upper arm represents the discontinuous series. The upper right arm represents the continuous series.
- The continuous series describes the evolution of the plagioclase feldspars as they evolve from being calcium-rich to more sodium-rich.
- The discontinuous series describes the formation of the mafic minerals olivine, pyroxene, amphibole, and biotite mica. These minerals are associated with the mafic and intermediate types of rocks.
- At lower temperatures, the branches merge and we obtain the minerals common to the felsic rocks - orthoclase feldspar, muscovite mica, and quartz.

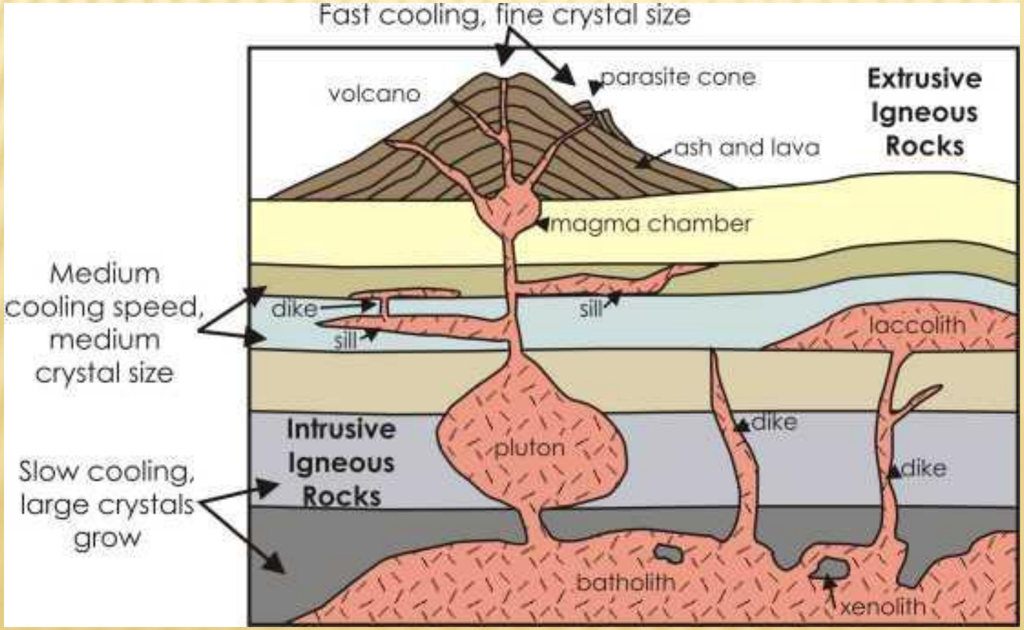
BOWEN REACTION SERIES

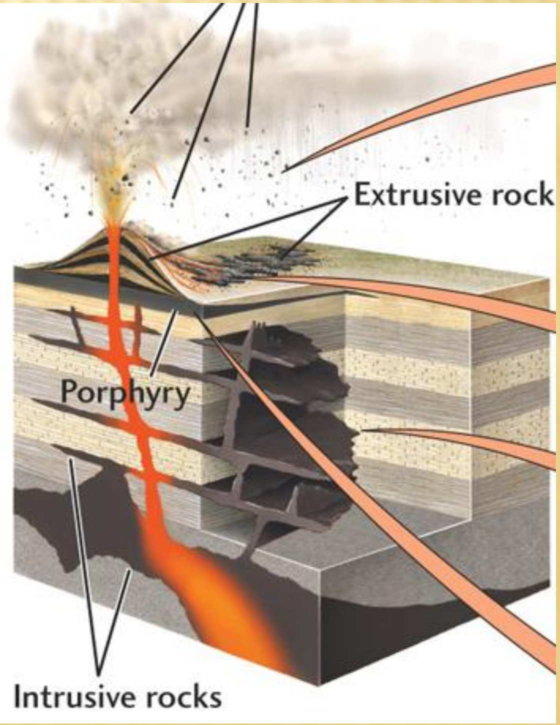


EXTRUSIVE AND INTRUSIVE IGNEOUS ROCKS

- Igneous rocks which are formed when the molten magma solidifies at the earth's surface are known as **Extrusive Igneous Rocks** or **Volcanic Rocks**.

- Sometimes the magma loses its mobility before reaching the surface and crystallizes at depths. Igneous rocks which are formed by the crystallization of the molten magma beneath the earth's surface or at depths are known as **Intrusive Igneous Rocks** or **Plutonic Rocks**.





TEXTURE OF IGNEOUS ROCKS

- The texture of a rock refers to the size, shape, and arrangement of its mineral grains, or crystals.

- Some igneous rocks consist of mineral grains that are too small to be seen with the naked eye; others are made up of thumb-size or even larger crystals.

- Volcanic /extrusive igneous rocks are usually fine grained, whereas plutonic/intrusive igneous rocks are medium or coarse grained.

FACTORS AFFECTING CRYSTAL SIZE

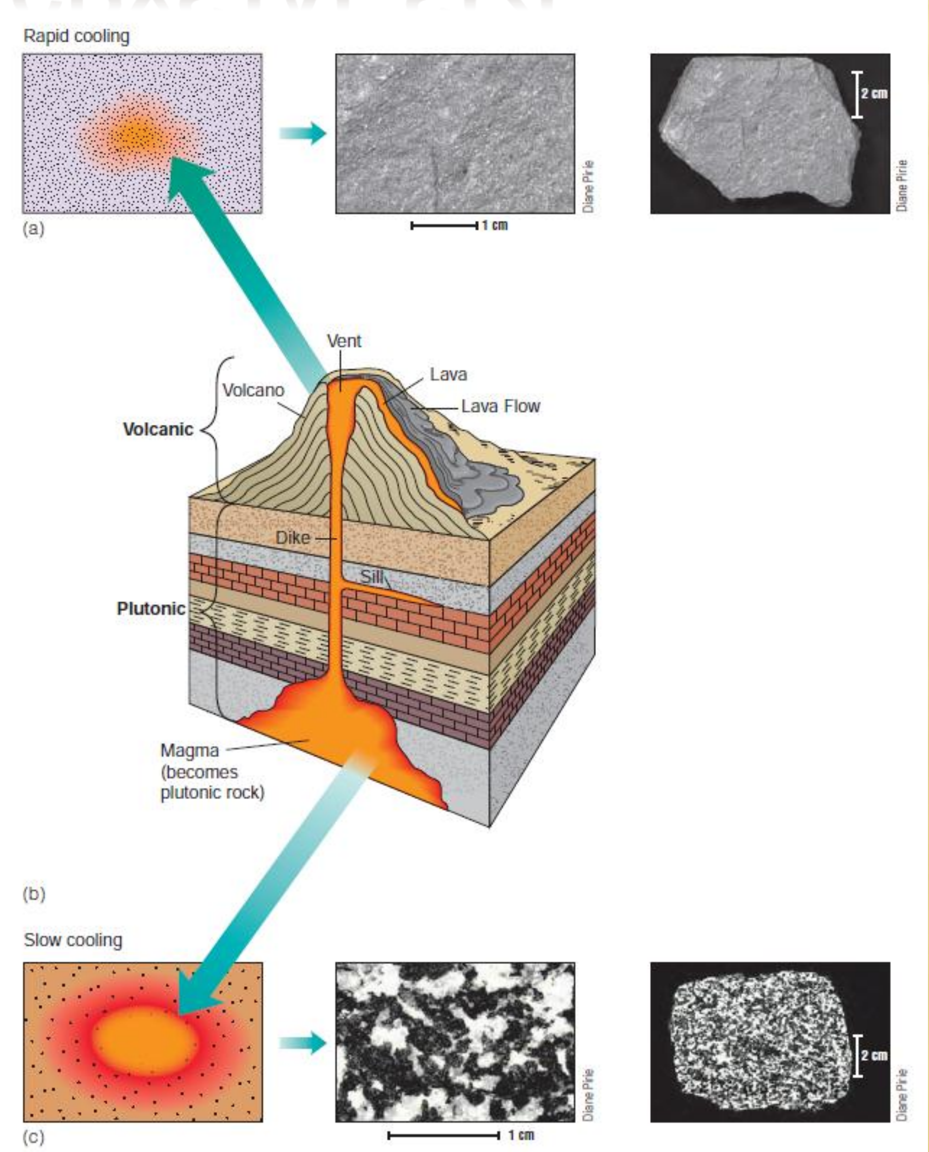
- A magma at depths, slowly loses its heat to the surrounding. The cooling of the magma may take tens or even thousands of years as fewer but large crystals are formed.

- On the other hand if the magma cools rapidly for example on the earth's surface, the crystals do not get time to increase in size and the result is a rock with small intergrown crystals.

- Sometimes the magma cools so rapidly that the ions do not get time to arrange themselves and the magma solidifies to form glass. There is no internal arrangement of ions in Glass.

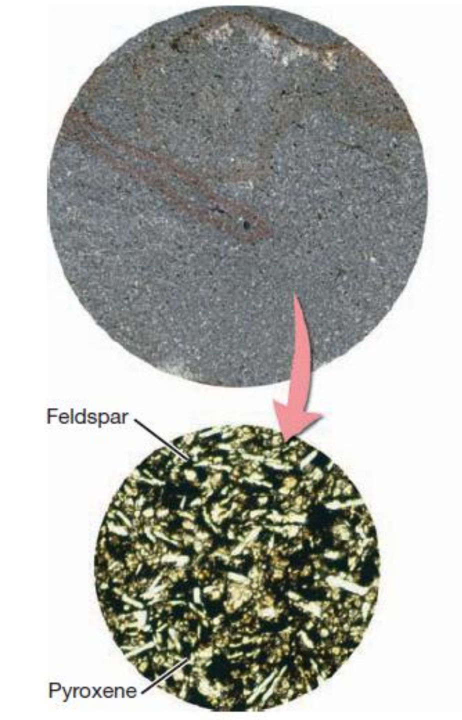
FACTORS AFFECTING CRYSTAL SIZE

- Three factors influence the textures of igneous rocks:
- (1) the rate at which molten rock cools;
- (2) the amount of silica present and
- (3) the amount of dissolved gases in the magma.
- Among these, the **rate of cooling** tends to be the dominant factor.



APHANITIC TEXTURE

- When the magma reaches the earth's surface, it undergoes rapid cooling as a result the crystals do not get a chance to grow in size.
- The resulting igneous rocks have a fine grained texture which is known as Aphanitic texture.
- The mineral grains in rocks having Aphanitic texture are so small that they can be seen only with the aid of a microscope

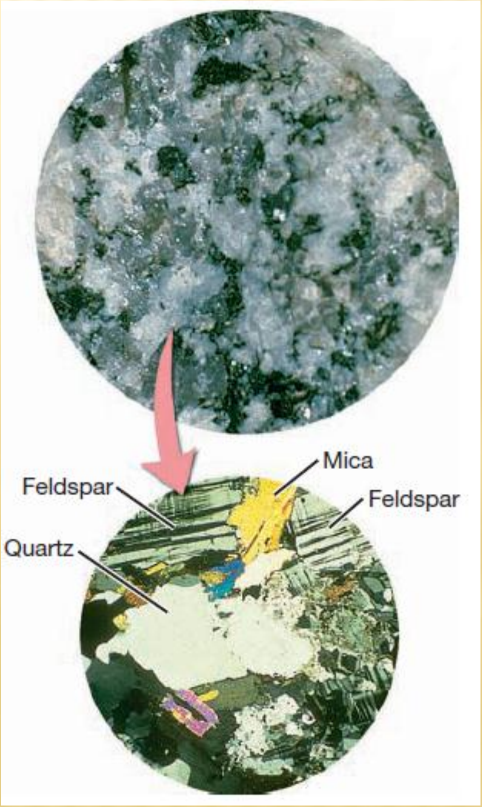


PHANERITIC TEXTURE

- Phaneritic textured rocks are comprised of large crystals that are clearly visible to the eye with or without a hand lens or binocular microscope.

- The entire rock is made up of large crystals, which are generally 1/2 mm to several centimeters in size; no fine matrix material is present.

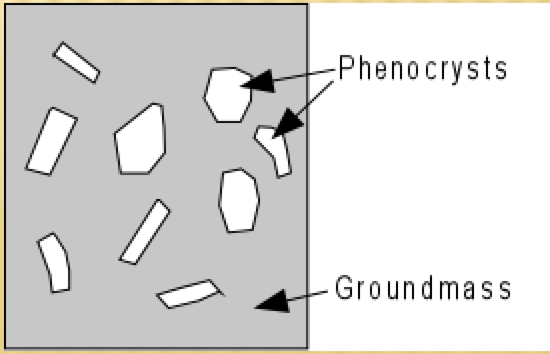
- This texture forms by slow cooling of magma deep underground in the plutonic environment.



PORPHYRITIC TEXTURE

- If magma rises slowly through the crust before erupting, some crystals may grow while most of the magma remains molten.

- If this mixture of magma and crystals then erupts onto the surface, it solidifies quickly, forming porphyry, a rock with the large crystals, called **phenocrysts**, embedded in a **fine-grained matrix/ground mass**. Such a texture is known as **porphyritic texture**

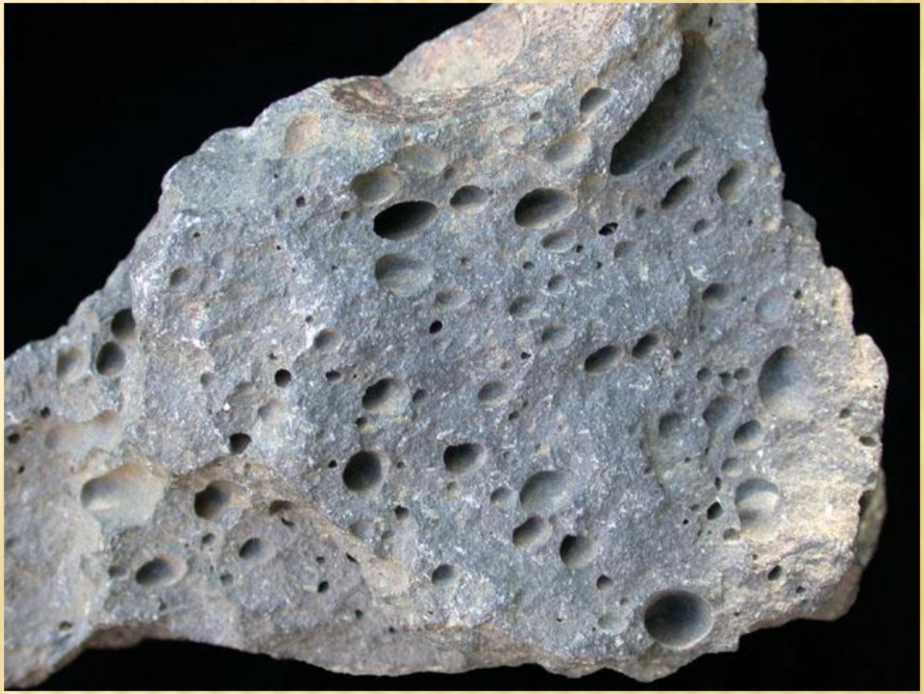


GLASSY TEXTURE

- Glassy textured igneous rocks are non-crystalline meaning the rock contains no mineral grains.
- Glass results from cooling that is so fast that minerals do not have a chance to crystallize.
- This may happen when magma or lava comes into quick contact with much cooler materials near the Earth's surface.
- Pure volcanic glass is known as obsidian.

VESICULAR TEXTURE

- Vesicular texture refers to vesicles (holes, pores, or cavities) within the igneous rock.
- Vesicles are the result of gas expansion (bubbles), which often occurs during volcanic eruptions.
- Pumice and scoria are common types of vesicular rocks.
- The image to the right shows a basalt with vesicles, hence the name "vesicular basalt".



PYROCLASTIC TEXTURE

- Some igneous rocks are formed from the consolidation of individual rock fragments that are ejected during a volcanic eruption.

- These particles may consist of fine ash, large angular blocks or molten blobs.

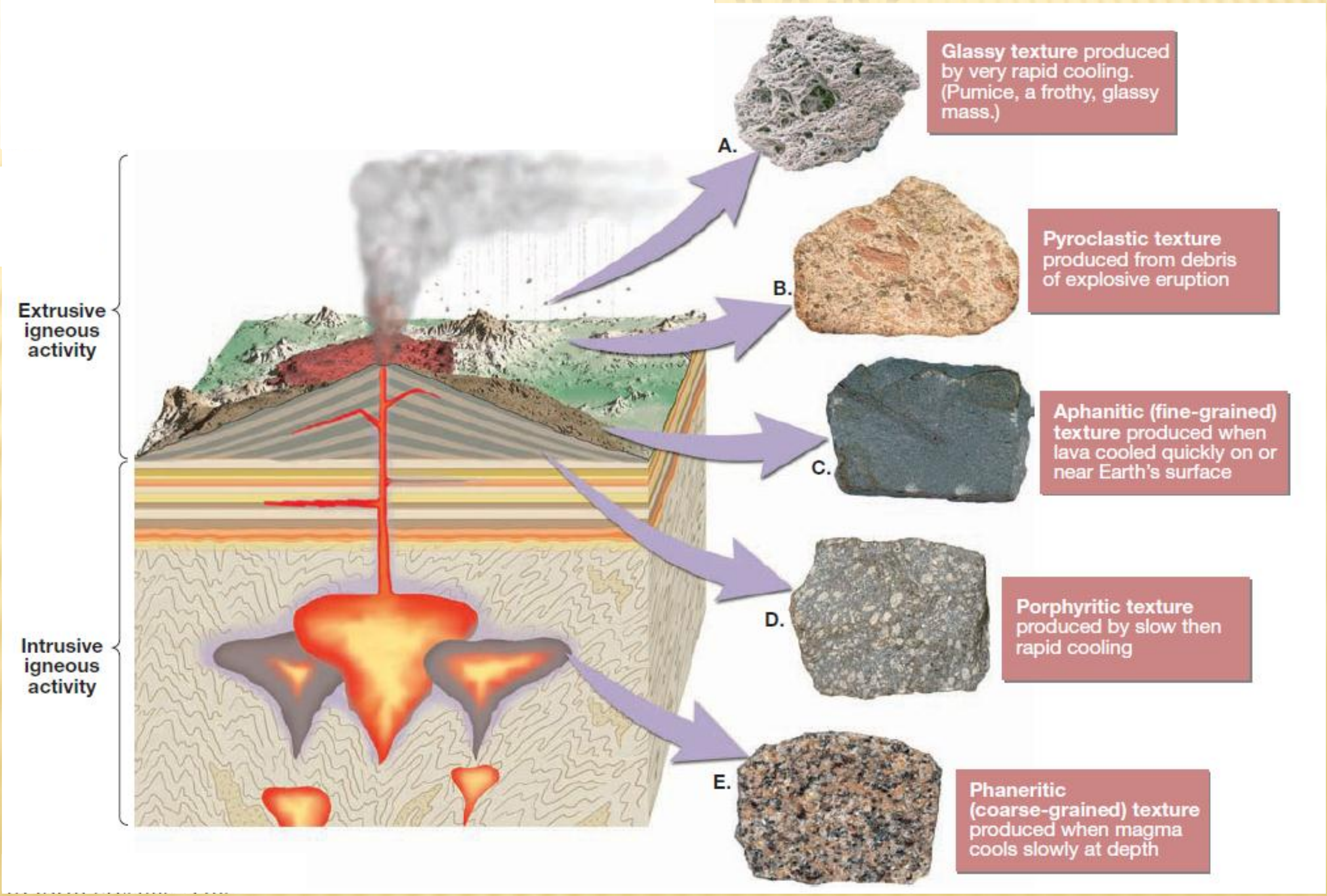
- The rocks composed of these rock fragments are said to have a pyroclastic texture.

PEGMATITIC TEXTURE

- Under special conditions certain course grained igneous rocks called pegmatites are formed.

- These rocks which are composed up of interlocking crystals which are generally more than a centimeter in diameter are said to have a pegmatitic texture.

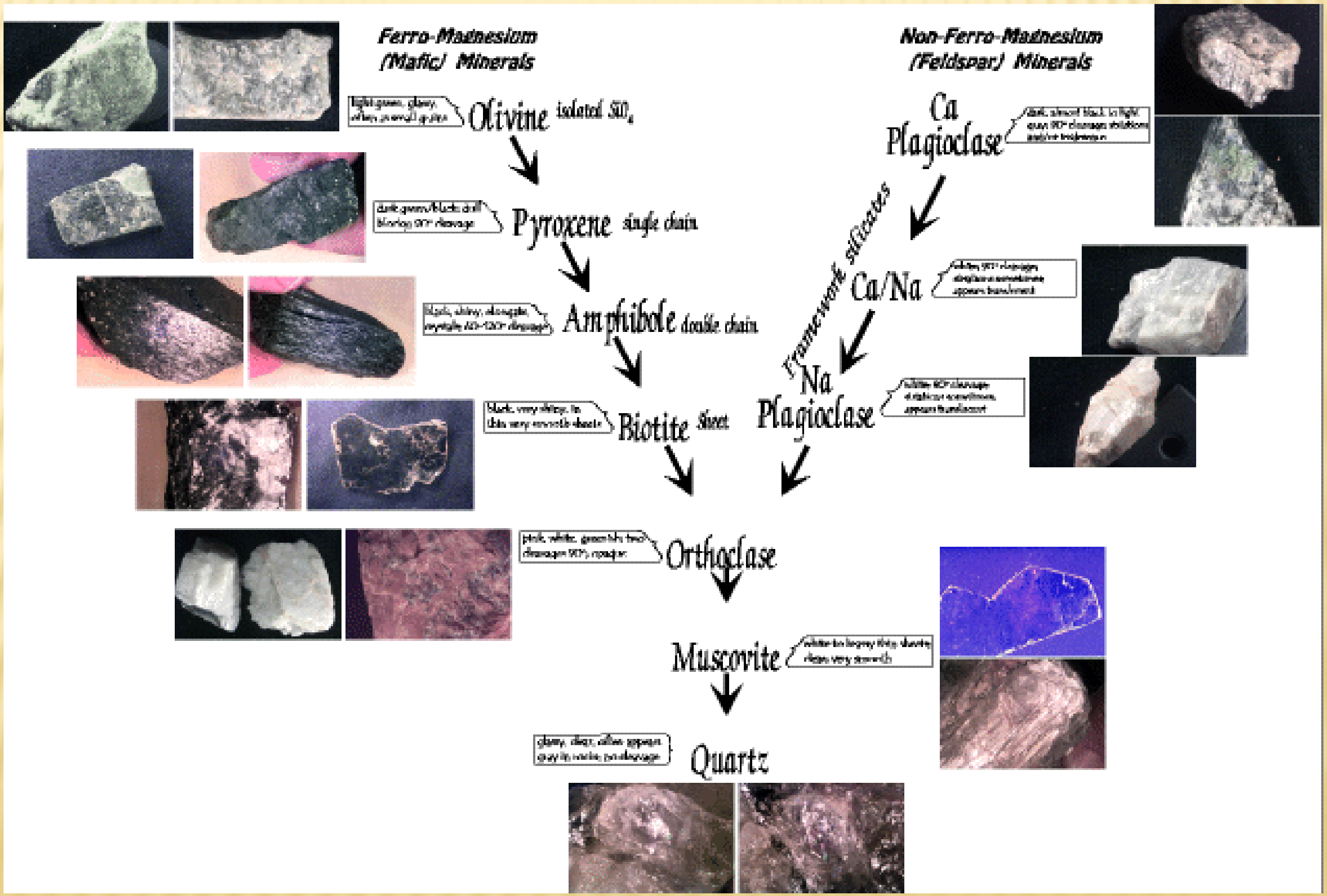
TEXTURE OF IGNEOUS ROCKS



IGNEOUS ROCKS COMPOSITION

- Igneous rocks are composed up of silicate minerals. Chemical analysis shows that Silica (Si) and Oxygen (O) is the most abundant constituent of igneous rocks.
- As the magma cools it solidifies to form the two major group of silicate minerals.
- The dark or (ferromagnesian) silicates are rich in iron, magnesium and are low in silica.
- Olivine, pyroxene, amphibole and biotite mica is common dark silicate minerals found on the earth.
- The light (nonferromagnesian) silicates contain greater amounts of potassium, sodium and calcium.
- These minerals are also rich in silica content. The light silicate minerals include feldspars, muscovite mica and quartz.

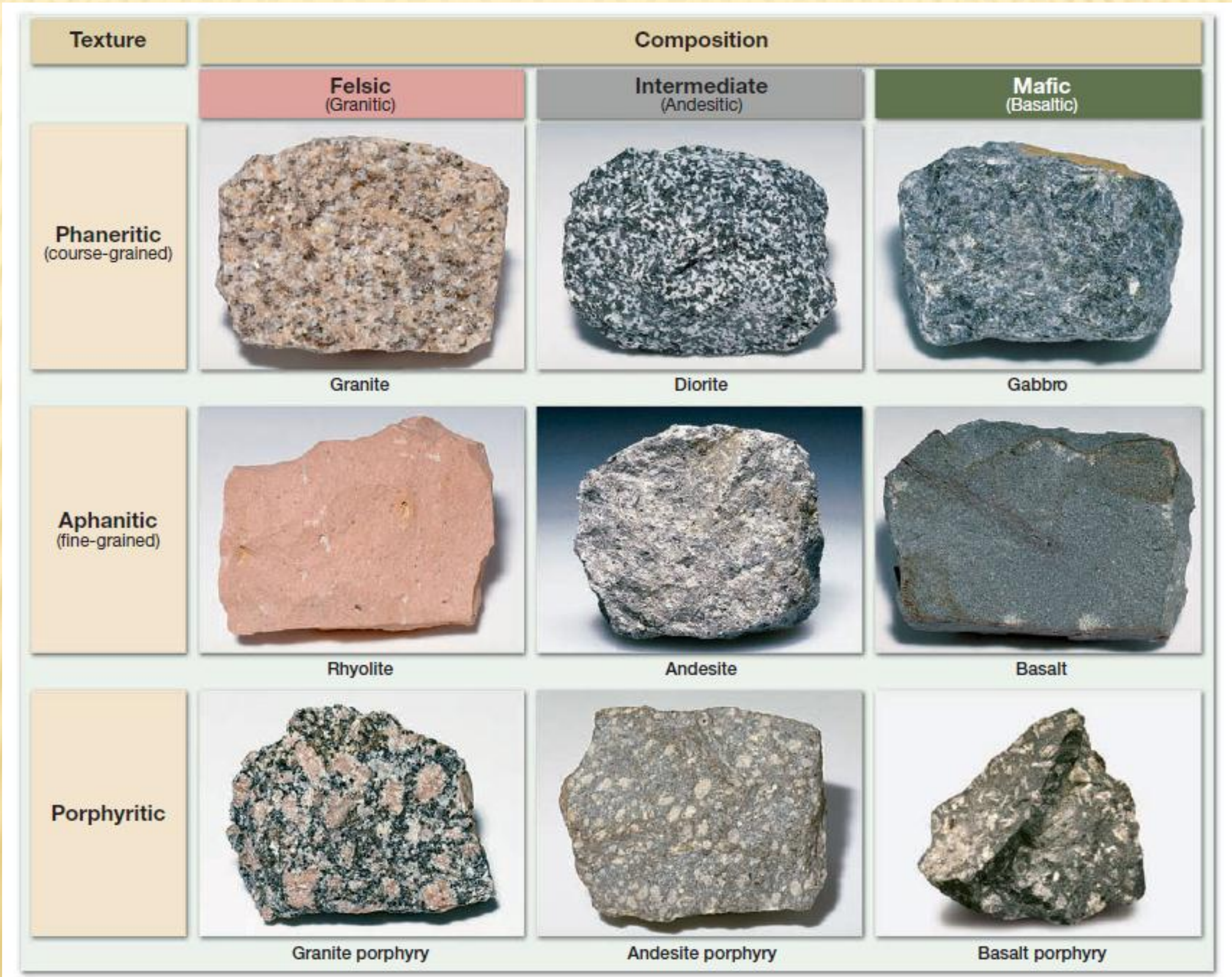
FERROMAGNESIAN AND NON-FERROMAGNESIAN MINERALS



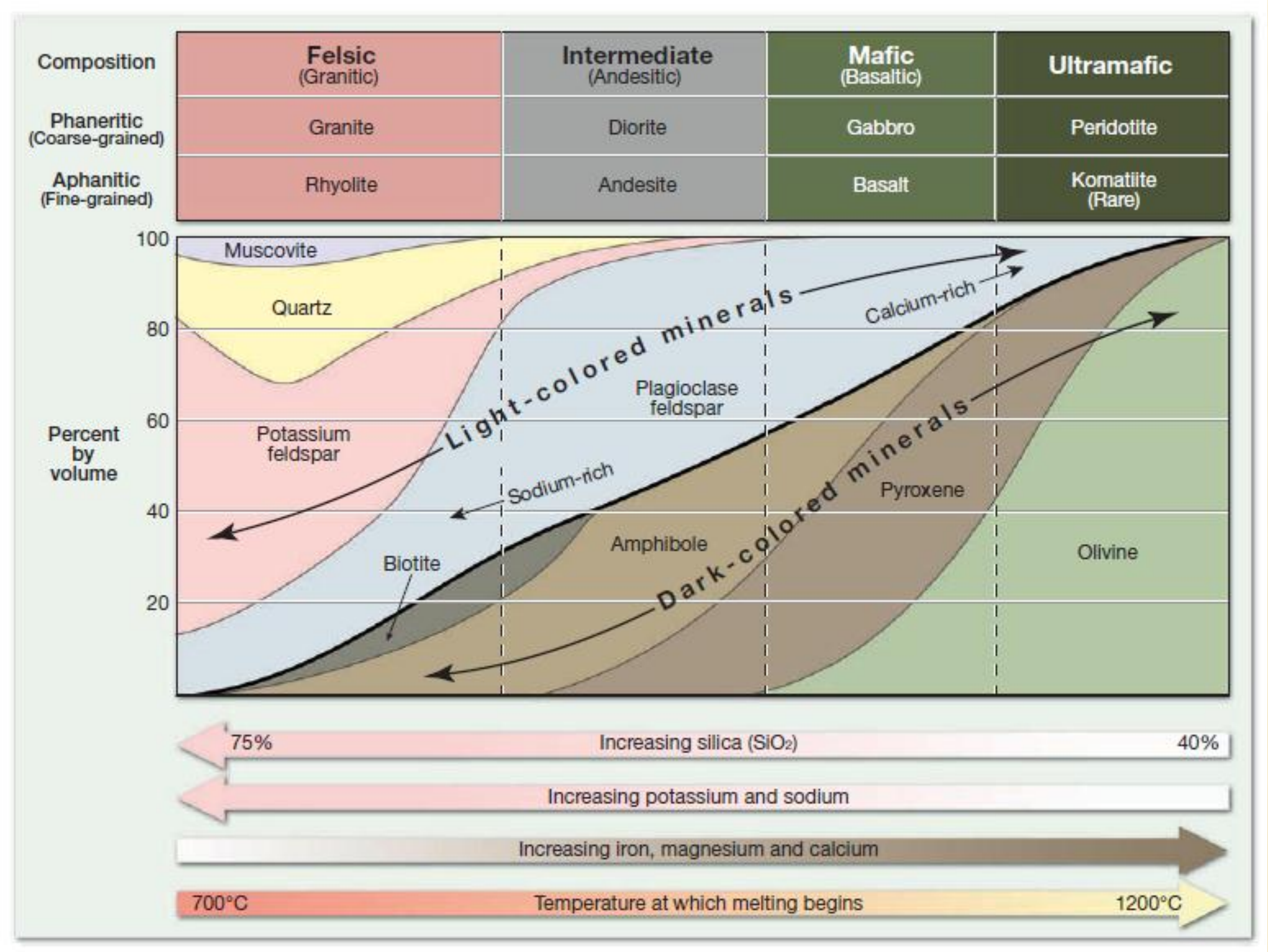
NAMING IGNEOUS ROCKS

- Geologists use both the minerals and texture to classify and name igneous rocks.
- The various igneous textures result mainly from the different cooling histories, whereas the mineral composition of an igneous rock is the result of the chemical makeup of the parent magma.
- Two igneous rocks having the same mineral composition but different textures will have a different name.

CLASSIFICATION OF IGNEOUS ROCKS



MINERALOGY OF COMMON IGNEOUS ROCKS



FELSIC (GRANITIC) IGNEOUS ROCKS

- Granite is the best known of all igneous rocks.
- Granite (and metamorphosed granitic rocks) are the most common rocks in continental crust.
- Granite has a phaneritic texture and is composed up of 25 percent Quartz and about 65 percent feldspar mostly the potassium and sodium rich varieties.
- The remaining 10 percent is made up of muscovite, biotite and some amphibole.

FELSIC (GRANITIC) IGNEOUS ROCKS

- Rhyolite is the extrusive equivalent of granite and like granite is composed essentially of light colored silicate minerals.

- Rhyolite has an aphanitic texture and frequently contains glass fragments and voids indicating rapid cooling in the surface environment.

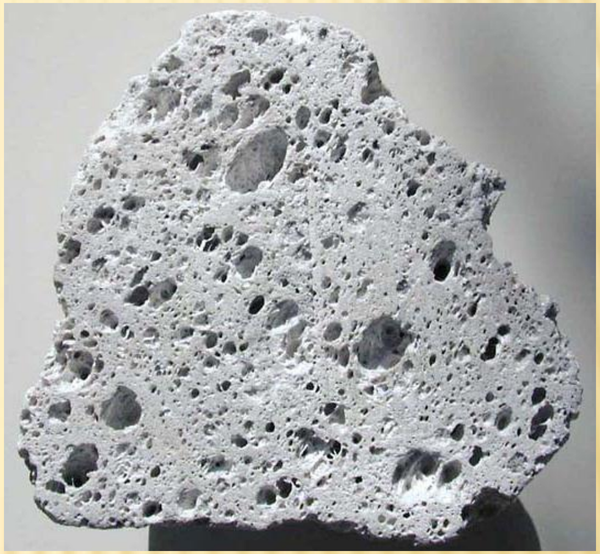
FELSIC (GRANITIC) IGNEOUS ROCKS

- Obsidian is a dark colored glass rock that usually forms when silica rich lava is quenched quickly.
- This means that there is no crystals formation in obsidian and it consists of unordered ions.
- Though obsidian appears dark in color but its chemical composition is similar to that of granites.

FELSIC (GRANITIC) IGNEOUS ROCKS

- Pumice is a volcanic igneous rock that like obsidian has a glassy texture but is formed when large amounts of gas escape through lava.

- Because of the large percentage of voids, many samples of pumice will float when placed in water.

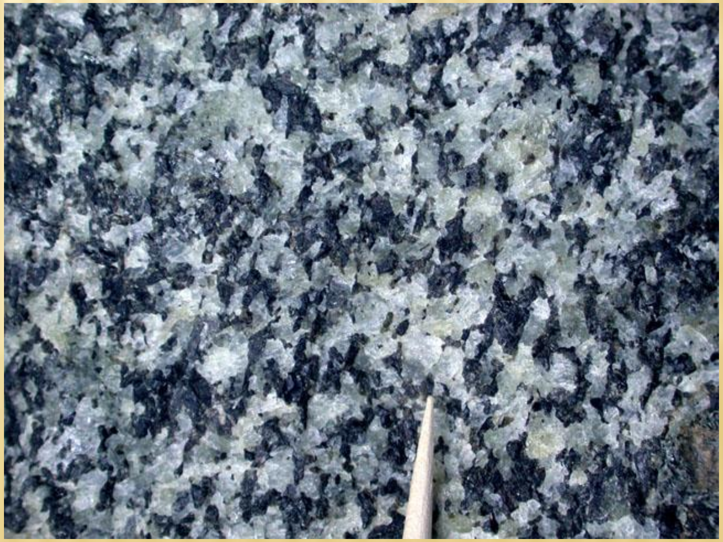


INTERMEDIATE (ANDESITIC) IGNEOUS ROCKS

- Andesite is a volcanic rock intermediate in composition between basalt and granite.
- It is commonly gray or green and consists of plagioclase and dark minerals (usually biotite, amphibole, or pyroxene).
- Andesite is a volcanic rock and is typically very fine grained.
- Andesite and Rhyolite sometimes appear similar but microscopic examination shows that Rhyolite is composed up of about 25 percent quartz whereas Andesite contains only minor amount of Quartz.

INTERMEDIATE (ANDESITIC) IGNEOUS ROCKS

- Diorite is the plutonic equivalent of andesite.
- It is a coarse grained intrusive igneous rock that forms from the same magma as andesite.
- It can be distinguished from granite by the absence of visible Quartz crystals and because it contains a higher percentage of dark silicate minerals.
- The mineral makeup of diorite is primarily sodium rich plagioclase feldspar and amphibole, with lesser amounts of biotite.



MAFIC (BASALTIC) IGNEOUS ROCKS

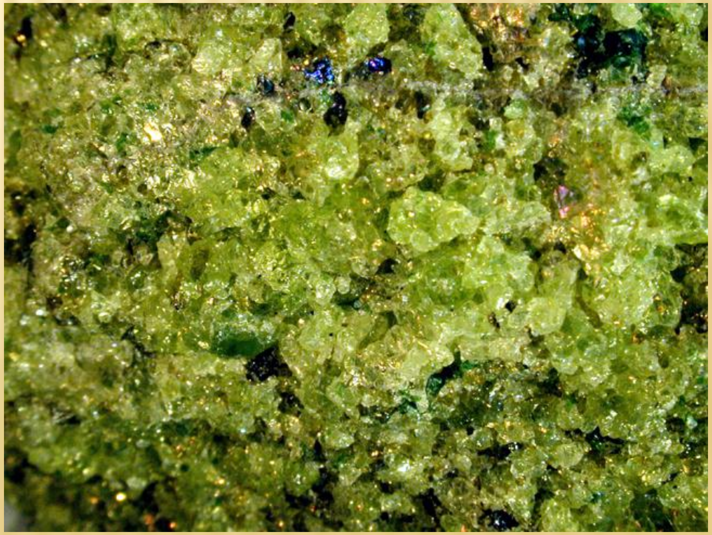
- Basalt is a very dark green to black fine-grained volcanic rock.
- It is composed primarily of pyroxene and calcium-rich plagioclase feldspar, with lesser amounts of olivine and amphibole present.
- Basalt is the most common extrusive igneous rock.

MAFIC (BASALTIC) IGNEOUS ROCKS

- Gabbro is the intrusive equivalent of basalt.
- Like basalt, it is very dark green to black in color and composed primarily of pyroxenes and calcium rich plagioclase feldspars.
- Gabbro is uncommon at the Earth's surface, although it is abundant in deeper parts of oceanic crust, where basaltic magma crystallizes slowly.

ULTRAMAFIC IGNEOUS ROCKS

- Peridotite is an ultramafic igneous rock that makes up most of the upper mantle but is rare in the Earth's crust.

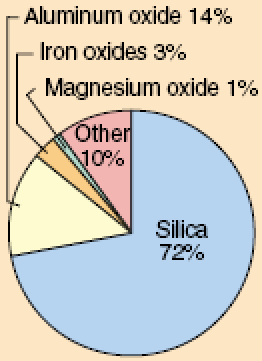
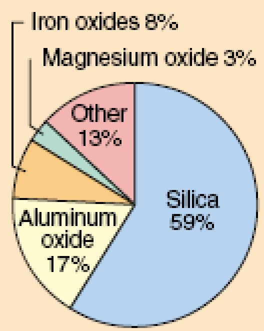
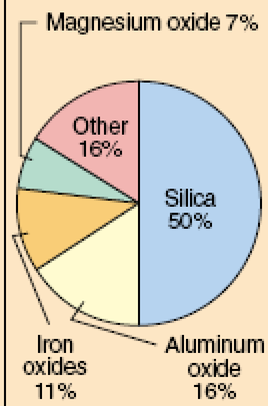
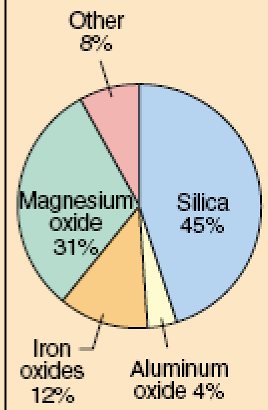


- It is coarse grained and composed of olivine, and it usually contains pyroxene, amphibole, or mica but no feldspar.

NAMING IGNEOUS ROCKS

Chemical Composition		Felsic (Granitic)	Intermediate (Andesitic)	Mafic (Basaltic)	Ultramafic
Dominant Minerals		Quartz Potassium feldspar Sodium-rich plagioclase feldspar	Amphibole Sodium- and calcium-rich plagioclase feldspar	Pyroxene Calcium-rich plagioclase feldspar	Olivine Pyroxene
Accessory Minerals		Amphibole Muscovite Biotite	Pyroxene Biotite	Amphibole Olivine	Calcium-rich plagioclase feldspar
TEXTURE: Phaneritic (coarse-grained)		Granite	Diorite	Gabbro	Peridotite
TEXTURE: Aphanitic (fine-grained)		Rhyolite	Andesite	Basalt	Komatiite (rare)
TEXTURE: Porphyritic		"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts			Uncommon
TEXTURE: Glassy		**Obsidian** (compact glass) **Pumice** (frothy glass)			
TEXTURE: Pyroclastic (fragmental)		**Tuff** (fragments less than 2 mm) **Volcanic Breccia** (fragments greater than 2 mm)			
Rock Color (based on % of dark minerals)		0% to 25%	25% to 45%	45% to 85%	85% to 100%

IGNEOUS ROCK CLASSIFICATION

Descriptive Terms	Felsic (granitic)	Intermediate (andesitic)	Mafic (basaltic)	Ultramafic
Intrusive Extrusive	Granite Rhyolite	Diorite Andesite	Gabbro Basalt	Peridotite
Composition				
Major minerals	Quartz Potassium feldspar Sodium feldspar (plagioclase)	Amphibole Intermediate plagioclase feldspar	Calcium feldspar (plagioclase) Pyroxene	Olivine Pyroxene
Minor minerals	Muscovite Biotite Amphibole	Pyroxene	Olivine Amphibole	Calcium feldspar (plagioclase)
Most common color	Light colored	Medium gray or medium green	Dark gray to black	Very dark green to black