جامعة جنوب الوادى

قسم الجيولوجيا

محاضرات في
الصخور النارية
Igneous Rocks

إعداد

د. طه محمد عمرون

مدرس بقسم الجيولوجيا

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Introduction

Rock is naturally occurring and coherent aggregate of one or more minerals. Such rocks constitute the basic unit of the solid Earth and typically form recognizable and map able volumes.

Rocks are commonly divided into three major classes according to the processes that resulted in their formation; these three classes are subdivided into numerous groups and types on the basis of various factors, the most important of which are chemical, mineralogical and textural attributes. The three types of rocks are **igneous, metamorphic and sedimentary** rocks.

Igneous comes from word "**ignis**" meaning fire. Igneous rocks are formed from solidification and cooling of magma. This **magma** can be derived from partial melts of pre-existing rocks in either a mantle or crust. Typically, the melting of rocks is caused by one or more processes.

The distribution of igneous rocks is controlled by plate tectonics. One of the important aspects of the plate tectonics is that it accounts for reasonably well for the variety of igneous rocks and their distribution (Carlson et al, 2008). Divergent plates are usually associated with creation of basalts and gabbros especially in the oceanic crust e.g. in the mid-Atlantic ridges. While in the intra-continental areas have wide range of rocks from basic, intermediate to the acidic rocks. In the convergent plates usually granites and andesites magmas are produced.

Igneous rocks can be thought of as "**primary**" rocks because they crystallize from magma. Sedimentary rocks may be thought of as secondary rocks.

Igneous rocks are rocks formed from the crystallization of a liquid (molten rock - magma).

Igneous rocks may be divided into two main categories. **Intrusive** or **plutonic rocks** crystallize from **magma** beneath the earth's surface. **Extrusive** or **volcanic rocks** crystallize from **lava** at the earth's surface.

The texture of an igneous rock depends on many factors. On the rate of cooling of the melt: slow cooling allows large crystals to form, but fast cooling yields small crystals. Plutonic rock bodies cool and crystallize slowly and are characterized by **coarse-grained** texture, in which the mineral crystals are visible to the unaided eye. On the other hand, lavas cool quickly at the earth's surface and are characterized by **fine-grained** texture, in which the crystals are too small to be seen by the unaided eye.

Very quickly cooled lavas, typically those in water, will have a **glassy** texture. They cool too quickly to form crystals. Glasses do not have an orderly arrangement of atoms and there are therefore no crystals, glass is called **obsidian**.

In addition to texture, igneous rocks may are classified according to many factors, **e.g**. <u>mode of occurrence</u>, <u>texture</u>, <u>mineralogy</u>, <u>chemical composition</u>, and <u>the geometry of the igneous</u> body…**etc**.

At the end of this part, you should be able to:

1) Define what are the most important characteristics of igneous rocks?
2) Define what is magma (Characteristics, Types, Sources, and Evolution of magma)?
3) Discuss the classification of igneous rocks.
4) Recognize of common igneous rock families (Granitic rocks, Gabbros and related rocks, Diorite ad related rocks, Syenite rocks, Ultramafic rocks)

Characteristics of igneous rocks

What are the most important characteristics of igneous rocks?

<u>The main characteristics of igneous rocks:-</u>

1) Igneous rocks do not have porosity (non-porous) like sedimentary rocks.
2) Igneous rocks are crystalline rocks and have crystals instead of grains (sedimentary rocks).

3) Igneous rocks are roughly hard rocks
4) Igneous rocks contain textures that are indicative of igneous processes
5) Igneous rocks do not have strata like sedimentary rocks
6) Igneous rocks are found in massive forms such as batholiths, laccoliths, dykes……. etc.
7) Water does not penetrate the igneous rocks easily and hence igneous rocks are less affected by chemical weathering
8) Igneous rocks do not contain fossils
9) Igneous rocks are mostly associated with the volcanic activities and thus they are generally found in the volcanic zones

Magma (Characteristics, Types, Sources, and Evolution)

Magma is the parent material of igneous rocks. Magma has been defined as molten rock material. Magmas are formed by partial melting of silicate rocks either in Earth's mantle or the continental crust. Primary magmas from Earth's mantle are basaltic in composition.

Turner and Verhoogen (1960) proposed the **term magma** is used to include all naturally occurring mobile rock material that consists in noteworthy part of liquid phase having the composition of silicate melt.

The contents of silica and volatile compounds will determine the physical properties of the magmas, such as density and viscosity, these factors play a key role in the processes of segregation and ascent of magmas.

Cooling and crystallization will change chemical composition of magma and in turn their physical properties.

The formation of magmas of different compositions can be explained by fractional crystallization of basaltic magma and the separation of residual magmas of different types, by assimilation of material of different compositions, and by the escape of volatile substances, all of which either singly or together are sufficient to produce significant changes in composition

Some useful definitions of magmas

Primary magma: Is the "first melt" produced by melting rock materials, and which has not yet undergone any **differentiation** and represent the starting composition of magma. A primary magma may therefore evolve into a parental magma by differentiation.

Igneous province: Is a field area where igneous activity has occurred over a distinct time period.

Primitive magma: Primary melts derived from the mantle are known as primitive melts or primitive magmas. Primitive magma that underwent minimal differentiation

Parental magma: least differentiated magma in a series leading to evolved rocks. It is magma capable of producing all rocks belonging to an igneous rock series by differentiation.

Igneous rock series: Is a group of igneous rocks that are genetically related (co-magmatic) and were collected from a relatively small area. Rocks of an igneous rock series display a continuous gradation in chemical composition from the most basic to the most acidic in the group.

Sources of magma the source of magma

- The magma **does not occur** everywhere below us.
- There are only some specific places where volcanoes exist.
- **This means** that Magma is formed under some **special conditions**, which exist in some limited area
- **Siliceous magmas** (andesitic – rhyolitic) could come from melting of the continental crust.
- **Basaltic magmas** must come from the mantle

How Magma is formed?

In general**, melting of a mantle source** (peridotite) results in **mafic/basaltic** magmas,

Melting of crustal sources yields more **siliceous** magmas.

In general more siliceous magmas form by low degrees of partial melting.

The initial **composition of the magma depends** upon the **composition of the source rock** and the degree of partial melting

The factors affecting the degree of partial melting

The mainly factors affecting the degree of partial melting are:-

1. Temperature
2. Pressure
3. Addition of water

Chemical composition of magmas

This part involves the dealing with the following topics:-

A. **The major element composition of magmas**
B. **Volatiles in magmas**
C. **Main chemical groups (types) of magmas**

A-The major element composition of magmas

It is clear from discussion that magmas are generated by partial melting in the upper mantle or lower crust, such a process occurs over a range of depths. Accordingly, not all magmas have the same composition. This is evidenced by the variety of igneous rocks that occur at the surface of the earth or at depth. Volcanic eruptions also show that lavas have different viscosities, which in turn are due to their different chemical compositions and/or temperatures.

The composition of primary magma from which all igneous, indicate the following elements predominate: **O, Si,**

Al, Fe, Mg, Ca, Na, and **K,** and magmas are multicomponent systems of these and other elements. The different **components do not vary randomly** but are interdependent.

The relations of the commonest rock-forming oxides were worked out by **Richardson (1922)**, the dominant oxide is **silica**; most igneous rocks contain between 30 and 80% SiO_2. **Alumina** varies commonly between 10 and 20%, low Al_2O_3 is characteristic of rocks with little feldspar or feldspathoid, but high Al_2O_3 is characteristic anorthosites rocks. **Soda** shows a very symmetrical variation, the common range being from 2 to 5%. Most rocks have less than 6% **K_2O**, and only rarely does it exceed 10%. The sum of **iron oxides** in igneous rocks vary symmetrical, but seldom exceeds 15% in magmatic iron ore. **Magnesia** percentage is very asymmetrical; most rocks have low MgO content, and only ultrabasic types rich in pyroxene and/or olivine have more than 20% MgO. The **CaO** have less than 10% CaO, in some pyroxenites CaO exceeds 20%. Three minor constituents like **TiO_2**, **P_2O_5** and **MnO** are present in most igneous rocks. Water content may be more than 6% in few volcanic rocks, but generally igneous rocks containing more or less than 2% H_2O.

The general chemical observations of magmas

1) Magmas range from about 30% to 80% SiO_2.

2) Fe, Mg and Al vary along with SiO_2.
3) Magmas with about 50% SiO_2, high amounts of Fe and Mg, and low Al are referred to as **mafic** in composition.
4) Magmas with about 70% or more SiO_2, low amounts of Fe and Mg, and high Al are referred to as **felsic** in composition.
5) Magmas with about 60% SiO_2 are referred to as **intermediate** in composition
6) Volatile content **varies with composition**, felsic magmas hold more volatiles than mafic magmas
7) Mafic magmas are generally hotter than felsic magmas
8) Felsic magmas are much more viscous than mafic magmas

B: Volatiles in magmas

Volatiles in magmas are either dissolved (at high pressures) or exsolved (closer to the surface). All studies show that magmas have ~ 1% by weight volatiles, and that H_2O is the most common volatile constituent of acidic magmas, whereas CO_2 is more common in basaltic ones.

CO_2 and **S** gases are more soluble in basaltic magmas. On the other hand, **F** and **Cl** are more soluble in acidic magmas.

Factors affecting the solubility of gases in magmas

1) **Pressure**: the higher **P**, the larger the wt% of H_2O dissolved in magmas.

2) **Temperature**: the higher **T**, the lower the wt% of H_2O dissolved in magmas.

3) Acidic magmas contain a larger amount of **volatiles**. This is because such magmas have already undergone a significant amount of crystallization of hydrous phases.

4) **Composition of the volatiles**: An increased amount of CO_2 in the volatiles decreases the solubility of H_2O in the magma.

C: Main chemical groups (Types) of magmas

By carefully studying the chemistry of the different types of igneous rocks, and their associations with each other were able to classify **magmas** into **four** main chemical groups:-

1- *Acidic magma*: rich in SiO_2, Na_2O and K_2O. Rocks produced from such magmas have between 66 and 77.5% by weight SiO_2. "*Granite*" is the best example of an acidic rock and acidic magmas are broadly known as "***granitic magma***".

2- *Intermediate magma*: rich in SiO_2, Na_2O, K_2O as well as CaO and Al_2O_3. Rocks produced from such magmas have

SiO_2 values in the range 52 to 66% by weight. Andesite is a good example of a rock formed by the crystallization of intermediate lava.

3- Basic magma*:** rich in CaO, MgO and FeO. Rocks of this magma type have SiO_2 values of 45 - 52% by weight. Basalt is an example of a basic rock and many basic magmas are broadly known as "basaltic magma*** ".

4- Ultrabasic magma: is poor in SiO_2 (**<** 45%) but with large amounts of FeO and MgO. Ultrabasic rocks may have SiO_2 values as low as 45% by weight. Peridotite is a good example of an ultrabasic rock.

Physical Properties of Magmas

The most important physical properties of magmas are:-

1. Temperature
2. Viscosity
3. Density

1-Temperature of magma

Temperature of magma varies from about 750 °C to about 1250 °C, and increases from acid to basic magmas

2- Density of magma

The density of magma is one of the most important factors controlling its physical and chemical behaviour.

Density plays a role in controlling the movement of magmas to shallower levels.

Density contrast between a silicate melt and minerals that may have crystallized from it plays a role in the differentiation of this magma.

Magma densities range between 2.2 and 3.1 $g/cm^{3.}$.

Mafic minerals such as pyroxenes and olivines are usually denser than the magma, and have a tendency to sink to the bottom of the magma chamber, resulting in a change in the chemical composition of the remaining magma.

On the other hand, calcic plagioclases may be denser than some sodic plagioclases and nepheline

The density of magma also depends on the chemical composition. Basic magmas have a higher density, whereas acid magmas have a lower density.

The lower density of acid magmas is because they have a lower concentration of heavy cations such as Fe, Mg , Ti, and Ca than basic magmas. The presence of dissolved volatile components produce a decrease in density, accordingly, degassed magmas have a higher density than gas-rich magmas, at constant major element composition and pressure.

Factors affecting the density of magma

- **Temperature**: the higher the T, the lower the density of magma.
- **Pressure**: the higher the pressure, the higher the density of magma. Accordingly, the density of magma will increase with increasing depth, until this magma is actually denser than the solid rocks (this is because fluids are more compressible than solids). This happens at depths of **~** 400 km. Accordingly, magmas generated from depths **>** 400 km do not raise to the surface
- **Composition**: The density of magma depends largely on its **Fe** content. Accordingly, basic magmas are denser than acidic ones

3-The viscosity of magma

The viscosity of magma depends on their chemical composition. Acid magmas have high viscosity but basic magmas have low viscosity. This difference in viscosity between basic and acidic magmas is attributed to **Volatile content** and the **higher silica** ratio in the acidic magmas. Viscosity decreases with increasing temperature.

Factors affecting the viscosity of magma

1) Temperature: the higher the T, the lower the viscosity of magma.

2) Pressure: has a small effect on viscosity; the higher the pressure, the lower the viscosity of magma.

3) Composition: Acidic magmas are more viscous than basic ones.

4) Amount and nature of volatiles: the higher volatile content, the higher the viscosity of magma.

Magma Properties		
	Acid Magma	**Basic Magma**
Temperature	Low (650-800ºC)	High (1000-1200ºC)
SiO_2 Content	High (≥ 70%)	Low (≤ 50%)
Volatile Content	High (up to 10% H_2O)	Low (less than 2% H_2O)
Viscosity	High	Low

Magmatic evolution

Magmatic evolution displayed in the mineralogy and chemistry of resulting lineages of associated igneous rocks. Magmas are commonly modified. General three processes are thought to be responsible for **evolutionary processes** reflected in common rock associations. **Processes responsible for changing magma composition are:-**

1- **Fractional crystallization**

2- **Magmatic assimilation**

3- **Mixing of magmas (Magma mixing)**

1-Fractional crystallization

Fractional crystallization is the process whereby crystals once produced are isolated from the melt and prevented from equilibrating with the liquid from which they crystallized, resulting in a series of residual liquids of more extreme compositions than would have resulted from equilibrium crystallization.

In reality, the crystals in most crystallizing magmas are neither perfectly in equilibrium with the residual melt or perfectly isolated from reaction with the melt immediately after crystallization.

As magma crystallizes, the magma becomes depleted in the elements that are entering the crystallizing minerals and so the melt changes composition over time. **Bowen's reaction series** is an example of fractional crystallization.

Bowen demonstrated that it was technically possible to produce a sequence of minerals from a ***single magma source*** through cooling and fractionation. This sequence is called ***Bowen's Reaction Series*** and it includes most of the common rock forming minerals. He further found that there are two sequences of minerals; the **discontinuous reaction series** and the **continuous reaction series**, and the reaction principles may be illustrated by the crystallization of a basaltic magma.

According to **Bowen,** the crystallization in a magma is characterized by reaction of two kinds: continuous reaction in a solid solution series, whereby early- formed crystals change in composition by reaction with the melt, e.g. early- formed phase reacts with the melt to give a new phase with a different crystal structure and different composition

The discontinuous reaction series

The discontinuous reaction series constitutes the left-hand side of **Bowen's reaction series**. These are a group of mafic or iron magnesium bearing minerals - olivine, pyroxene, amphibole, and biotite.

These minerals react discontinuously to form the next mineral in the series. What this means?, if there is enough silica in the melt, each mineral will change to the next mineral lower in the series as the temperature drops.

As you go down Bowen's Reaction Series, the minerals increase in the proportions of silica in their composition.

In a basaltic melt, olivine will be the first mafic mineral to form. When the temperature is low enough to form pyroxene, all of the olivine will react with the melt to form pyroxene and pyroxene will crystallize out of the melt. At the crystallization temperature of amphibole, all the pyroxene will react with the melt to form amphibole and amphibole will crystallize. At the crystallization temperature of biotite, all of the amphibole will react to form biotite and biotite will crystallize. Thus all igneous rocks should only have biotite. But we know that it is not true.

If you are crystallizing olivine and there is not enough silica to form pyroxene, then the reaction will not occur and olivine will remain. If you are crystallizing olivine and the temperature drops too fast for the reaction to take place (the magma is belched onto the surface by a volcano) then the reaction will not have time to occur, the rock will solidify quickly and the mineral will remain olivine.

Another noteworthy feature in the discontinuous reaction series is the increasing degree of replacement of Si by Al as the crystallization trend heads downward. In the olivine there is no evidence of any such replacement; in most magmatic pyroxenes the amount of o replacement of Si by Al is generally low, but it is greater in the magmatic amphiboles, and in biotite at least one-fourth of the **Si** is always replaced by **Al**, in contrast the **Si** : **Al** ratio in the continuous reaction series of the plagioclase shows a steady decrease from 1 : 1 in anorthite to 1 : 3 in albite and potash feldspar.

The continuous reaction series

The continuous reaction series constitutes the right-hand side of Bowen's Reaction Series. They are the plagioclases. Plagioclase minerals have the formula (Ca, Na)(Al, Si)$_3$O$_8$.

The highest temperature plagioclase has only calcium (Ca). The lowest temperature plagioclase has only sodium (Na). In between, these ions mix in a continuous series from 100% Ca and 0 % Na at the highest temperature to 50% Ca and 50% Na at the middle temperature to 0 % Ca and 100% Na at the lowest temperature.

In a basaltic melt, the first plagioclase to form might be 100% Ca and 0% Na plagioclase. As the temperature drops the crystal would react with the melt to form 99% Ca and 1% Na plagioclase, and 99% Ca and 1% Na plagioclase would crystallize. Then those would react to form 98% Ca and 2% Na and the same composition would crystallize, etc. All of this is happening continuously provided there is enough time for the reactions to take place and enough sodium, aluminum, and silica in the melt to form each new mineral.

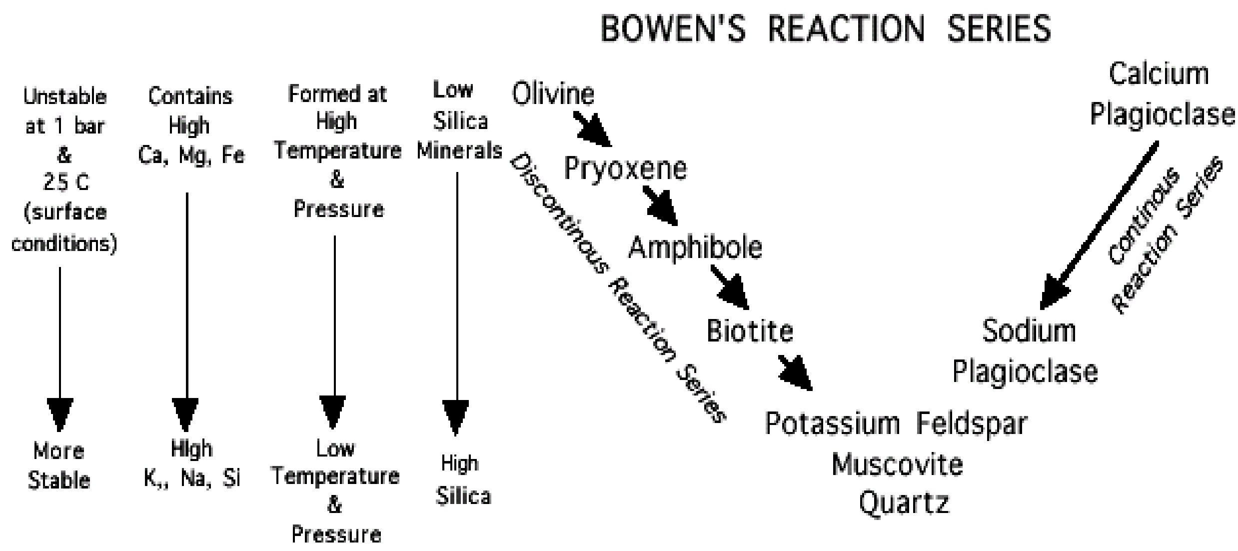


Figure 1: Bowen's Reaction Series

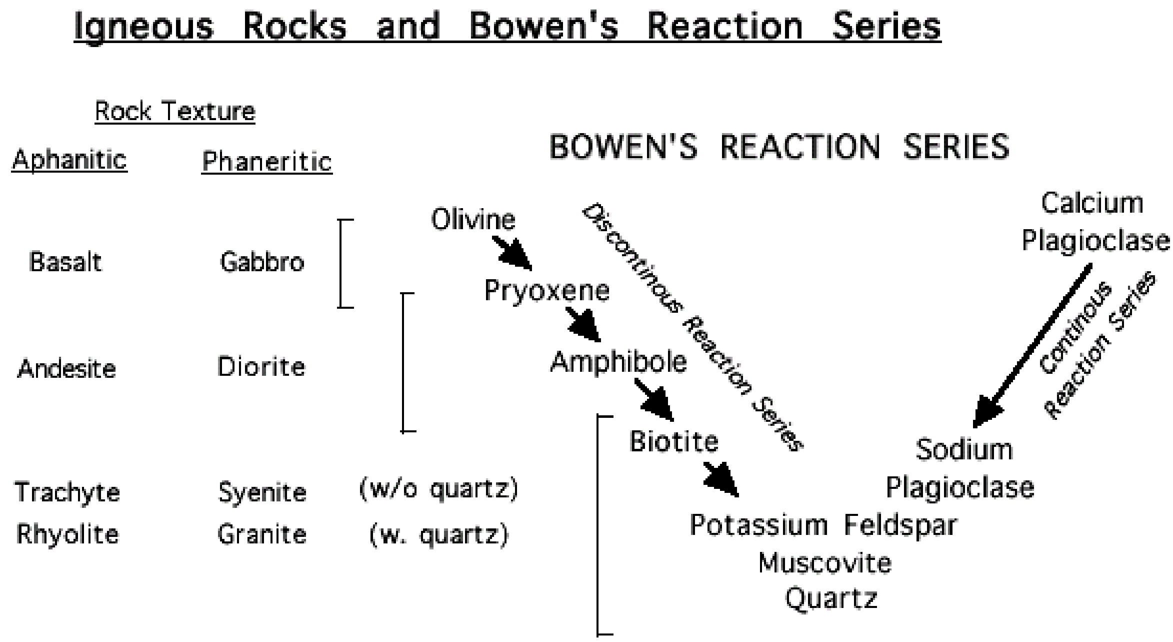


Figure 2: Igneos rocks and Bowen's Reaction Series

On both sides of Bowen's reaction series, the silica content of the minerals increases as the crystallization trend heads downward, for example biotite has more silica than olivine, and sodium plagioclase has more silica than calcium plagioclase

Generally, if basaltic magma cools at very deep, it will cool very slowly giving big crystals. The first minerals to crystallize will be olivine and calcium plagioclase. These will sink to the bottom. By being deposited at the bottom, they will be isolated from the melt and will not be able to react with it. As the temperature drops you will still have a layer of olivine and calcium plagioclase at the bottom of the magma chamber. When the temperature of the melt reaches the right you for pyroxene and Ca-Na plagioclase, those minerals will crystallize and sink to the bottom and be isolated from the melt. Now you have a layer of olivine, a layer of Ca plagioclase, a layer of pyroxene, and a layer of Ca-Na plagioclase.

Notice that, removing most of Fe, Mg, and Ca from the melt, and the magma must be relatively enriched in Na, K, and Si, now magma will start to crystallize a diorite (amphibole and Na-Ca plagioclase). Then magma is becoming granitic and next to crystallize will be biotite and Na plagioclase. Finally the remaining magma is high in Na, K and Si and will crystallize as granite.

By the crystallizing order shown by Bowen's Reaction Series and the effects of gravity, a **granitic magma is made from a basaltic magma**.

2- Magmatic assimilation

When magma rises upward towards surface, it engulfs the fragments of country rock through which it passes. If magma digest these fragments of country rock then this process is termed as "Assimilation". If the magma does not digest these fragments but these fragments entrapped within magma then these are called Xenoliths

Assimilation is that process of magmatic differentiation whereby ascending magmas evolve chemically by dissolved components from the walls of country rock.

Because the composition of the crust is generally different from the composition of magmas which must pass through the crust to reach the surface, so there is always the possibility that reactions between the crust and the magma could take place.

If crustal rocks are picked up, incorporated into the magma and dissolved to become part of the magma, now we say that the crustal rocks have been assimilated by the magma. If the magma absorbs part of the rock through which it passes we say that the magma has become contaminated by the crust. Either of these processes would produce a change in the chemical composition of the magma

In order to assimilate the country rock enough heat must be provided first to the country rock, then it will begin to melt and then further heat must be added to change from the solid state to the liquid state. The only source of this heat, of course, is the magma itself.

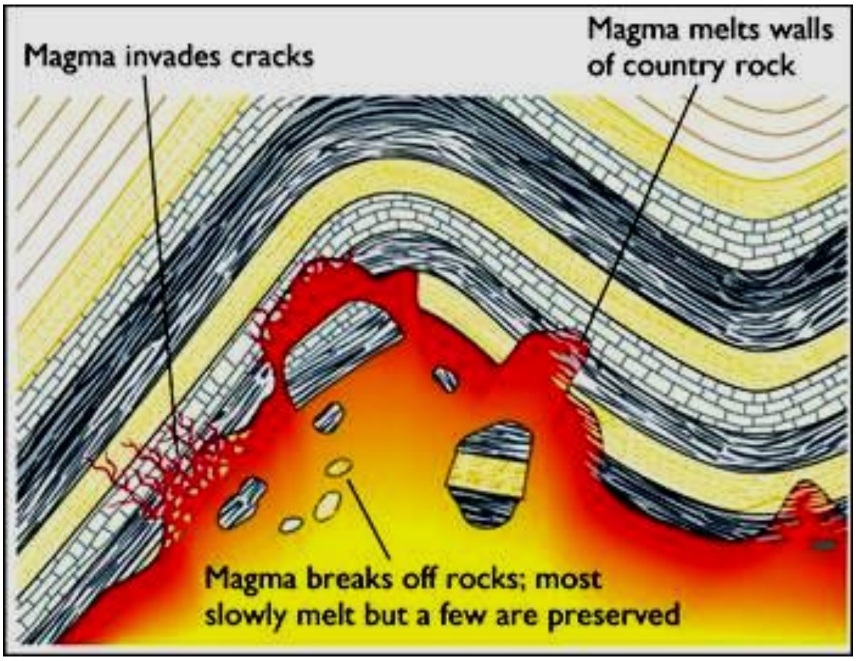


Figure 3: Magmatic assimilation

For example when magma has granitic composition rises upward (when hornblende and oligoclase are crystallizing), and the wall rock is gabbro (composed of augite and labradorite), labradorite and augite are earlier members of the continuous and discontinuous series respectively, so the magma cannot dissolve either the labradorite or the augite.

For a hotter magma from which Mg-olivine is crystallizing and the wall rock include crystals of augite. Under these conditions the augite could become dissolved in this magma.

Generally, the magmatic assimilation depend on the minerals of wall rocks and the minerals which crystallizing from the adjacent magma.

3- Magma Mixing

Magma mixing occurs when bodies of magma of different composition come in contact and mix to produce a third magma with a composition intermediate between the two parent magmas.

If two or more magmas with different chemical compositions come in contact with one another beneath the surface of the Earth, then it is possible that they could mix with each other to produce compositions intermediate between the end members.

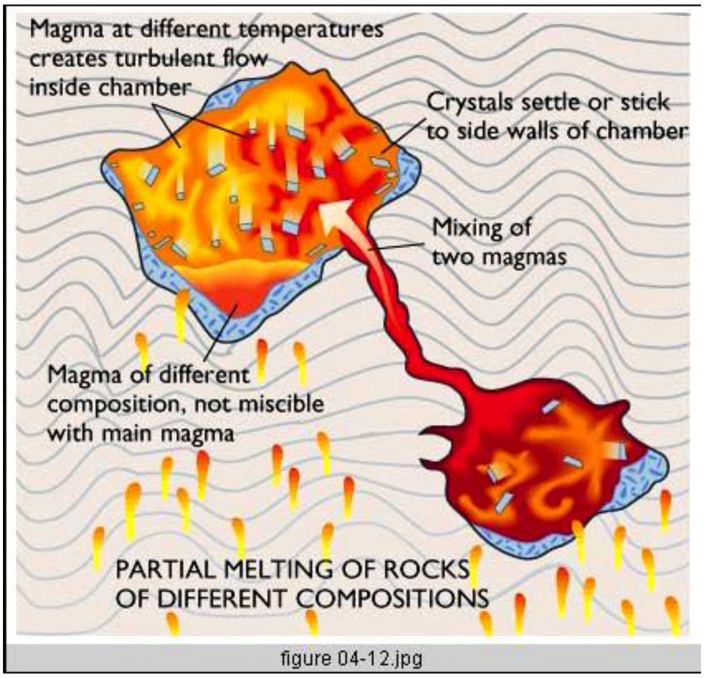


Figure 4: Magma Mixing

If the compositions of the magmas are greatly different (i.e. basalt and rhyolite), **there are several factors that would tend to inhibit mixing:-**

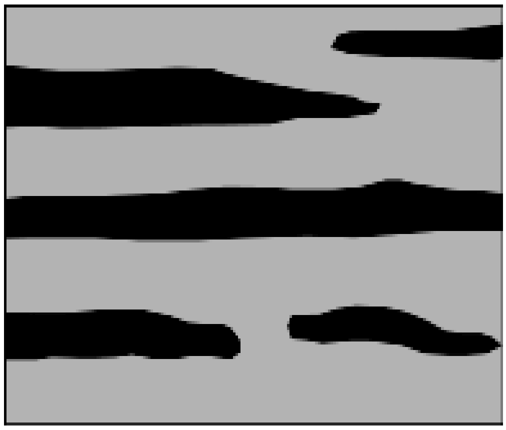
1. **Temperature contrast** - basaltic and rhyolitic magmas have very different temperatures. If they come in contact with one another the basaltic magma would tend to cool or even crystallize and the rhyolitic magma would tend to heat up and begin to dissolve any crystals that it had precipitated.
2. **Density Contrast**- basaltic magmas have densities on the order of 2600 to 2700 kg/m^3, whereas rhyolitic magmas have densities of 2300 to 2500 kg/m^3. This contrast in density would mean that the lighter rhyolitic magmas would tend to float on the heavier basaltic magma and inhibit mixing.
3. **Viscosity Contrast**- basaltic magmas and rhyolitic magmas would have very different viscosities. Thus, some kind of powerful stirring would be necessary to get the magmas to mix.

Despite these inhibiting factors, there is evidence in rocks that magmas do sometimes mix. The smaller the difference in chemical composition between two magmas, the smaller will be the contrasts in temperature, density, and viscosity, then it is possible that they could mix with each other to produce compositions intermediate between the end members.

If magmas of contrasting composition come in contact and begin to mix some kind of stirring mechanism would first be necessary. Such stirring could be provided by convection, with the hotter magma rising through the cooler magma.

Evidence for Mixing

1- Rocks that show a **marble cake** appearance, with dark colored mafic rock intermingled with lighter colored rhyolitic rock. This, however, is mixing of magmas.

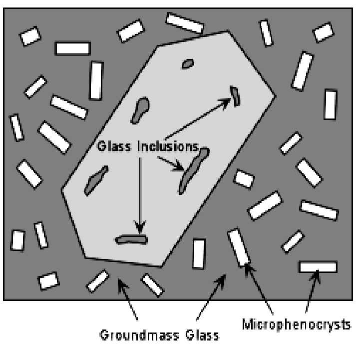


Note that differences in color are always due to differences in composition, so in rocks that show this banding, mingling or mixing of magmas may have occurred.

2- **Disequilibrium mineral assemblages**. Some evidence might be preserved if the crystals present in one of the magmas does not completely dissolve or react. This might leave disequilibrium mineral assemblages. For example, if a basaltic magma containing Mg-rich olivine mixed with a rhyolite magma containing quartz, and the magma was erupted before the quartz or olivine could be re dissolved, then we would produce a rock containing mineral that are out of equilibrium.

3- **Reverse zoning in minerals**. When a mineral is placed in an environment different than the one in which it originally formed, it will tend to react to retain equilibrium. Instead of dissolving completely or remaking their entire composition, solid solution minerals may just start precipitating a new composition that is stable in the new chemical environment or at the new temperature. This can result in zoned crystals that show reversals of the zoning trends. For Example: Mg-Fe solid solution minerals normally zone from Mg-rich cores to Fe-rich rims. If a Fe-rich olivine or pyroxene is mixed into Mg-rich magma that is precipitating Mg rich olivine or pyroxene, it may precipitate the more Mg-rich composition on the rims of the added crystals. Analyses of such crystals would reveal a reversal in zoning.

Similarly, if a Na-rich plagioclase originally crystallizing from a rhyolitic magma were mixed into a basaltic magma precipitating Ca-rich plagioclase, so Ca-rich rim may be added to the Na-rich plagioclase.



4- **Glass inclusions.** Sometimes the crystal grows incompletely trapping liquid inside, this trapped liquid will be revealed as glass inclusions in the crystal. The glass inclusions should represent the composition of the magma that precipitated the crystal. If the composition of glass inclusions is different from the composition of crystal, this provides evidence of magma mixing.

Classification of igneous rocks

Igneous rocks are classified on the basis of mineralogy, chemistry, and texture. As discussed earlier, igneous rocks subdivide into two major groups:

(1) The plutonic rocks, with mineral grain sizes that are visible to the naked eye,

(2) The volcanic rocks, which are usually too fine-grained or glassy for their mineral composition to be observed without the use of a petrographic microscope.

Igneous rocks: very diverse in chemistry and texture, yet they have very gradational boundaries. We must pick a rational basis for classifying them.

The classification system used will depend on how much we know about the rock being examined.

<u>Basis for classification of igneous rocks</u>

A) Field and hand specimen examination

B) Colour index

C) Texture

D) Mineral identification (Petrographic examination)

E) Chemical data (Rock chemistry)

Examine these classification systems in more detail as the following:-

A) Field classification of igneous rocks

The most primitive classifications are based on rock characteristics such as **Extrusive** or **Intrusive rocks**

A) - I Extrusive rocks

If the rocks fracture, the resulting magma will be forced up through the fractures to the surface, forming a volcano. Molten rock material (called lava) will flow from the volcano and spread out.

Extrusive igneous rocks (Volcanic rocks) are the result of volcanic eruptions (volcanic activity) and therefore, solidify in atmospheric conditions.

Because lava cools and crystallizes rapidly, it is fine to very fine grained. Because of this fine grained texture it is much more difficult to distinguish between the different types of extrusive igneous rocks than between different types of intrusive igneous rocks.

Cooling has been so rapid as to prevent the formation of even small crystals the resulting rock may be a glass (such as the rock obsidian).

Generally, the mineral constituents of fine grained extrusive igneous rocks can be determined by examination of thin sections of the rock under a microscope, so only an approximate classification can usually be made in the field.

Material may be violently forced out of the volcano during igneous activity as blocks of rock and ash. This material is called pyroclastic rock (also called fragmented igneous rock) and may fall nearby, forming part of the volcano itself, or may be spread over great distances by the wind.

Volcanic rocks are ccharacterized by especial textures and structures, e.g. flow structure, pillow structure, columnar structure, vesicular texture, amygdaloidal texture…. etc.

A– 2 Hypabyssal rocks

Hypabyssal rocks are formed at shallow depths. They are fine grained, may contain phenocrysts, and solidified mainly as such minor intrusions as dykes or sills.

A hypabyssal rock also known as subvolcanic rock, it is an intrusive igneous rock that is emplaced at depths less than 2 km within the crust, and has intermediate grain size and often porphyritic texture between that of volcanic rocks and plutonic rocks. Subvolcanic rocks include diabase (also known as dolerite) and porphyry.

A– 3 Intrusive rocks

Intrusive (plutonic) igneous rocks crystallize within the crust interior. They are formed from magma that cools and hardens within the earth, where the magma cools slowly, and as a result these rocks are course grained. The mineral crystals in such rocks can generally be identified with the naked eye.

Intrusive igneous rocks are holocrystalline. Every mineral is in a crystalline form and there is no glassy fraction. Typical they have large crystals because they cooled over a very long time period, which allowed the individual crystals to grow large, e.g. granite and diorite … etc.

Intrusive rocks can be classified according to the shape and size of the intrusive body and its relation to the other formations into which it intrudes.

Intrusive rocks are found in large blocks, cover wide areas of hundred kilometers. These rocks are ccharacterized by holocrystalline texture.

The main difference between Intrusive and Extrusive Rocks

1) Intrusive rocks are formed from magma whereas extrusive rocks are formed from lava.

2) Intrusive rocks are formed deep inside of the earth whereas extrusive rocks are formed at the surface of the earth when magma finds a way to eject or pour out of the surface.

3) Cooling and solidification of intrusive rocks takes place very slowly whereas contact with air and water causes cooling of extrusive rocks to take place at a very rapid rate.

4) Intrusive rocks are made up of coarse crystals whereas extrusive rocks have tiny crystals that can be seen only with a microscope.

5) Granite is the best example of intrusive rocks whereas the basalt is example of extrusive rocks.

B)- Color index

The most obvious characteristic of a rock specimen is its color. The color of a rock specimen is ranging from almost light (in some granites) to nearly black (in basalts).

The colour index of igneous rocks is a very useful indicator of the types of minerals present in the rock and therefore the specific type of rock.

The color index of an igneous rock is a measure of the ratio of **dark** colored, or **mafic** minerals to **light** colored, or **felsic** minerals.

Colour index = a number that represents the percent by volume of dark coloured (mafic minerals) minerals in rocks.

The **dark rocks** are rich in: pyroxene, amphiboles, olivine, and biotite; while, **light rocks** are rich in feldspars (with or without quartz or feldspathoids).

According to Bowen's Reaction series, minerals crystallize at different temperatures depending on their chemical composition. At high temperatures only minerals that have structures stable under those conditions will be able to crystallized and typically those minerals are olivine, pyroxene, and plagioclase feldspar. Therefore igneous rock that forms at high temperature would be composed of these minerals and hence be dark or mafic in color.

Rocks that have formed from magma at relatively low temperatures would be composed of the light colored quartz, potassium feldspar, and muscovite. These rocks are termed felsic because of their typically high content of both feldspar and silica.

Leucocratic, Mesotype and Melanocratic are the terms which used in identifying color index.

Color-index-based descriptive terms

	% Dark minerals	Color index
Leucocratic*	< 30	0–30 (a light-colored rock)
Mesotype	30–60	30–60 (an intermediate rock)
Melanocratic†	> 60	60–100 (a dark-colored rock)

* *Leuco-* is commonly used in rock names as a prefix indicating abnormally light-colored.

† *Melano-* is used as a prefix indicating abnormally dark-colored.

C) The textural classification of igneous rocks

The textures of igneous rocks are highly dependent on the mode of emplacement and degree of cooling of magma. Plutonic or intrusive rocks result when magma cools and crystallizes slowly within the Earth's crust and a very common example of this type is coarse grain granite.

The volcanic or extrusive rocks result from magma reaching the surface either as lava or fragmental ejecta, forming the rocks such as pumice or basalt. There are numerous intermediate igneous rocks.

Texture of igneous rocks defines on the shape, size and mutual relationship of the minerals.

The texture in igneous rocks depends on the following four factors:

1) Crystallinity or degree of crystallisation
2) Granularity or grain size
3) Shape of mineral crystals

4) Mutual relationship amongst crystals

1) Crystallinity or degree of crystallisation

Crystallinity or degree of crystallisation refers to degree or amount of crystals formed during the process of solidification of magma. The igneous rocks may be composed of the crystals, partly crystals and partly glassy matter or totally glassy matter.

Degree of crystallisation is measured by the ratio between the crystallised matter and the glass in an igneous rock. Degree of crystallisation is the modal percentage of mineral crystals relative to glass and varies between 0 – 100 %.

Let us learn few more terms related to crystallinity

- **Holocrystalline**: The prefix 'holo' implies when the rock wholly composed of mineral crystals in the rock. Holocrystalline texture is seen in plutonic rocks
- **Hemicrystalline (**hypocrystalline): implies when the rock comprises partly of crystalline and partly of glassy material. This is mainly observed in the rocks which are crystallised near the surface or at an intermediate depth from the surface.
- **Holohyaline**: The rocks exhibiting this texture are entirely made up of glassy matter or non-crystalline matter. This results when the rate of cooling is very

rapid. This texture is mostly seen in volcanic rocks, e.g. obsidian, pitchstone.

2) Granularity or grain size

Grain size or granularity in igneous rocks shows wide variation. It varies from a meter size (e.g. pegmatite) to even 0.01 mm size or sometimes even glassy as found in volcanic rocks.

Generally, **phaneritic** and **aphanitic** terms are used to describe coarse- and fine-grained rocks respectively. Coarse grained crystals can be seen with unaided eyes and mineral grains in rocks are identified easily. The study of fine-grained minerals in rocks require petrological microscope for their identification.

The factors controlling grain size or granularity in igneous rocks are **viscosity**, **rate of cooling** and **volatile content:**

- **Viscosity**

Magmatic viscosity defines the degree of fluidity of the magma, e.g. water has low viscosity and will flow easily while glue has high viscosity and will flow very slowly.

Magmatic viscosity is the resistance to flow (opposite of fluidity). Viscosity depends on the composition of the magma, and temperature.

Magmatic viscosity increases with increasing SiO_2 concentration in the magma.

Magmatic viscosity decreases with increasing temperature of the magma.

Thus, **basic** magmas tend to be fairly fluid (**low viscosity**). **Acidic** magmas tend to have even **higher viscosity**. Viscosity is an important property in determining the eruptive behaviour of magmas.

If the magma is viscous, it opposes ionic diffusion thereby and hindering crystallisation. Viscosity is directly related to water vapour and gaseous (e.g. CO_2, H_2S, Cl, F) phases. Fine-grained or glassy rocks like rhyolite and obsidian resulted from siliceous viscous magma.

- **Rate of Cooling (Rate of growth)**
  - In most cases, the more slowly crystallization, and slow cooling gives rise to a **Coarse Grain** (>1 cm) and **Holocrystalline** texture.
  - Faster cooling produces a **Medium Grain** size (1 cm – 1mm).
  - Further faster cooling produces a very **Fine Grain** size (**crypto-crystalline**) rock where the mineral grains are not visible by the naked eye but can be seen by a hand lens or a microscope.

- A very fast cooling (no time for crystals to form) produces a **Glassy** rock or **natural glass**, e.g., obsidian mineral.

Hence gradation in grain size in igneous rocks produces:-

- Coarse grain size **(>** 1 cm)
- Medium grain size (1 cm – 1mm)
- Fine grain size **(<** 1mm)
- Natural glass.

- **Volatile content**

Presence of volatiles, particularly H_2O, in magma reduces the viscosity, but promotes larger crystal growth. Pegmatites crystallised from hydrous magmas, and they are very coarser than granites. Aplites are fine-grained and they form from dry magmas.

Common metal cations, e.g. Fe, Mg, Ca, Na, K, etc. and dissolved water in magmas hinder linkage formation or Si-O polymerisation and decrease viscosity. Water rich magma is therefore more fluid

3) Shape of crystals

- Well-formed crystals that show complete or nearly complete development of crystal shape are called **Euhedral** crystals
- Less developed crystal faces produces **Subhedral** crystal.

- Without crystal faces or irregular forms produce **Anhedral** crystals

Three types of texture are commonly referred to:

1. If most of the crystals are ***euhedral*** - that is they are bounded by well-formed crystal faces. The fabric is said to be ***idomorphic texture***.
2. If most of the crystals are ***subhedral*** - that is they bounded by only a few well-formed crystal faces, the fabric is said to be ***hypidiomorphic texture***.
3. If most of the crystals are ***anhedral*** - that is they are generally not bounded by crystal faces, the fabric is said to be ***allotriomorphic texture***.

Common textures of igneous rocks

C) - 1 Phaneritic

Phaneritic igneous rocks are comprised of large crystals that are clearly visible with necked eye or without adding a hand lens or microscope.

The phaneritic rock is made up of large crystals, which are **>** 1 mm to several centimetres in size. Phaneritic texture forms by slow cooling of magma in the plutonic environment.

The prefix micro- should be used to indicate that plutonic rock is finer-grained than usual, rather than giving the rock a special name. The only exceptions are dolerite and diabase = micro gabbro, which are long established terms.

Examples of phaneritic igneous rocks are gabbro and granite.

C) - 2 Aphanitic texture

Aphanitic igneous rock consists of small crystals that cannot be seen by necked eye or without adding hand lens.

The aphanitic rock is made up of small tiny crystals, which are generally less than 1 mm in size.

Aphanitic texture commonly results from rapid cooling in volcanic, subvolcanic or hypabyssal (shallow subsurface) environments.

Examples of aphanitic igneous rock include basalt and rhyolite.

C) - 3 Porphyritic texture

Porphyritic igneous rocks are composed of at least two mineral phases having a conspicuous (large) difference in grain size. The larger grains are termed ***phenocrysts*** and the finer grains either ***matrix or groundmass***.

Porphyritic rocks are thought to have undergone two stages of cooling; one at depth where the larger phenocrysts formed and a second at or near the surface where the matrix grains crystallized.

C)- 4 Glassy texture

Glassy igneous rocks are non-crystalline, meaning the rock contains no mineral crystals.

Glass results from cooling that is so fast that minerals do not have a chance to crystallize. This may happen when lava comes into quick contact with much cooler materials near the Earth's surface. Pure volcanic glass is known as **obsidian**.

If the volcanic rock contains **0-20** %, **20-50%**, and **50-80%** glass the prefix ***glass - bearing***, ***glass-rich,*** and ***glassy*** terms should be used respectively.

C) – 5 Vesicular texture

Vesicular texture term refers to vesicles (cavities) within the igneous rock. Vesicles are the result of gas expansion (bubbles), which often occurs during volcanic eruptions. **Pumice** is common type of vesicular rocks.

C) – 6 Pyroclastic texture

Pyroclastic are rocks blown out into the atmosphere during volcanic eruptions. These rocks are collectively termed fragmental because they are comprised of numerous grains or fragments that have been welded together by the heat of volcanic eruption.

Based on the proportions of the grain size of rock fragments (block and bomb, lapilli and ash contents) the **pyroclastic rocks** can be classified and named individually.

Pyroclastic rocks have a range of fragment sizes. They range from the largest **agglomerates**, to very fine **ashes** and **tuffs**.

C)- 7 Pegmatitic Texture

Pegmatitic texture is formed when magma cools and some crystals increase in size extensively. The size of crystals may range from some centimetres to quite a number of meters.

A pegmatitic texture is one in which the mineral crystals are exceptionally large. The largest ones are more than about 3 cm long.

The extra large size of crystals in pegmatitic texture does not mean that they cooled extra slowly, but the large crystals of a pegmatite formed in a magma that was rich in dissolved water.

Pegmatites often form in veins that opened up at the end of the crystallization of a large intrusive mass.

D- Mineralogical classifications (Classification based on Petrographic Examination)

Thin sections of rocks are relatively easy to make and identification of rocks based on the mineralogy observed is possible.

The most important criteria which are used in mineralogical classification of igneous rocks:-

1) Identify the major components of mineralogy and estimate their relative proportions.
2) Proportion of mafic to felsic components
3) Composition of the plagioclase
4) Proportion of alkali feldspar to plagioclase
5) Presence or absence of quartz
6) Presence or absence of feldspathoid minerals
7) Grain size or texture (extrusive or intrusive)
8) The relative **volume** of a rock occupied by crystals in any one size division is the important factor, **not the number** of crystals.

Streckeisen's classification of plutonic igneous rocks:

In 1967 Albert Streckeisen, with the cooperation of many geologists in many countries, came up with a generally accepted rock classification system.

- Streckeisen's classification of plutonic igneous rocks: (Fig.): This is based on the relative modal abundance of the following minerals:
    1) quartz (**Q**)
    2) alkali feldspar (**A**) (sum of K-feldspar + albite) *including orthoclase, microcline, perthite, anorthoclase, sanidine and albite*
    3) plagioclase feldspar (**P**) (**An**$_{10}$ to **An**$_{100}$)

4) feldspathoids (**F**) *including, e.g. nepheline, leucite ...etc.*

- Note that feldspathoids cannot coexist with quartz, so you are really always recalculating the modes of only 3 minerals (either **Q - A - P,** or **F - A - P**) to a sum of 100% and plotting the recalculated modes on one of the ternary (triangular) diagram
- The International Union of Geological Sciences (**IUGS**) modified and expanded his work to form what is an internationally accepted igneous rock classification system (**IUGS Classification**).
- In order to use this system, you must be able to determine the percentage of five minerals (or mineral groups): quartz, plagioclase, alkali feldspars, ferromagnesian minerals and feldspathoids (such as nepheline or leucite).

Root names for this classification and the relevant QAPF field numbers are given in Figure 5. Field details are outlined below:-

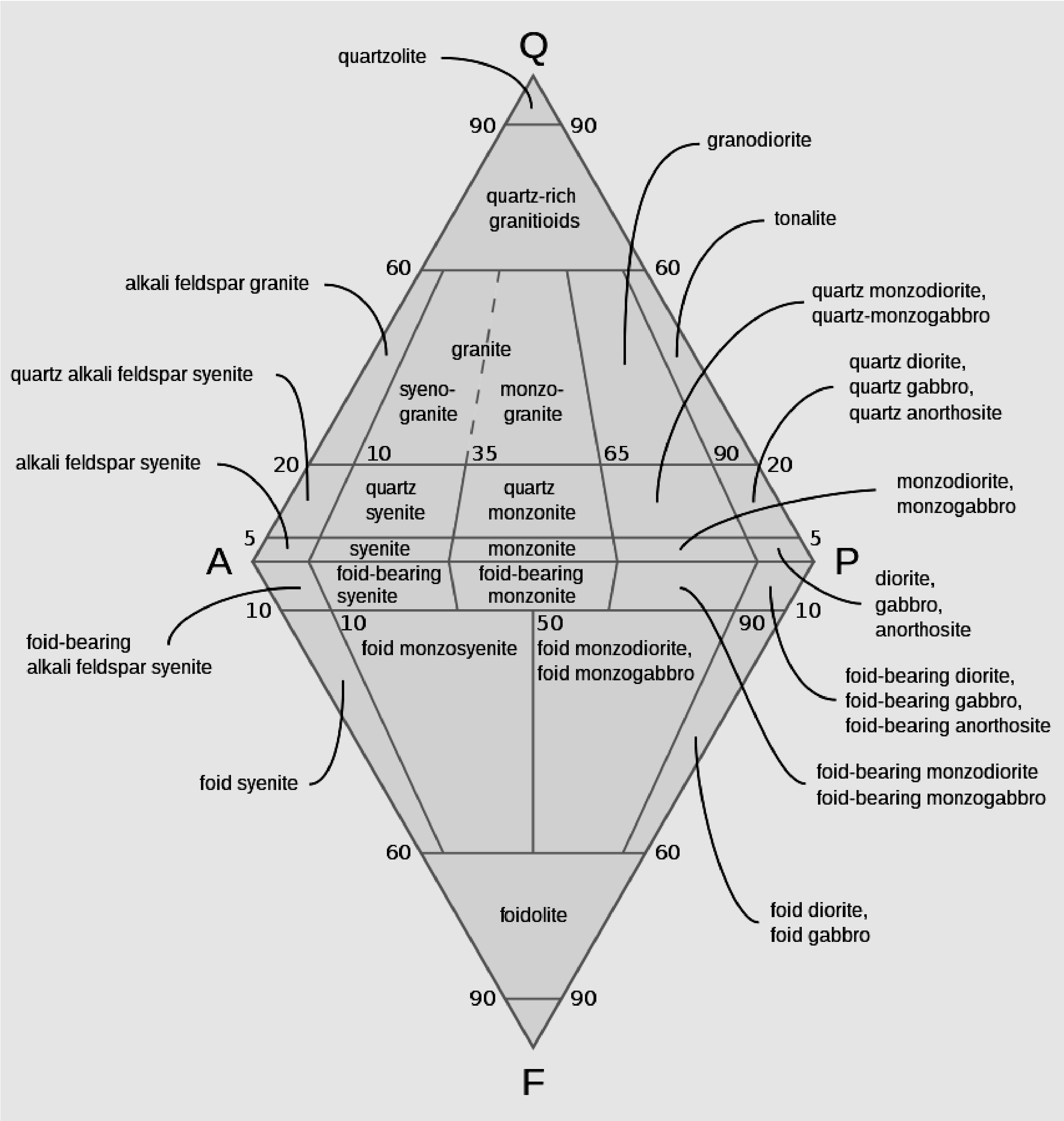
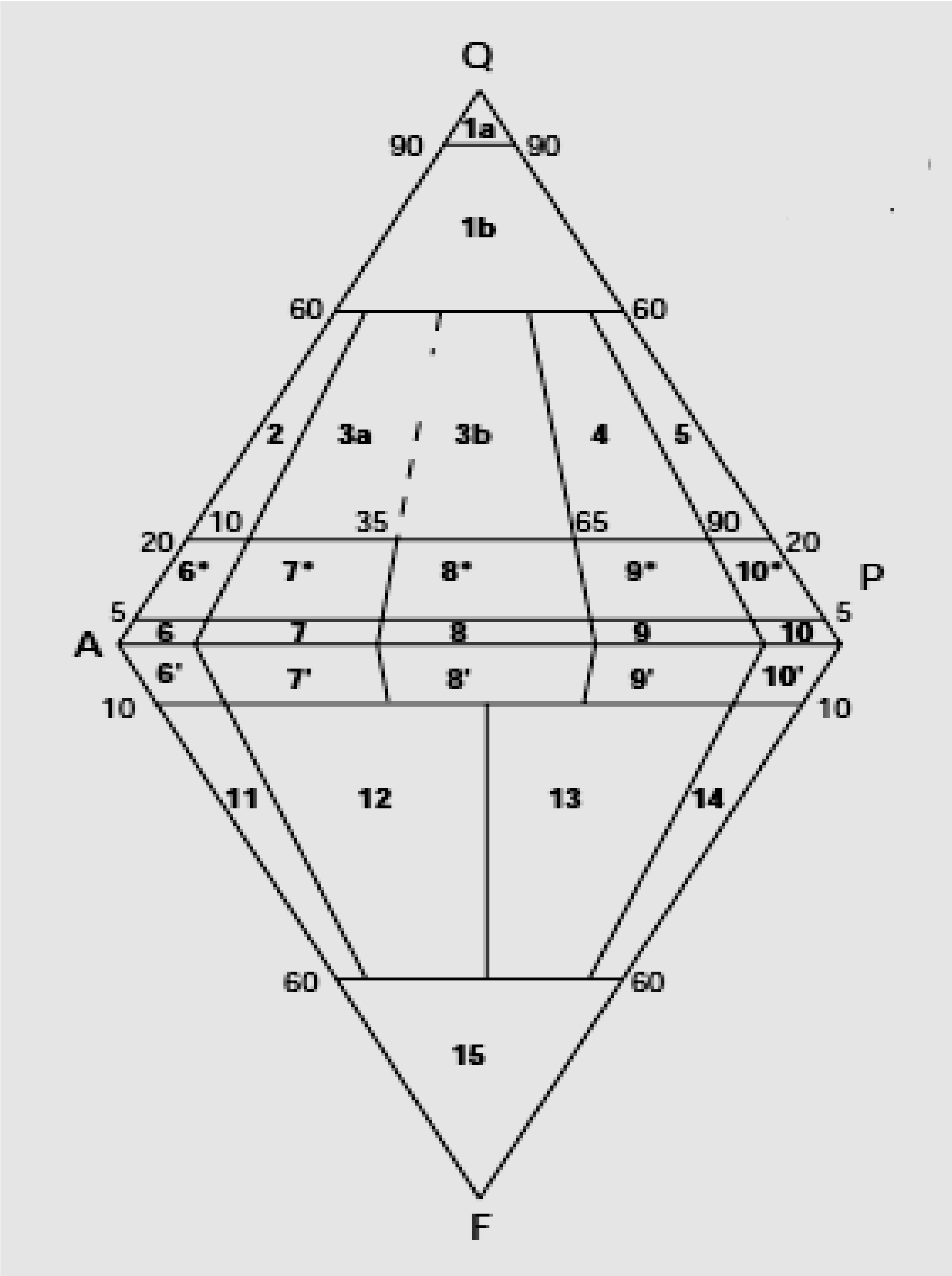


Figure 5: Classification of coarse-grained crystalline rocks according to their modal mineral contents using the QAPF diagram (based on Streckeisen, 1976). The corners of the double triangle are Q = quartz, A = alkali feldspar, P = plagioclase and F = feldspathoid.



Field 1a: **Quartzolite** is a collective term for coarse grained crystalline rocks in which **quartz** comprises **more than**

90% of the felsic minerals. These extremely rare rocks are unlikely to be wholly of primary igneous origin.

Field 1b: **Quartz-rich-granitic-rock** is a collective term for granitic rocks in which quartz comprises more than 60% of the felsic minerals.

Field 2: **Alkali-feldspar-granite** is a granitic rock in which plagioclase comprises less than 10% of the total feldspar. If one particular type of alkali feldspar is dominant (**>** 50% of alkali feldspar) the mineral name can be used in place of alkali feldspar, for example **albite-granite**, **orthoclase- granite**. **Alkali-feldspar-granite** is not synonymous with ***alkali*** **granite** which should be restricted to rocks containing alkali amphiboles and/or alkali pyroxenes.

Field 9: The two root names in this field, **monzodiorite** and **monzogabbro**, are separated according to the average composition of their plagioclase: if **An** (the anorthite content of plagioclase) is less than 50% the rock is **monzodiorite**: if An exceeds 50 **%** the rock is **monzogabbro.**

Field 10: The three root names in this field–**diorite**, **gabbro** and **anorthosite**–are separated according to the average composition of their plagioclase and the colour index: if **M** is less than 10**%** the rock is **anorthosite**

If **An** is less than 50% the rock is **diorite** if **An** is greater than 50% the rock is **gabbro** and may be subdivided further, as shown below.

Rocks which plot in field 10 of the **QAPF** diagram and in which the **An** content of plagioclase exceeds 50% (Gabbro QAPF) may be subdivided according to relative abundance of the mafic minerals orthopyroxene, clinopyroxene, olivine and hornblende.

Field 11: **Foid-syenite** is the root name. Where it is known, the name of the most abundant foid mineral should appear in the rock name, for example **nepheline-syenite**.

Field 12: The root name is **foid-monzosyenite**. The name of the most abundant foid mineral should appear in the rock name, for example **nepheline-monzosyenite.**

Field 13: The two root names in this field, **foid-monzodiorite** and **foid-monzogabbro**, are distinguished according to the average composition of their plagioclase:

If **An** is less than 50% the rock is **foid-monzodiorite (**for example **nepheline-monzodiorite)**; if **An** exceeds 50% the rock is **foid-monzogabbro**.

Field 14: two root names in this field, **foid-diorite** and **foid-gabbro**, are distinguished according to the average composition of their plagioclase: if **An** is less than

50**%** the rock is **foid-diorite**: but if An exceeds 50**%** the rock is a **foid-gabbro**. Where it is known, the name of the most abundant foid mineral should appear in the rock name, for example **nepheline-diorite**.

Field 15: This field **contains** rocks in which the light-coloured minerals are almost entirely foids, and is given the root name **foidolite** to distinguish it from the fine-grained equivalent, which is called **foidite**. As <u>these rocks are rare</u> the field has not been divided.

Volcanic classification of the Streckeisen

Volcanic classification (using the **QAPF diagram**), (Figure 6) is a simplified version of Streckeisen's classification, where the rock is assigned to a "family", and is quite useful for field geologists.

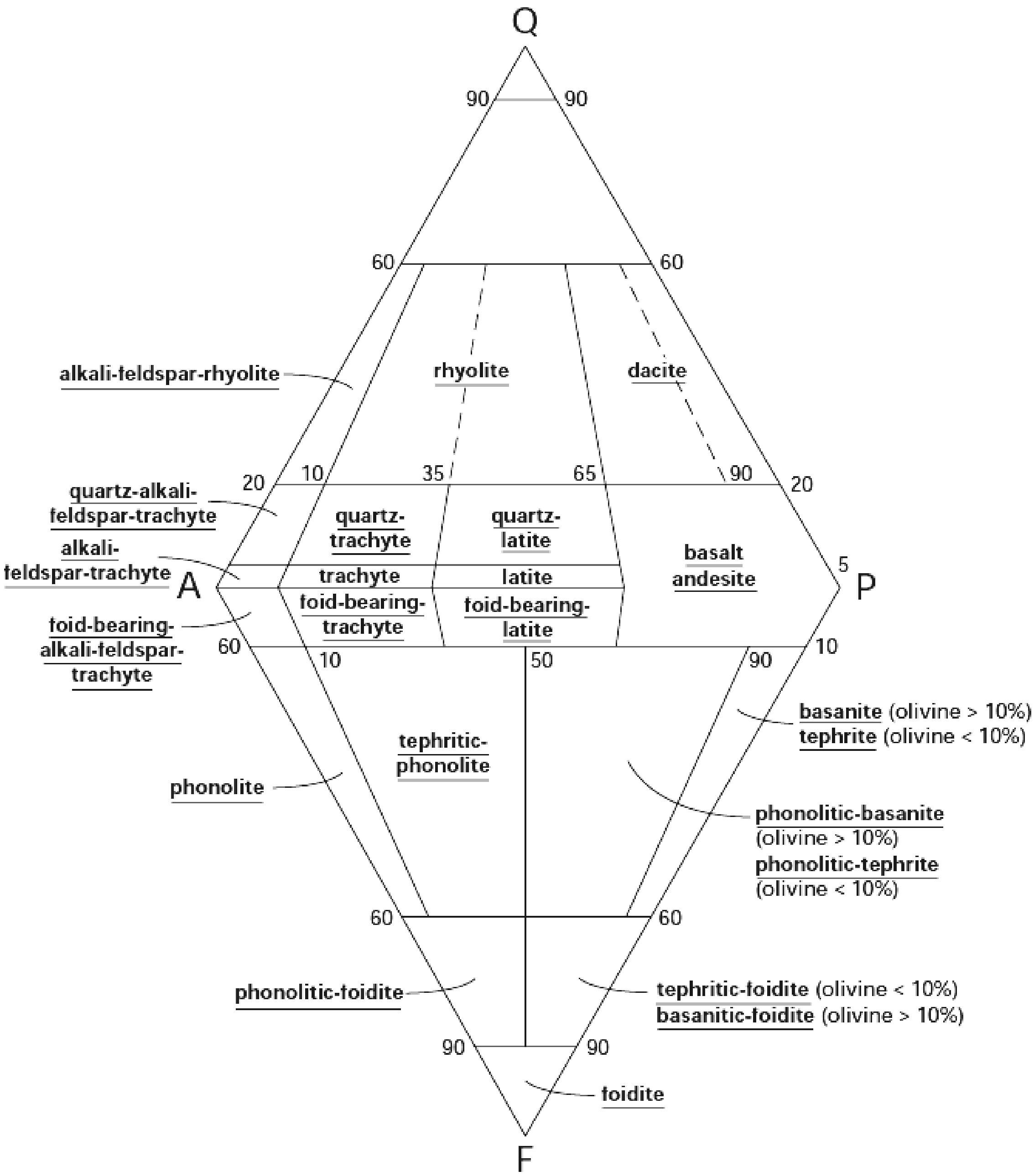


Figure 6: Classification and nomenclature of fine-grained igneous rocks (Volcanic rocks) according to their modal mineral contents using the QAPF diagram (based on Streckeisen, 1978). Q = quartz, A = alkali feldspar, P = plagioclase, and F = feldspathoid.

D- Chemical classifications

Chemical classifications of igneous rocks are based on a few concepts as the following:

1- Concept of SiO_2 saturation (Shand's classification)

This is an easy concept which leads to a simple classification that actually utilizes the mineralogy of the rock. Igneous rocks are classified into 3 groups:

a- **Oversaturated igneous rocks**: rocks containing quartz.

b- **Saturated igneous rocks**: rocks which do not contain either quartz or feldspathoids.

c- **Undersaturated igneous rocks**: rocks which contain feldspathoids (do not contain quartz).

2- Concept of the amount SiO_2

Classification based on chemistry takes into account the amount of total silica content (SiO_2) and the composition of feldspar minerals (K, Na, Ca).

Igneous rock chemistry is determined mainly by the source of the magma and any interactions between magma and the rocks through which it migrates. Chemical composition usually is indicated by the minerals or colour of an igneous rock.

Four main compositional categories of igneous rocks (based on Travis 1955):-

1. **Felsic igneous rocks** – These rocks are rich in feldspars and silica. Silica content ranges from about 65% to **>**77%. Potassium feldspar makes up more than one-third of total feldspars; plagioclase (Na & Ca) feldspars are less than two-thirds of total feldspars. Typical of continental crust.
2. **Intermediate igneous rocks** are located between felsic and mafic rocks. Silica content ranges from about 55% to 65%. Plagioclase feldspars make up more than two-thirds of total feldspars. Na-rich plagioclase slightly predominates over Ca-rich plagioclase. Found in association with subduction zones.
3. **Mafic igneous rocks** -- These rocks are rich in magnesium and iron with less silica. Silica content is 45% to 55%. Ca-rich plagioclase is the dominant feldspar with little Na-feldspars. Typical of oceanic crust.
4. **Ultramafic igneous rocks** -- These rocks are very rich in magnesium and iron and poor in silica. Silica content is less than 45%, and little or no feldspar is present. Derived from the mantle.

3- Concept of Al_2O_3 saturation

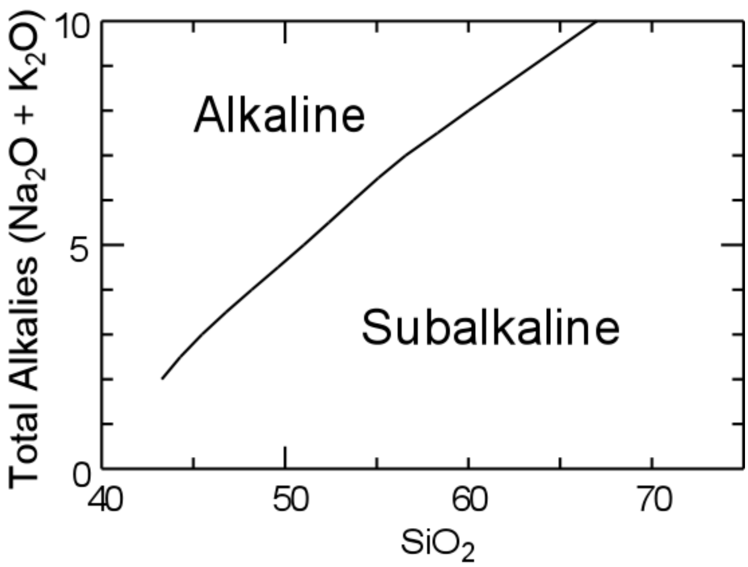
This concept is based on comparing the **mole proportions** of the alkalis to alumina in a rock (***mole proportion = weight % of oxide / molecular weight of this oxide***). Most igneous rocks are metaluminous. Peraluminous rocks are almost always plutonic, whereas volcanic peralkaline rocks are more common than plutonic ones.

Igneous rocks are subdivided into three groups according to this classification:

Group	Chemical characteristics	characteristic minerals
Peraluminous	$Al_2O_3 > Na_2O + K_2O + CaO$	**Corundum, Andalusite, almandine, Muscovite, Tourmaline**
Metaluminous	$K_2O + Na_2O + CaO > Al_2O_3 > Na_2O + K_2O$	**Feldspars + most Cpx**
Peralkaline	$K_2O + Na_2O > Al_2O_3$	**Aegirine, Riebeckite, Arfvedsonite,**

4- Total alkali - silica diagram classification

A simple plot of total alkalis ($Na_2O + K_2O$) vs. SiO_2 has been used to classify volcanic rocks. Figure .. shows this classification.



5- CIPW norm calculations and classification

The **CIPW** norm is a quantitative system initially developed to classify igneous rocks.

In 1902, **Cross**, **Iddings**, **Pirsson** and **Washington**, four American petrologists, devised a system for converting the chemical analysis of an igneous rock into a group of minerals predicted to crystallize from magma of this composition. These predicted minerals, are known as "**normative minerals**" and are represented in weight % to give the "norm of the rock" which should add up to ~ 100%.

Normative calculations are based on the observed sequence of crystallization of minerals from a melt, and take into account which minerals can and cannot coexist in equilibrium.

Normative calculations are thus important tools that enable their users to relate chemical analyses to petrographic observations, to classify rocks and to interpret samples in terms of magmatic suites

CIPW classification is used to name rocks, to group samples into the units and the comparison of lithological units from different regions.

CIPW calculations are based on the following assumptions:-

1- The norm is expressed in the form of end-members, and does not take into account many types of solid solution (e.g. Ti in pyroxenes, ... etc).

2- Pyroxenes and olivines are assumed to have the same Fe/Mg ratio.

3- The fero - magnesium minerals are assumed to be free of Al_2O_3

4- Normative minerals are always formed (calculated) in the same order, regardless of the composition of magma.

Because of these assumptions, the normative mineralogy will almost be different from the modal mineralogy of a rock.

Normative calculations are generally useful for *basic volcanic* rocks. This is simply because basic magmas have less H_2O compared to acidic ones, and these volatiles are themselves lost upon eruption, leaving behind mostly anhydrous minerals to crystallize from such lavas.

The CIPW norm calculations are normally made by computer, and there are various published programs for the calculation of the CIPW (***Streckeisen and others****,* proposed several classification diagrams for igneous rocks).

The Common Igneous Rock Types
(The rock families)

Igneous rocks, as the name indicates, are those types which have been formed by the cooling and consequent solidification of a once hot and fluid mass. The name means "fire formed". This liquid mass is known as magma. This magma is containing elements, when it cools sufficiently; unite to form the various minerals that go to make up the resulting rock.

The elements which form the chief constituents of the magmas of igneous rocks are **oxygen, silicon, aluminum, iron, calcium, magnesium, sodium** and **potassium,** named in the order of their abundance within the earth’s crust.

In most igneous rocks there is a more or less definite order of crystallization for their mineral constituents

In general, the more basic minerals or those which contain the smaller amounts of silica, are observed to crystallize from the melt first and the more acid minerals last.

Among the commoner rock-making minerals the following would be the usual order of crystallization; iron oxides like magnetite first, then the ferromagnesian minerals like olivine, pyroxene, the plagioclase and lastly quartz.

The type of minerals to be found in any igneous rock depends chiefly upon the chemical composition of the original magma.

If the magma was acid in character, i.e., had a high percentage of silica, the resulting rock contains the more acid minerals and an abundance of free quartz. It usually is light in color.

On the other hand, if the magma had a low percentage of silica, or in other words was basic in character, the resulting rock contains the more basic minerals and would not show free quartz. It also in general is dark in color.

In addition to the wide variation in chemical and mineral composition shown by igneous rocks there is also a variation in their physical structure, this is dependent upon the chemical composition of the original magma and the mode of origin of the rock.

If a rock has been formed from a magma buried at a considerable depth in the crust of the earth it must have cooled very slowly and taken a long period of time for crystallization and solidification. Under these conditions the minerals grow to considerable size. A rock having such a deep-seated origin has, a coarse grained structure and the various minerals that form this rock can be recognized by the unaided eye. Such rocks are commonly termed plutonic.

On the other hand, if a rock has been formed by volcanic forces, the magma has been extruded upon the surface of the earth or intruded in the form of dikes into the rocks lying close to the surface; its subsequent cooling and solidification go on quite rapidly. Under these conditions the minerals have little chance to grow and the resulting rock is fine-grained in character.

In some cases, the cooling has been too rapid to allow the separation of any minerals and the resulting rock is like a glass.

Because of the variation possible in the chemical composition of magmas, and because of the various conditions under which they may form, **igneous rocks show a wide variation in characters**.

On a **chemical** - **mineralogical basis**, igneous rocks may be **divided** into **a number of families**, each family includes rocks of both volcanic and plutonic, which have essentially the same composition and each series (family) ranging in structure from the glassy and porphyritic of volcanic to the coarsely crystalline and granular forms of plutonic rocks.

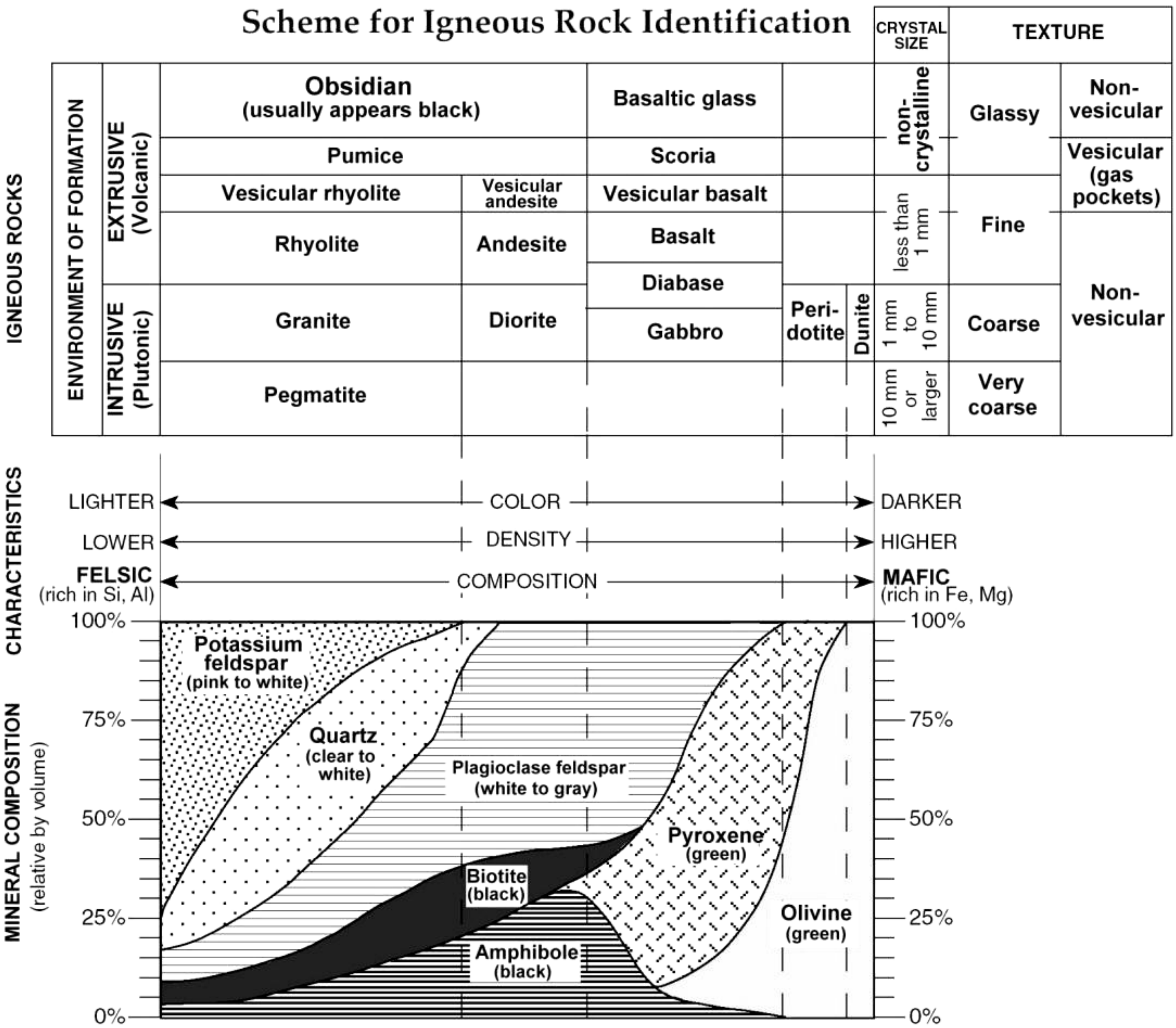


Figure 7: igneous rock families

The major igneous rock families

The major mineralogical classification of igneous rock families are:-

1) **Granite - rhyolite family**
2) **Gabbro - basalt family**
3) **Diorite - andesite family**
4) **Syenite - trachyte family**

5) **Monzonite -latite family**
6) **Peridotite family**
7) **Pegmatite dikes and veins**

The major mineralogical criteria which used to classify igneous rocks:

Three major mineralogical criteria are used to classify igneous rocks:-

1) **The presence or absence of quartz**. Quartz is an essential mineral in felsic or silicic rocks. It is an essential mineral, on which the classification is based.
2) **Composition of the feldspars**. Potassium feldspars and sodium plagioclase are essential minerals in silicic rocks, but are rare in intermediate and absent in mafic rocks. Calcium plagioclase is characteristic of mafic rocks.
3) **Proportion and kinds of ferromagnesian minerals**. Generally mafic rocks are rich in ferromagnesian minerals. Olivine is generally restricted to mafic rocks. Pyroxenes and amphiboles are present mainly in mafic rocks. Biotite is common in intermediate and silicic rocks.

<u>The more common and important rock families of igneous rocks, are very briefly described below:-</u>

Granite- rhyolite family

Granite- rhyolite family: Granite among plutonic rocks and rhyolite among volcanic rocks.

The most important characteristics of granite- rhyolite family

1) They are a light-colored igneous rock. The mineral composition usually gives these rocks a red, pink, gray or white color.
2) They are rich in silica, usually containing about 70 % silica (65 to 80%)
3) They have from 10 to 15% of alumina
4) The quantity of alkalies (Na and K) is relatively large (6 to 8 %)
5) They have small amounts of iron oxides (2 to 4%), magnesia (1 to 2%), and CaO (1 to 4%).
6) The principal minerals are orthoclase, quartz and plagioclase (oligoclase), with smaller amounts of iron oxide and ferromagnesian minerals (mainly biotite and hornblende).
7) They have different structures and textures, give rise to rocks of different appearance,

8) **Obsidian** is typically developed from felsic (silica-rich) igneous rocks. **Obsidian** occurs as a natural glass formed by the rapid cooling of viscous lava. Obsidian is extremely rich in silica and has a chemical composition similar to rhyolite.

Obsidian can form in a variety of cooling environments:

- along the edges of a lava flow
- along the edges of a volcanic dome
- around the edges of a sill or a dike
- where lava contacts water

9) Pumices are most abundant and most typically developed from felsic (silica-rich) igneous rocks. Pumice is a very light, porous volcanic rock that forms during explosive eruptions.

10) Rhyolite ordinarily occurs as the lava outflow of a granitic magma, but yet more slowly cooled than obsidian.

11) Granite- rhyolite family: divide into **two sub families**, include both plutonic and volcanic rocks:-

i) Granite rocks (plutonic)

ii) Siliceous volcanic and hypabyssal rocks

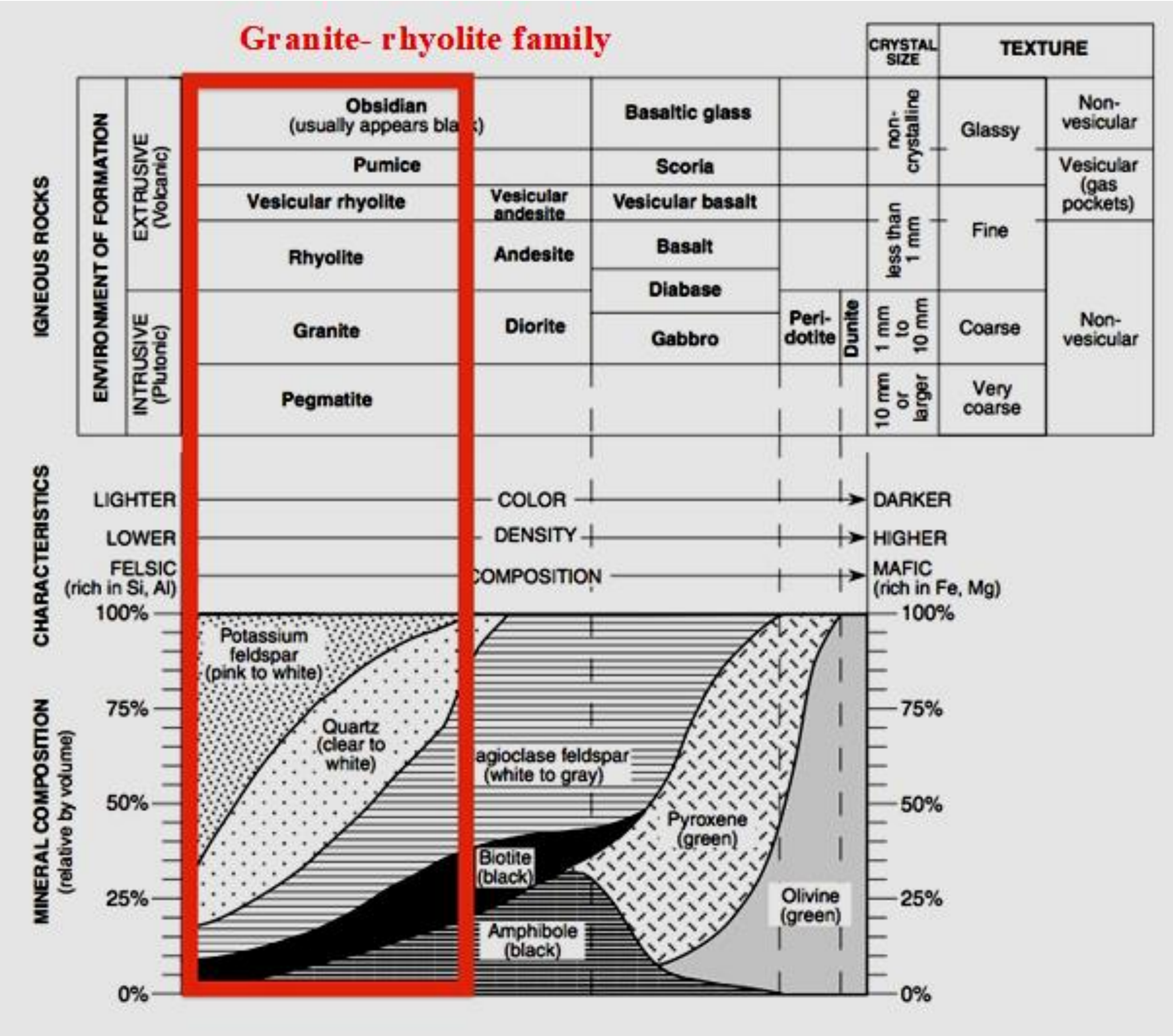


Figure 8: Granite- rhyolite family

Granitic Rocks

Granitic rocks are holocrystalline igneous rocks, medium to coarse grain and composed essentially of quartz (> 10 percent by volume) and one or more feldspars, usually with some ferromagnesian mineral in addition.

Granitic rocks include peralkaline granites and alkali granites which have alkali feldspar

Granite which hase alkali feldspar and Ca-bearing plagioclase,

Granodiorite in which Ca-bearing plagioclase is accompanied by subordinate alkali feldspar

Tonalite in which alkali feldspar is either absent or makes unless than 10 % of the total feldspar content

The common minerals of granitic rocks

Feldspars: make up the greater part of granitic rocks. Two types of peralkaline and alkali granite may be distinguished according to the nature of the alkali feldspar present:-

1- Hypersolvus types have single type of alkali feldspar, normally a microperthite.

2- Subsolvus types, have two type of alkali feldspars, microperthite (orthoclase or microcline) and albite

In the remaining granitic rocks, the alkali feldspar present as microperthite or orthoclase or microcline.

The Ca -bearing plagioclase: generally present in granites, granodiorites and tonalites.

Quartz: The quartz is found filling up the spaces between the other constituent.

Micas: Include both biotite and muscovite in characteristic plates and flakes. Generally, the biotite of the granitic rocks is moderately rich in iron.

Amphibole: when present, it is sodic variety in the peralkaline granites, commonly riebeckite. But in the granites, granodiorites, and in tonalites, the amphibole is hornblende.

Pyroxene: is uncommon in granitic rocks, but few aegirine or aegirine-augite may be present in peralkaline granites and in some alkali granites.

Accessory Constituents: such as apatite, zircon, magnetite, ilmenite are found sometimes

General textures and structures of granitic rocks are;

1- Subhedral granular texture

2- Micrographic intergrowth of quartz and feldspar texture

3- porphyritic texture

5- Rapakivi texture

Main varieties of granitic rocks

1- Peralkaline granites

The peralkaline granites is a term that be used for a variety of alkali feldspar granite that contains alkali pyroxene and /or amphibole.

The peralkaline granites have a distinctive mineralogy and characterized by sodic species

Peralkaline granites those igneous rocks which have a deficiency of alumina ((Na + K)/Al ratio > 1), and are marked by amphiboles and pyroxene rich in sodium and iron, and also by much albite.

The common varieties of peralkaline granites have riebackite, and aeigirine, as their mafic constituents. The common feldspar is microcline-microperthite, some rocks have single type of alkali feldspar (hypersolvus type)

2- Alkali feldspar granite

Alkali feldspar granite is a type of granite rich in the potassium feldspar mineral (K-spar). It is a dense rock with a phaneritic texture. The abundance of K-spar gives the rock a predominant pink to reddish.

Alkali feldspar granite contains between 20% – 60% quartz (less quartz content would lead to “quartz alkali feldspar syenite).

It contains more than 90% of the total feldspar content is in the form of alkali feldspar, which less than that amount would designate the rock as a granite.

Other silicate minerals may include, minor amounts of plagioclase, mica and amphibole (often hornblende, sometime hastingsite), Oxide minerals such as magnetite and ilmenite. apatite may also be present.

3-Granite

Granite is a common type of felsic intrusive igneous rock that is granular and phaneritic in texture. Granites can be predominantly white, pink, or gray in color, depending on their mineralogy.

Granite is an igneous rock with between 20% and 60% quartz by volume, and at least 35% of the total feldspar consisting of alkali feldspar, commonly the term "granite" is used to refer to a wider range of coarse-grained igneous rocks containing quartz and feldspar.

Granitic rocks mainly consist of feldspar, quartz, mica, and amphibole minerals, which form an interlocking, somewhat equigranular of feldspar and quartz with scattered darker biotite mica and amphibole (often hornblende)

Sometimes individual crystals (phenocrysts) are larger than the groundmass, in which case the texture is known as porphyritic. A granitic rock with a porphyritic texture is known as granite porphyry.

Granite is classified according to the percentage of alkali feldspar (orthoclase, , or microcline) and plagioclase into **Syenogranite** and **monzogranite**

Syenogranite is a coarse grained intrusive igneous rock. The feldspar component of syenogranite is predominantly alkaline in character (usually orthoclase). Syenogranite is similar to syenite; however the major difference is its higher content of quartz.

The expense of alkali feldspar and the domination of biotite over hornblende are characteristic in the syenogranite.

The presence of muscovite occurs as additional accessories in the syenogranite. Some syenogranite contain rare amphibole (e.g. Fe-hornblende and Fe-edenite), and biotite (annite)

Monzogranite is biotite granite rock. It is a coarse grained igneous rock composed mostly of quartz, plagioclase and alkali-feldspar. It having an alkali-feldspar/total feldspar ratio from 35 % to 65 % on the QAPF diagram

4-Granodiorite

It is a darker color than granite. It is a coarse-grained igneous rock consisting of essential quartz, plagioclase, biotite, hornblende and (some amount of alkali feldspar), with accessory sphene, apatite, and magnetite.

Plagioclase is the dominant feldspar in this rock, greater than two-thirds of the total feldspar present.

Granodiorite has higher quartz content than diorite, and a higher mafic mineral content than granite.

Biotite and amphiboles (often hornblende) are more abundant in granodiorite than in granite, and giving darker appearance of rock.

5-Tonalite

Tonalite has a dark color. Tonalite is a coarse-grained igneous rock and rich in mafic minerals, and consisting of essential quartz (>20%) and plagioclase (oligoclase or andesine).

Plagioclase is the dominant feldspar in this rock >90% of the total feldspar.

Mafic minerals are biotite, hornblende, and sometimes pyroxene.

Tonalite has minor alkali feldspar with <10% vol. of the total feldspar.

6- Granite- aplites

Granite- aplite is an intrusive igneous rock in which the mineral composition is the same as granite, but in which the grains are much finer than granite (less than 1 mm across).

Quartz and feldspar are the dominant minerals. The term 'aplite' or 'aplitic' is often used as a textural term to describe veins of quartz and feldspar with a fine to medium-grain "sugary" texture.

Granite- aplites are usually very fine-grained, white, and grey or pinkish and their constituents are visible only with the help of a magnifying lens.

Dykes and veins of aplite are commonly observed traversing granitic bodies

Aplites usually have a genetic affinity to the rocks they intrude. The granite- aplite, for example, is the last part of the magma to crystallize, and correspond in composition to the quartzo-feldspathic aggregates that fill up the spaces between the early main bodies of the granite.

The essential components of aplites are quartz and alkali feldspar (usually orthoclase or microperthite), microcline and albite.

The relation of aplite to quartz-porphyry, granophyre and felsite is very close

Nomenclature of granitic rocks depending on their content of mafic minerals

How can you name granitic rocks depending on their content of mafic minerals?

Granitic rocks are show many varieties depending on the character and amount of the **mafic minerals**. The common mafic minerals observed in granitic rocks are biotite and hornblende, and many varieties of granites show an increase in the amount of hornblende the biotite.

Sometimes, the granitic rocks have **been named as to indicate the dominant of these mafic minerals as the following:**

- **Biotite granite**
- **Hornblende-biotite granite**
- **Biotite granodiorite**
- **Hornblende-biotite granodiorite**
- **Hornblende tonalite**
- **Muscovite-biotite granites**

Siliceous volcanic and hypabyssal rocks

The siliceous volcanic rocks comprise the very fine-grained to glassy equivalent of the granitic rocks.

The siliceous volcanic rocks are rhyolites and rhyolite-obsidian, rhyodacite and rhyodacite-obsidian, dacite and dacite-obsidian and others.

These siliceous volcanic rocks occur as flows and as volcanic domes, and have been produced by magmas of granitic type.

The siliceous rocks are cryptocrystalline or have a partially or wholly glassy groundmass, it is often necessary to have a chemical analysis before they can be assigned to their proper group.

The members of siliceous volcanic and hypabyssal rocks

The members of silicic volcanic and hypabyssal rocks include:-

1-Rhyolite **2-Alkali feldspar rhyolite**

3-peralkaline rhyolite

4-Dacite **5- Felsite** **6-Rhyodacites**

7- Obsidian (Rhyolite-obsidian, Dacite –obsidian)

The main varieties of siliceous volcanic rocks, are very briefly described below:-

1--Rhyolite

It is the extrusive equivalent to granite. Due to their high content of silica, rhyolite magma form highly viscous lavas.

Rhyolite is found usually as pink or light-colored with so small crystals and they are difficult to observe without a hand lens.

Rhyolite is volcanic rock, of felsic (silica-rich) composition (typically > 70% SiO_2).

The mineral assemblage in rhyolite is usually: quartz, alkali feldspar (sanidine) and plagioclase (mainly oligoclase) as phenocrysts.

Rhyolite is dominated by quartz (>20%) and alkali feldspar (>35%) with alkali feldspar present in at least twice the amount of plagioclase.

Ferromagnesian or dark minerals in rhyolite are rare as phenocrysts, and being mostly biotite when present. Hornblende and oxides are common accessory minerals.

The groundmass of rhyolites is microfelsitic, or spherulitic and composed essentially of feldspars and one or more silica minerals. Rhyolites may have any texture from glassy to aphanitic to porphyritic with fine-grained or glassy groundmass.

Slower cooling during formation of rhyolite forms micro-crystals, and results in textures such as flow foliations, spherulitic, and nodular textures. Some rhyolite is highly vesicular called **Pumice**.

Rhyolites that cool too quickly, they have no chance to grow crystals and form a natural glass and consist mainly of glass, and called **Obsidian**. Most of obsidians are banded due to small differences in composition in the glass.

What are the common differences between rhyolite and granite?

Certain differences between rhyolite and granite are noteworthy:

- Muscovite occurs a common mineral in some granites.
- Muscovite occurs very rarely, and only as an alteration product in rhyolite.
- In most granite, the alkali feldspar is a soda-poor microcline or microcline-perthite and orthoclase.
- In most rhyolites, the alkali feldspar is sanidine, and not rich in soda.
- A great excess of potassium over sodium, uncommon in granite, but it is common in rhyolites.

2-Alkali feldspar rhyolite

Alkali feldspar rhyolite, also known as red rhyolite, and is a felsic volcanic rock and is rich in the potassium feldspar minerals.

Alkali feldspar rhyolite is highly leucocratic rocks, and it commonly **is characterized by phenocryst**s of sanidine and quartz, or of sanidine alone.

Rarely small amounts of Ca-bearing plagioclase may appear among the phenocrysts in alkali feldspar rhyolites, but Ca-bearing plagioclase is always absent from the groundmass.

In some varieties of alkali feldspar rhyolites, biotite may be present in small amount in the phenocrysts.

Alkali feldspar rhyolites are those in which >90% of total feldspars are alkali feldspars and plagioclase is less than 10% of total feldspars.

The groundmass of alkali feldspar rhyolites compose mainly of alkali feldspar and cristobalite (***quartz***), and they may be in large part cryptocrystalline with small fibrous patches, spherulitic or may be microspherulitic.

3-peralkaline rhyolite

- Peralkaline rhyolite belongs to peralkaline igneous rocks.
- Peralkaline rhyolite is characterized by phenocrysts of alkali pyroxenes (e.g. aegirine, aegirine- augite), alkali amphiboles (e.g. riebeckite, arfvedsonite), and minor albite.
- Peralkaline rhyolite is originally described as alkali rhyolite. Peralkaline rhyolite is found as end-members of alkaline magma series.

4-Dacite

Dacite is a felsic extrusive rock, intermediate in composition between andesite and rhyolite. It is often found associated with andesite.

Dacite consists mostly of plagioclase with biotite, quartz, hornblende, and small amount of pyroxene (if present).

Dacite has quartz as some rounded and corroded phenocrysts, or as an element of the ground-mass.

The plagioclase ranges in dacite from oligoclase to andesine.

The relative proportions of feldspars and quartz in dacite are illustrated in the QAPF diagram.

In some dacites, sanidine occurs in small proportions, and when abundant sanidine gives rise to rocks that form transitions to the rhyodacites. Rhyodacites have phenocrysts of sanidine and can then be distinguished from dacites.

Groundmass of dacite, generally consists mostly of plagioclase mixed with interstitial grains of quartz, amphibole (mainly hornblende), biotite, tridymite, cristobalite, and sometimes glass

Dacite is the volcanic equivalent of granodiorite. Dacite has a distinct porphyritic texture.

Porphyritic dacites contain highly zoned plagioclase phenocrysts and rounded corroded quartz phenocrysts (this serves to distinguish them from andesite).

Sometimes subhedral hornblende and elongated biotite crystals grains are present in porphyritic dacites.

5- Felsite

Felsites are fine-grained of sub-volcanic to volcanic rock that may or may not contain larger crystals.

The term felsite is used by field geologists to describe microcrystalline rocks of granitic composition, with less than 20 % mafic minerals that is not notably porphyritic.

According to Greenberg (1981), the felsites are related to or comagmatic with the Younger Granites.

Felsite is a field term for a fine-grained and light-coloured igneous rock. Colour of felsites is generally of creamy, reddish, buff, yellowish brown and brown colours.

Felsites occur typically in small intrusions such as dykes and sills or at the margins of a larger intrusion.

Felsite rock consists of a fine-grained of felsic materials, particularly quartz, alkali feldspar and plagioclase, embedded in very fine grained felsitic groundmass together with subordinate amounts of biotite, and iron oxides

Felsitic texture, graphic intergrowths of quartz and K-feldspar, porphyritic and granophyric textures are characteristic of felsite rocks.

Quartz is the only silica phase present in the felsites (**felsites** not contain high **T** silica polymorphs such as **tridymite** or **cristobalite**), this leading to conclude that the felsites formed in shallow intrusions rather than volcanic rocks

Felsite rocks may be termed quartz felsite or quartz porphyry if it riches in quartz phenocrysts.

Felsites are considered subvolcanic intrusions belonging to the late, acidic members of the Dokhan volcanic.

6-Rhyodacites

Rhyodacites has characteristics, mineralogy and textures intermediate between Dacites and Rhyolities.

7- Obsidian

Obsidian is a naturally occurring volcanic glass. Obsidian is produced when felsic lava extruded from a volcano cools rapidly with minimal crystal growth. It is commonly found within the margins of rhyolitic lava.

Obsidian is extremely rich in silica (about SiO_2= 65 to 80 %), is low in water. Obsidian has a glassy lustre.

Obsidian is dark in colour, due to the presence of hematite (iron oxide) produces red and brown varieties. Other types with dark bands or mottling in gray, green, or yellow are also known

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2- Gabbro- basalt family

The gabbro- basalt family is a coarse-grained rock, and consists of mafic rocks. These rocks are dark in color and denser than rocks in the granite family.

The dark minerals (pyroxene and olivine) and Ca-plagioclase are the most domain minerals in a gabbro rocks.

Gabbro and basalt are respectively the plutonic and volcanic types of this family. Generally they have average composition of about 50 % of silica, 10 % of iron oxides, 10 % of CaO and 6 % of MgO.

The most common rock in the gabbro- basalt family is basalt. Basalt has a composition similar to that of gabbro, but it is fine-grained. Basalt is typically dark gray or black.

Other members of the gabbro - basalt family include diabase and basalt glass. The texture of diabase is finer than that of gabbro but coarser than that of basalt. Basalt glass resembles obsidian but is mafic.

Main varieties of gabbro - basalt family

The members of the gabbro - basalt family include:-

A) **-Gabbroic rocks (plutonic variety of the family)**

B) **-Volcanic rocks and hypabyssal equivalents of basic rocks**

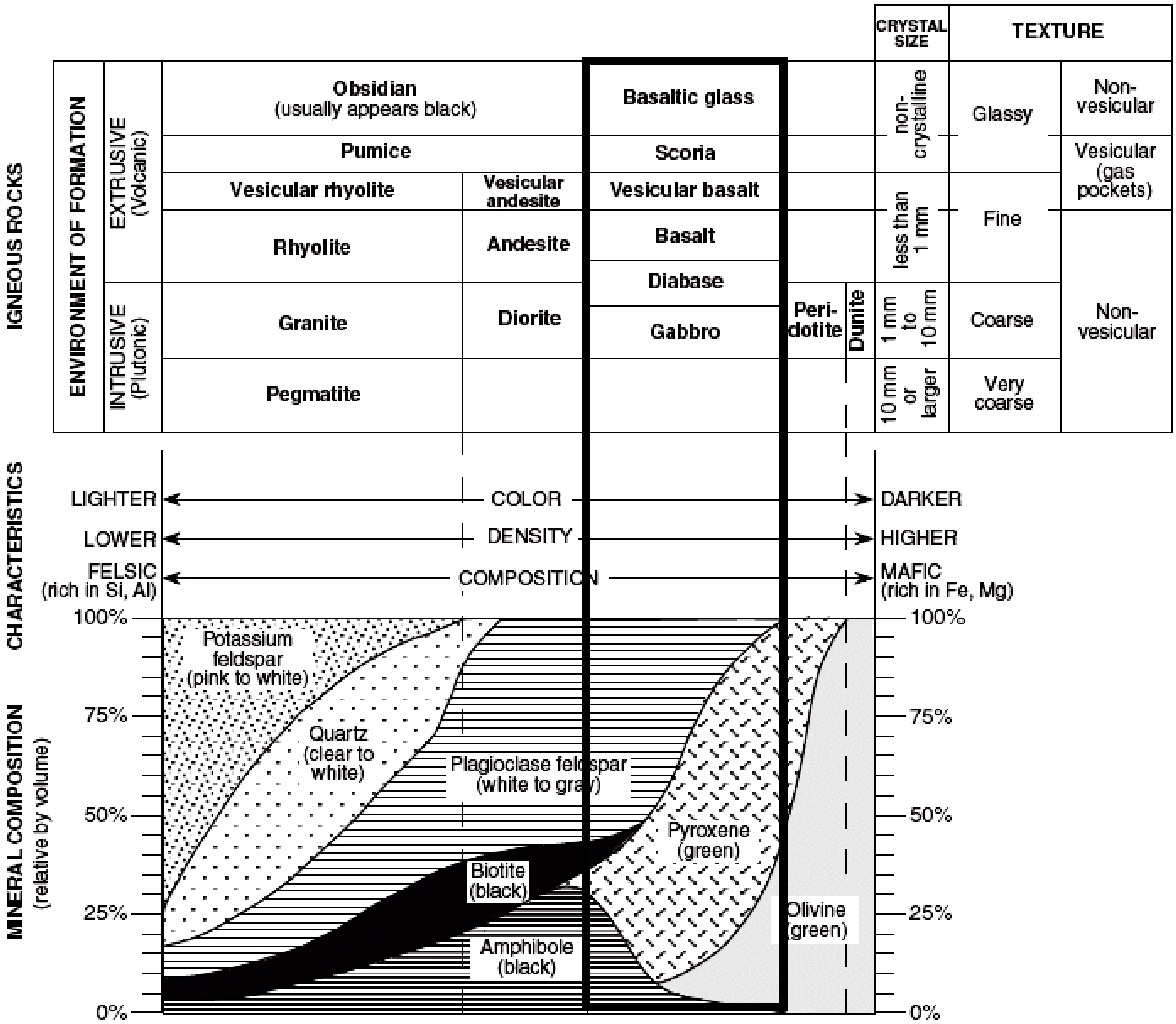


Figure 9: - Gabbro- basalt family

A- Gabbroic rocks

The main Mineralogy of gabbroic rocks is: **Ca-**Plagioclase, Orthopyroxene, Clinopyroxene, Olivine and minor amount of hornblende**.**

Texture and structure of gabbroic rocks

Some gabbros have a subhedral-granular texture, other have a poikilitic or subophitic texture in which plates of pyroxene partially enclose the crystal of plagioclase and ophitic texture. Porphyrific texture in gabbros is rare. Some gabbroic intrusions have a well-marked banded or layered structure.

The main rock types of Gabbros

The main rock types that are included under the term gabbro in the larger sense are:-

1-Normal Gabbro 2- Norite 3- Olivine Gabbro

4- Alkali Gabbro

5- Anorthosite 6- Troctolite 7- Quartz Gabbro

8- Hornblende Gabbro 9- Hornblende Norite

10- Olivine Norite

The main rock types of gabbro rocks are very briefly described below:-

1-Normal gabbro

Normal Gabbro is mafic, intrusive and coarse-grained rock. Normal gabbros are mostly dark colour, ranging between dark gray and greenish black colour, because of the high proportion of ferromagnesian minerals.

Normal gabbros are common members of the gabbro family, contain mainly ferromagnesian minerals and plagioclase, the amount of ferromagnesian minerals equalling or exceeding that of the plagioclase.

The pyroxene in normal gabbros is mostly clinopyroxene (augite) with or without small amounts of orthopyroxene (hypersthene).

If the amount of orthopyroxene is more than 95% of the total pyroxene content then the rock is termed Norite.

The plagioclase in normal gabbros is chiefly calcic plagioclase, generally 50–60% labradorite [$(Ca, Na)(Al, Si)_4O_8$].

Normal Gabbro may also contain small amounts of olivine and sometimes amphibole (then is called hornblende gabbro).

Gabbro may be contain small amounts of quartz (quartz gabbro), but the quartz content in gabbro is less than 5% of total volume, and are probably derived from magma that was oversaturated with silica.

Gabbros may also contain small amounts of feldspathoid minerals (Foid -bearing gabbros) like nepheline.

2- Norite

Norite is a mafic intrusive igneous rock composed largely of the Ca-rich plagioclase (labradorite), orthopyroxene (hyperstene), and small amount of olivine.

Norite is a coarse-grained basic igneous rock dominated by essential calcic plagioclase and orthopyroxene.

Norite may be essentially indistinguishable from gabbro without thin section study under the petrographic microscope.

The principal difference between **norite** and **gabbro** depends mainly on the type of pyroxene of which it is composed.

Norite is predominately composed of orthopyroxenes (orthopyroxene is more than 95% of the total pyroxene content) and largely high magnesian enstatite or an iron bearing intermediate hypersthene,

Norites may have accessory olivine, and then it is olivine norite, but olivine norites in which olivine as an essential mineral, appear to be rare.

3 - Olivine Gabbro

Gabbro with **>** 5% olivine is called olivine gabbro. Olivine gabbro is predominately composed of clinopyroxenes (augite), olivine and calcic plagioclase

Plagioclase in olivine gabbro is ranging from labradorite to bytownite in composition.

Orthopyroxene in olivine gabbro sometimes is present only as accessory constituent.

4 - Alkali Gabbro

Alkali gabbros differ from gabbros in having **titaniferous augite** (Ti-rich variety of Augite) as their usual pyroxene; **amphibole may be hastingsite** (alkali amphibole).

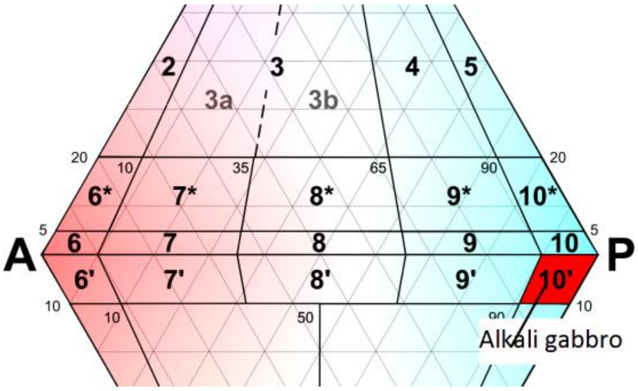
Sometimes alkali gabbros have olivine as a further constituent.

Alkali gabbros contain small amounts of feldspathoid minerals (like nepheline)

Plagioclase in alkali gabbro is ranging in composition from about **An_{50}** to **An_{70}** **.**

Alkali gabbros occur as small intrusions associated with other alkali rocks.

*Alkali gabbro is **in section 10'** of the **QAPF** diagram.*



5-Anorthosite

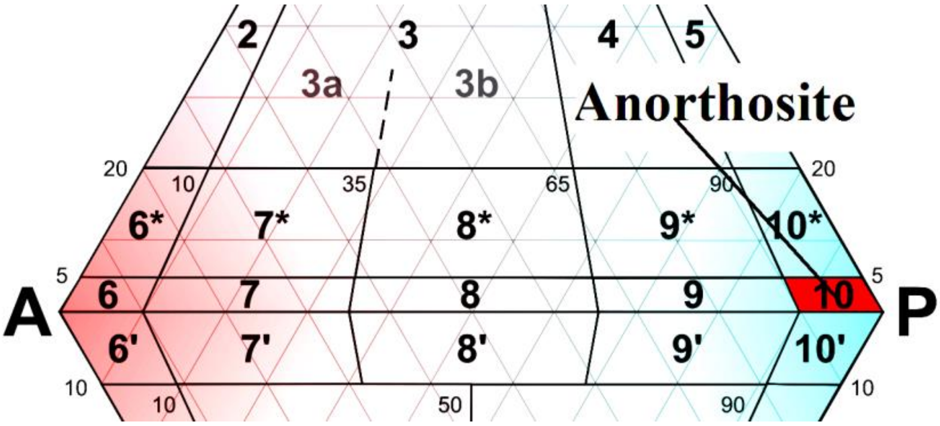
Anorthosite is a coarse-grained mafic intrusive igneous rock consisting mostly of calcic plagioclase (usually labradorite) makes up more than 90 % by volume of the rock and <10% by volume of the rock is mafic minerals.

The mafic mineral may be clinopyroxene, orthopyroxene, and more rarely olivine. Oxides, mostly magnetite or ilmenite are also common.

Anorthosites occur in two different ways: as large intrusions, or as bands or lenses forming part of gabbroic - ultramafic character.

In general, anorthosites that found as lenses in gabbroic - ultramafic intrusions have a plagioclase of more calcic composition (composition ranges from about **An$_{60}$** to **An$_{80}$**)

Anorthosite is in section 10 of the QAPF diagram.



6- Troctolite

If olivine gabbro does not contain pyroxene and is primarily **composed of calcium plagioclase and olivine,** it is known as **troctolite**.

Troctolites are gabbroic rocks made up essentially of olivine and plagioclase whose composition range from **labradorite** to **anorthite**. It is an olivine-rich anorthosite,

Troctolites are found as bands, lenses, or small masses in some layered intrusions.

Troctolite is necessarily a cumulate of crystals that have fractionated from magma.

B-Volcanic rocks and hypabyssal equivalents of basic rocks

1-Basaltic rocks

Basalt, extrusive igneous (volcanic) rock that is low in silica content, dark in colour, and comparatively rich in iron and magnesium.

A basalt is containing essential calcic plagioclase and pyroxene (usually Augite) with or without olivine.

Basalts can also contain hornblende, hypersthene (orthopyroxene) and feldspathoids.

Basalts contain between 45-50% silica, abundant Fe, Mg and Ca, and little Na.

Basalt is distinguished from pyroxene andesite by it contains more calcic plagioclase.

Some basalts exhibit porphyritic texture, with larger crystals (phenocrysts) of olivine, augite, or plagioclase in a fine crystalline matrix (groundmass). Olivine and augite are the most common porphyritic minerals in basalts

There are **two main chemical subtypes** of basalt: **tholeiites** which are silica saturated and **alkali basalts** that are silica under saturated.

The feldspathoid minerals occur in a large number of alkali basaltic rocks

Basalts may be broadly classified on a chemical and petrographic basis into two main groups: the **tholeiitic basalts** and the **alkali basalts**.

Tholeiitic basaltic basalts are characterized by calcic plagioclase with augite, pigeonite or hypersthene, and olivine (rarely) as the dominant mafic minerals.

Tholeiitic basalts, which contain 45 to 63 % silica, are **rich in iron** and include the tholeiites (basalts with calcium-poor pyroxene). Alkali basalts contain relatively high **TiO_2 (~**1.5 – 4 wt.%)

Tholeiitic basalts dominate in the upper layers of oceanic crust and oceanic islands, but ***alkali basalts*** are common on oceanic islands and in continental magmatism.

Comparison between the Tholeiitic and Alkali basalts

	Tholeiitic Basalts	**Alkali Basalts**
Formation	Mid-ocean ridges, oceanic islands	Island arcs, collision/subduction zones
Composition of Groundmass	No olivine Quartz, interstitial glass common Clinopyroxene (augite, pigeonite) Orthopyroxene is found No feldspathoid minerals	Olivine is common No quartz Clinopyroxene = Titaniferous augite (reddish) No orthopyroxene Interstitial feldspathoid minerals
Composition of Phenocrysts	Olivine rare, unzoned or has orthopyroxene rims Orthopyroxene rare Early phase of plagioclase is common Clinopyroxene = pale brown augite	Olivine is common, zoned Orthopyroxene is absent Plagioclase appears later Clinopyroxene = reddish titaniferous augite

2- Diabase (dolerite)

Diabase or **dolerite** or **microgabbro** is a mafic subvolcanic rock equivalent to volcanic basalt or plutonic gabbro.

Diabase dikes and sills are typically shallow intrusive bodies and often exhibit fine grained chilled margins.

Diabase differs from gabbros chiefly in their textural characteristics and occurrence and the nature of the pyroxenes.

Diabase has an ophytic texture, with slender plagioclase laths wrapped by anhedral to subhedral pyroxene. Sometimes the larger plates of pyroxene may enclose the plagioclase crystals.

Diabase is the preferred name in North America, yet ***dolerite*** is the preferred name in most of the rest of the world

Diabase normally has a fine, but visible texture of euhedral lath-shaped plagioclase crystals (60% by volume of the rock) set in a finer groundmass of clinopyroxene, typically augite (20–30%), with minor olivine (3% up to 10% in olivine diabase), magnetite and ilmenite as accessories

The texture is termed diabasic and is typical of diabases. This diabasic texture is also termed interstitial texture.

The plagioclase in diabase is high in anorthite and most commonly labradorite.

Diorite- andesite family

Diorite - andesite family: Diorite and andesite are the plutonic and volcanic type rocks of this family

The diorite- andesite family is intermediate in compositions between granite – rhyolite and gabbro- basalt families.

Diorites are rich in the dark coloured ferromagnesian minerals. They are usually dark-gray or greenish, running into black in some varieties. The dark colour results from the colour of the hornblende and other mafic minerals to the proportion of plagioclase.

With regard to silica content, this family is intermediate group, namely 52 % to 66 % silica, with more than 66% silica the diorites pass into the granodiorites, and with less than 52 % silica, diorites pass into the gabbros.

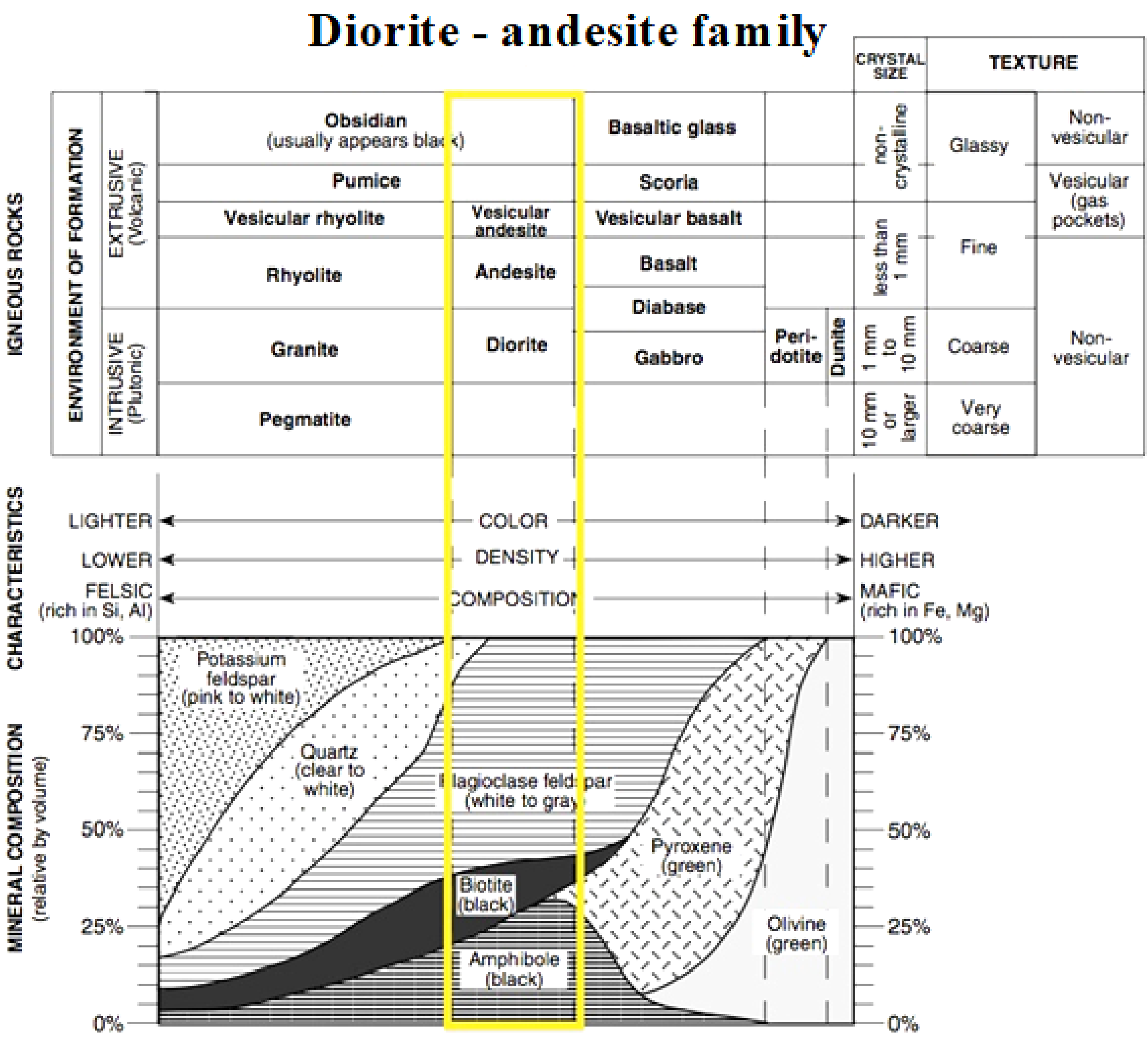


Figure 10: Diorite- andesite family

The texture of the diorite is the granular texture. The porphyritic texture is far less common than in granite. Sometimes the black hornblende prisms are distinct enough to produce porphyritic texture.

The dominant feldspar is soda-lime feldspar ranging from **oligoclase** to **andesine**, but small amount of orthoclase may present in diorites.

Hornblende and biotite are present in considerable amounts in diorites. Usually more or less iron oxide in fine grains present in diorites.

Quartz often occurs interstitially between minerals, in some varieties of diorites.

Pyroxenes is so less abundance in diorites relative to gabbros

The the main rock types of Diorite - Andesite family

The main rock types of Diorite - Andesite family include:-

A - Dioritic rocks: include the following rock types:

1-Hornblende-biotite diorite 2- Biotite diorite

3-Hornblende diorite

4-Augite – diorite 5-Quartz - diorite

6-Porphyritic hornblende quartz -diorite

7- Monzodiorite

8-Quartz-monzodiorite 9 Alkali diorite

10- Foid -bearing diorite

11- Foid -bearing monozodiorite

B - Andesitic rocks : include the following rock types:

1-Basaltic andesite 2- Pyroxene andesites

3 - Hornblende - porphyritic andesite

4- latite-andesite

A -Dioritic rocks

Typical diorites are medium- or course- grained rocks in which plagioclase feldspar (andesine or calcic oligoclase) is the predominant mineral and hornblende and biotite and /or pyroxene are the chief mafic constituents.

Some of varieties of diorite rocks contain small amounts of quartz, with increasing quartz content, diorite are transitional into quartz diorites.

More basic diorites, usually carry pyroxene, and cannot be easily distinguished from gabbros. When olivine and more iron-rich augite are present in diorite, the rock grades into ferro-diorite, which is transitional to gabbro.

If orthoclase (potassium feldspar) is present at greater than 10 percent the rock type grades into **monzodiorite**.

The main differences between Diorite and Gabbro rocks:

The petrographic study can be distinguishing between **diorite** and **gabbro** rocks.

1) Gabbros are characterized by more calcic plagioclase and are more mafic than diorites.
2) Pyroxene is an essential mafic mineral in gabbros, while the commonest mafic mineral in diorites is hornblende.

3) Pyroxenes are so less abundance in diorites but more basic diorites usually carry small amount of pyroxenes.
4) Gabbros form intrusions of large size.
5) Diorites occur as small bodies, or perhaps as a phase, often as border phase of larger siliceous intrusions.
6) Diorite must also be distinguished from hornblende gabbro, where hornblende gabbro contains more basic feldspars (Ca -Plagioclase), sometimes olivine and no quartz.

Mineralogy of diorites

The commonest kinds of diorites consist essentially of plagioclase feldspar (oligoclase to andesine), hornblende, biotite, and trace of interstitial quartz and orthoclase and/or pyroxene. Zoning plagioclase crystals are common in diorites

Hornblende: is a common constituent of many diorites, and is commonly present as subhedral, prismatic crystals.

Biotite: is present of many diorites. It is found as flakes of small tablets in association with hornblende.

Pyroxene: when present, it is found as clinopyroxene.

The main accessories are zircon, sphene and iron-oxides (ilmenite, magnetite).

Usual classification and definition of the diorites based on the ferromagnesian minerals (e.g. **Hornblende diorite**, **Augite diorite)**. Further varieties of diorites are defined based on the occurrence of **quartz** or **feldspathoids** and considering the relative amount of **alkali feldspar** and **plagioclase** (e.g. Quartz-diorite, Monzodiorite**)**

Main varieties of dioritic rocks

The main varieties of dioritic rocks are very briefly described below:-

1 - Hornblende-biotite diorite (normal diorite)

It is one of the commonest types of dioritic rocks and composed essentially of zoned plagioclase, hornblende, and biotite with accessory orthoclase.

2- Biotite - diorite

It is one of the diorites, composed essentially of plagioclase and biotite, accompanied by minor amount of hornblende.

Pyroxens are often absent. Quartz is commonly presents, with increasing quartz content, transitions into quartz diorites.

The percentage of orthoclase varies widely, and occurs as anhedral interserial between plagioclases.

With extreme decreasing in amount of biotite and increasing hornblende, this type of diorites transitions to **Hornblende diorite**.

3- Hornblende diorite

It a coarse grained diorite with prominent porphyritic hornblende and plagioclase phenocrysts set in a fine-grained groundmass which is predominantly by plagioclase and hornblende and small amount of biotite.

4 - Augite – diorite

It is a dioritic rock in which augite is a prominent mafic mineral. It is composed essentially of augite (iron-rich augite), hornblende and plagioclase.

The plagioclase in this type of diorites ranges in composition from andesine to labradorite and is partially zoned.

There is a little accessory biotite and orthopyroxen with/ or not olivine (this type of diorites without quartz).

5 - Quartz-diorite

Quartz diorite is a variety of diorites with felsic composition.

Quartz diorite is variety of diorites containing quartz and less potassium feldspar (orthoclase). Quartz is present at between 5% and less than 20% of the rock.

The plagioclase varies from oligoclase to andesine.

Biotite and hornblende are common dark accessory minerals in Quartz diorite.

6 - Porphyritic hornblende quartz diorite

It is facies of the quartz diorite, in which hornblende is the dominant phenocrysts mafic mineral.

This rock is composed mainly of hornblende phenocrysts (long narrow, dark -green laths) in a fine-grained groundmass, which is predominantly by plagioclase, hornblende and considerable amount of quartz and orthoclase.

7 - Monzodiorite

It is consisting essential of plagioclase, biotite, orthoclase, and hornblende, with or / without pyroxene.

Plagioclase is the dominant feldspar of the total feldspar and varying from oligoclase to andesine in composition.

The presence of the considerable amount of orthoclase distinguishes this rock from a normal diorite.

The principal difference between monzodiorite and monzogabbro is based on the type of plagioclase (*in monzodiorite and monzogabbro, plagioclase is dominant, and making up between 65 and 90 % of the total feldspar content*).

Plagioclase varies from oligoclase to andesine in composition in **monzodiorite**, whereas plagioclase is labradorite in **monzogabbro**.

8- Quartz-monzodiorite

It is a variety of monzodiorite, composed of plagioclase, alkali feldspar, quartz and mafic minerals (hornblend, biotite). This rock characterise by 5-20% quartz and 10-35% alkali feldspar on the **QAPF** diagram.

9 - Alkali diorite

It is a variety of diorite with alkaline character due to the presence of dark minerals as **alkali amphibole minerals**.

It is a variety of diorite, composed essentially of Ca-Na plagioclase, alkali amphibole, alkali pyroxene, nepheline, orthoclase with or / without biotite.

B- Andesitic rocks

Andesite is a gray to black volcanic rock, with aphanitic to porphyritic texture. In a general sense, it is the intermediate type between basalt and dacite, and ranges from 57 to 63% silicon dioxide (SiO_2) as illustrated in **TAS** diagrams.

The mineral assemblage is typically dominated by plagioclase (esp. andesine) with one or more of the mafic minerals as hornblende and augite, or biotite (usually small amount), with a groundmass composed generally of the same minerals. Magnetite, ilmenite and quartz are common accessory minerals in andesite.

Alkali feldspar may be present in minor amounts in andesite; and increasing in the percentages of alkali feldspars marks the change from andesite into trachyandesite.

Some of the andesites that cool rapidly may contain amount of glass, and others have a vesicular or amygdaloidal texture.

Mineralogy of andesites

The main mineral compositions of andesites are:

Plagioclase: is the dominated mineral. The plagioclase is often as phenocrysts as well as small laths in the groundmass.

The plagioclase phenocrysts are usually zoned and show a considerable variation in composition, cores of phenocrysts are more calcic and outer zones are oligoclase.

The plagioclases of the groundmass are in general less calcic and may show some zoning.

Augite: is the second most abundant type of phenocrysts in Andesite, the core of the augite crystals in andesite usually has more Ca- composition. Augite is also the most abundant crystals in the groundmass

Orthopyroxene: is rare and found in some andesites (e.g. basaltic andesite). It may be present as phenocrysts, or in the groundmass, or in both situations.

Hornblende and biotite: When they present, are usually forming phenocrysts.

Main varieties of andesite rocks

The main varieties of andesite rocks are very briefly described below:-

1-Basaltic andesite

It is a volcanic rock and it is distinct from basalt and andesite in having a different percentage of silica content. Basaltic andesite composed mainly of plagioclase, clinopyroxene (augite) and hornblende phenocrysts set in a fine – grained groundmass that consist of plagioclase, augite and olivine.

2 - Pyroxene andesite

When both pyroxene groups (clino- and orthopyroxene) occur in andesitic rock, it is called -**pyroxene-andesite**.

In these rocks, the pyroxene minerals dominate as phenocrysts, and carry abundant phenocrysts of zoned plagioclase with some hornblende. The dominant clinopyroxene in pyroxene andesites is Ca- augite.

Pyroxene Andesites generally have plagioclase with cores of calcic plagioclase and rims mainly of oligoclase. Generally, plagioclases are in a groundmass as andesine or oligoclase.

3 - Hornblende - porphyritic andesite

It is a volcanic rock carries abundant of plagioclase with hornblende as the principal phenocrysts.

4 - Latite-andesite

It is a porphyritic, volcanic rock containing phenocrysts of zoned plagioclase, augite (clinopyroxene), and some orthopyroxene, set in a groundmass of plagioclase (andesine), alkali feldspar, pyroxene, and iron oxides.

Usually alkali feldspar and plagioclase in approximately equal amounts in **latite-andesite.**

Latite-andesite is transitionally to a true **andesite**, which is characterized by plagioclase forming more than 90% of the total feldspar content.

4) Syenite - trachyte family

Syenite among plutonic rocks and trachyte among volcanic rocks are the types of this family. This rock types are not rich in silica as the members of the granite rhyolite family

Syenitic rocks form relatively small intrusive bodies or parts of larger intrusions. Most syenitic seem to be associated with extensional tectonic regime (rifting continents).

Some of syenitic rocks are believed to be fractionation products of alkali-rich basaltic magmas, but there are several different mechanisms responsible for the genesis of a syenitic magma.

In this family the magma much resembles that of the granite group, except that the quantity of silica is less (50 to 65 %); hence it is nearly or quite taken up in the formation of silicates, leaving little or none to crystallize out separately as quartz, and orthoclase is thus the chief mineral. Syenite is much resembling granite in appearance but having less or no quartz.

Syenite is composed typically of orthoclase, perthite and hornblende, with plagioclase, and accessories.

Some syenites contain larger proportions of mafic components and smaller amounts of felsic material than most granite; those are classed as being of intermediate composition.

When the hornblende is replaced by biotite in syenite, the rock is called mica syenite, and when by augite, called augite syenite.

Foid syenites contain significant amount of feldspathoids (**F**) minerals. Nepheline Syenite is marked by the presence of nepheline

Trachyte is a volcanic rock, consisting of phenocrysts of sanidine and groundmass of fine feldspar crystals, but having little or no glass, together with more or less, amphibole, pyroxene or biotite.

On the **QAPF** classification diagram, Different syenitic rock types cover large part of the diagram

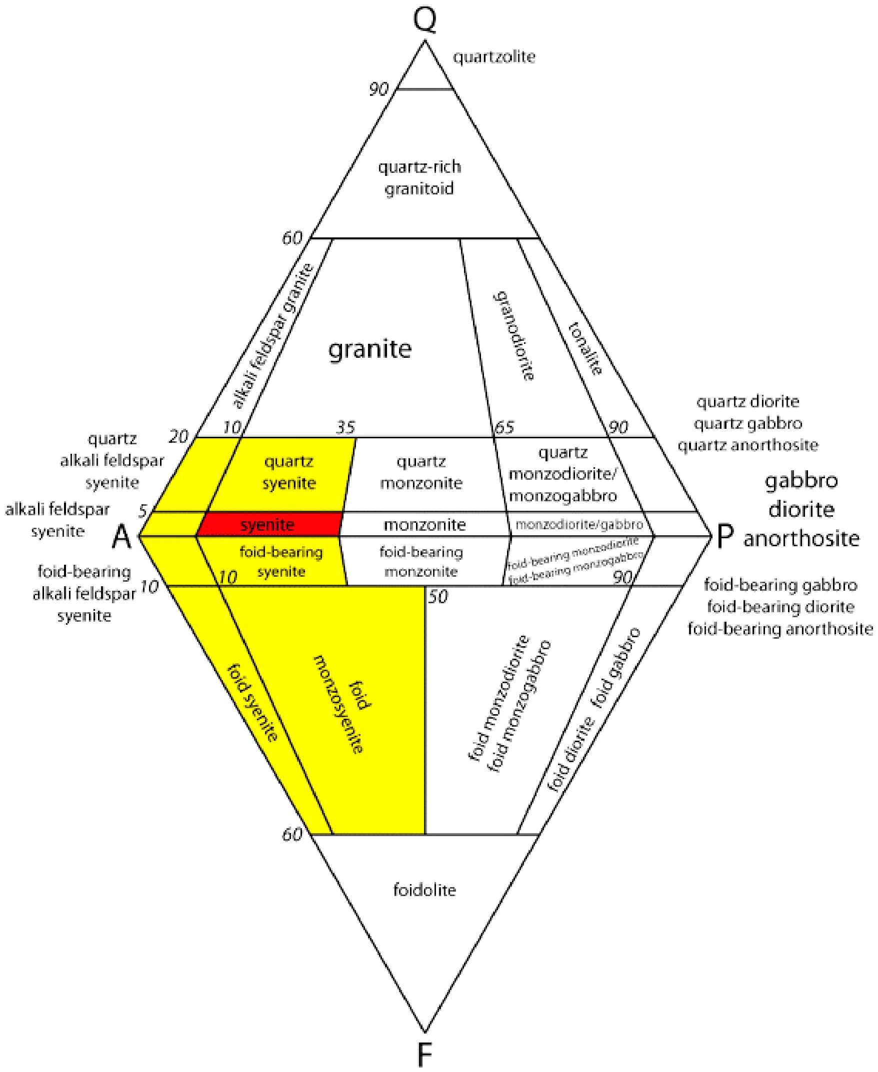


Figure 11: Syenite - trachyte family

The the main rock types of Syenite - trachyte family

1-Syenite 2-Quartz-syenite 3-Foid-bearing syenite

4-Alkali-feldspar syenite 5- Foid-bearing alkali feldspar syenite

6- Quartz-alkali feldspar syenite 7-Trachyte

8- Quartz- trachyte 9-Foid-bearing trachyte

10-Alkali feldspar trachyte

11- Foid-bearing alkali-feldspar trachyte

12- Quartz-alkali feldspar trachyte **13 - Phonolite**

The main varieties of of syenite - trachyte family are very briefly described below:-

1-Syenite

Syenite is a feldspar-rich plutonic rock. Syenite is an intrusive rock belonging to the alkali series plutonic rocks.

Syenite is a coarse-grained intrusive igneous rock of the same general composition as granite but with the quartz either absent or present in very small amounts (**<**5%).

The feldspar component of syenite is predominantly alkali feldspar (e.g. orthoclase and perthite), and it is **>** 65% of total feldspar. Plagioclase presents in small quantities.

Clinopyroxene, hornblende or olivine and biotite may be present in minor proportions in syenites.

Syenites are usually either **peralkaline** with high proportions of alkali elements relative to aluminum, or **peraluminous** with a higher concentration of aluminum relative to alkali elements.

General mineralogy of syenite

**** Alkali feldspar**: alkali feldspar content is **>** 65% of total feldspar, include, orthoclase, microcline, microperthite and albite.

Potash feldspar forming the majority of most syenitic rocks, and is usually intergrown with sodium-rich plagioclase feldspar (is named perthite)

**** Ca-bearing plagioclases**: are usually oligoclase.

** **Hornblende**: is the common amphibole of syenite, but soda-and iron-rich amphiboles such as **arfvedsonite** may occur in peralkaline syenite and **ferrohastingsite** in alkali syenite.

** **Mica**: is biotite.

** **Clinopyroxene**: when present in syenite, is augite or diopsidic.

Common accessory minerals : are apatite, titanite, zircon and other opaques.

Difference between granite and syenite

Granite contains between 20% and 60% quartz by volume, and at least 35% of the total feldspar consisting of alkali feldspar.

Granite mainly consists of feldspar, quartz, with scattered biotite mica and amphibole minerals.

Syenite is a coarse-grained intrusive igneous rock with a general composition similar to that of granite, but deficient in quartz (i.e. <5%). The alkali feldspar minerals in syenite are predominant. Syenites are much less common than granites

2-Quartz-syenite

Quartz-syenite is syenitic rock with 5-20% quartz on the **QAPF** diagram, and **no feldspathoids** minerals.

3-Foid-bearing syenite

Foid-bearing syenite is syenitic rock with no quartz and containing up to **10% feldspathoids** minerals

4-Alkali feldspar syenite

Alkali feldspar syenite is a syenitic rock, where plagioclase is less than 10% of the total feldspar.

5- Foid-bearing alkali feldspar syenite

It is an alkali-feldspar-syenite with no quartz and contains feldspathoid minerals (e.g. **Nepheline**,…) up to 10% by volume. They are distinguished from ordinary syenites not only by the presence of nepheline but also by the occurrence of many other minerals rich in alkalis.

Nepheline Syenite: A syenitic rock composed essentially of alkali feldspar and nepheline (nepheline is the most abundant feldspathoid). It may contain alkali ferromagnesian minerals, such as an amphibole (riebeckite, arfvedsonite) or a pyroxene (aegirine or aegirine-augite). In addition, apatite, sphene, and opaque oxides, are common accessories.

6- Quartz-alkali feldspar syenite

It is an alkali-feldspar-syenite with 5-20% quartz, and no feldspathoids minerals.

7-Trachyte

Trachyte is a feldspar-rich volcanic rock. Trachyte is light-coloured, fine-grained extrusive igneous rock. Compositionally, trachyte is the volcanic equivalent of the plutonic rock syenite.

Trachyte is composed chiefly of alkali feldspar with minor amounts of dark-coloured minerals such as biotite, amphibole, or pyroxene (normal trachytes may contain diopside).

Most trachytes show porphyritic texture in which abundant, large and well-formed crystals (phenocrysts) of early generation are embedded in a very fine-grained matrix (groundmass). The phenocrysts are usually sanidine, also smaller phenocrysts of other minerals may also occur.

Trachyte shows a banded structure due to flowage of the congealing lava. This structure may be revealed by a parallel arrangement of large tabular phenocrysts.

Microscopic examination of thin sections reveals the trachytic texture of the fine matrix; is tiny lath-shaped sanidine crystals are closely packed in parallel fashion and form flow lines that tend to wrap around the large phenocrysts.

Rapid cooling and solidification of trachytic lava produces the fine texture of the groundmass, and may be small quantities of glass.

Two types of trachyte are commonly recognized as **Potash trachyte** or **normal trachyte** and **Soda**, or **alkali trachyte**:

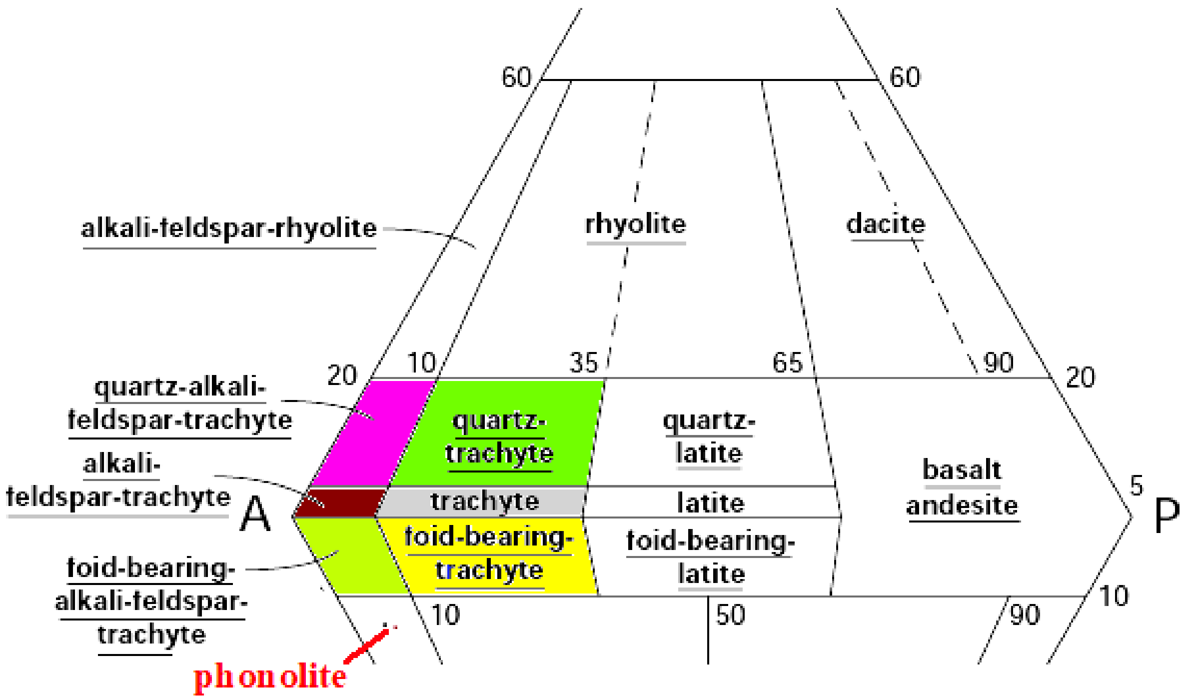
- In normal trachyte, sanidine or orthoclase is the dominant feldspars, with considerable amount of Lime-bearing plagioclases (generally oligoclase).
- In soda, or alkali trachyte, both the feldspar and the dark minerals are rich in sodium. The alkali feldspar becomes predominant

As the ratio of alkali feldspar to plagioclase **decreases**, trachyte passes into **latite**.

Silica-rich trachyte may have small amounts of quartz, tridymite and cristobalite are commonly found interstitial to feldspar.

As the free silica content (*quartz, tridymite and cristobalite*) **increases**, trachyte passes into **rhyolite**.

Decreasing in silica favours the formation of such feldspathoids as, nepheline. With the increasing of quantity of feldspathoids, trachyte passes into **phonolite**.



8- Quartz trachyte

It is Trachytic rock that contains between 5 to 20 % quartz in the **QAPF** fraction. It is silica-rich trachyte, and may have small amounts of quartz that is interstitial to feldspar; also tridymite and cristobalite are commonly found.

9- Alkali feldspar trachyte

It is a trachytic rock, where plagioclase is less than 10% of the total feldspar. Alkali trachyte is rich in sodium, and alkali feldspars are strongly perthitic or anorthoclase, and plagioclase is albite or albite-oligoclase.

Mafic minerals in **alkali trachyte** are **iron-rich**, e.g. (Fe-rich biotite) (amphiboles including hastingsite, arfvedsonite or riebeckite) and (pyroxenes including aegirine-augite and aegirine)

10- Quartz-alkali feldspar trachyte

It is trachytic rocks, comprising 5-20% quartz and alkali feldspar > 90% of total feldspar

11- Foid-bearing trachyte

Trachytic rocks, comprise **<**10% feldspathoid minerals and alkali feldspar from 65 -90% of total feldspar

12- Foid- bearing alkali feldspar trachyte

Trachytic rocks, comprise **<**10% feldspathoid minerals and alkali feldspar is more than 90% of the total feldspar.

13 - Phonolite

Phonolite rock belong alkaline igneous rocks. Phonolitic rocks have felsic composition, comprising 10 - 60% feldspathoid minerals and alkali feldspar is more than 90% of the total feldspar.

Phonolite is extrusive or fine grained igneous rock equivalent to nepheline syenite.

Phonolite is any member of a group of extrusive igneous rocks (lavas) that are rich in nepheline and potash feldspar.

The most important constituent of phonolite is alkali feldspar, either sanidine or anorthoclase, which forms not only the bulk of the groundmass (matrix) but forms most of the large crystals (phenocrysts) in porphyritic varieties.

Nepheline rarely appears in large crystals but may occur either interstitially or in well-formed microphenocrysts in groundmass.

The principal dark-coloured mineral in phonolite is pyroxene (aegirine or titaniferous augite). Pyroxene phenocrysts occur as well-formed crystals; and pyroxene in the groundmass occurs as slender needles. Often abundant pyroxene is enough to colour the rock green. An alkali amphibole (barkevikite, riebeckite, or arfvedsonite) always occurs as phenocrysts.

Feldspathoids other than nepheline may be present as accessory minerals; the most common are sodalite, and leucite

Monzonite -latite family

The main varieties of of monzonite -latite family are very briefly described below:-

1 - Monzonite

Monzonite is an intermediate igneous intrusive rock. Monzonite is one of the rocks which dominated by feldspar. Monzonite is composed of approximately equal amounts of K–feldspars and Na–plagioclase with minor amount of quartz (<5%) and it also contains subordinate amounts of ferromagnesian minerals (hornblende, biotite and pyroxene).

Monzonite is defined as rock having less than 5% quartz in its **QAPF** classification and in which alkali feldspar makes up between 35% and 65% of the total feldspar content. The plagioclase in monzonite is sodium-rich, ranging from oligoclase to andesine, and is moderately well shaped (subhedral to euhedral). The alkali feldspar is typically orthoclase.

If quartz in monzonite constitutes greater than 5% of the **QAPF** classification, the rock is termed a **quartz monzonite**

If feldspathoids in monzonite are present as up to 10% of the **QAPF** classification, the rock is termed a feldspathoid-bearing monzonite.

If monzonite rock is rich in alkali feldspar is classified as syenite, while rock richer in plagioclase is termed a monzodiorite.

Monzonite is a relatively uncommon rock type. It usually does not form its own plutons, but is typically found around the edges of other felsic plutons, such as plagiogranites or granodiorites. Monzonitic magma most likely forms only a part of generally more acidic (granitic) intrusions.

Although monzonite itself is not a particularly well-known or widespread rock type, but it has given part of its name (monzo-) as a prefix to several other varieties of plutonic rocks (monzogranite, monzogabbro, foid monzosyenite,.. etc.). This prefix means that there are significant amount of both alkali and plagioclase feldspars. Because monzonite is light colored it is often confused with granite but granite has quartz **>**20%

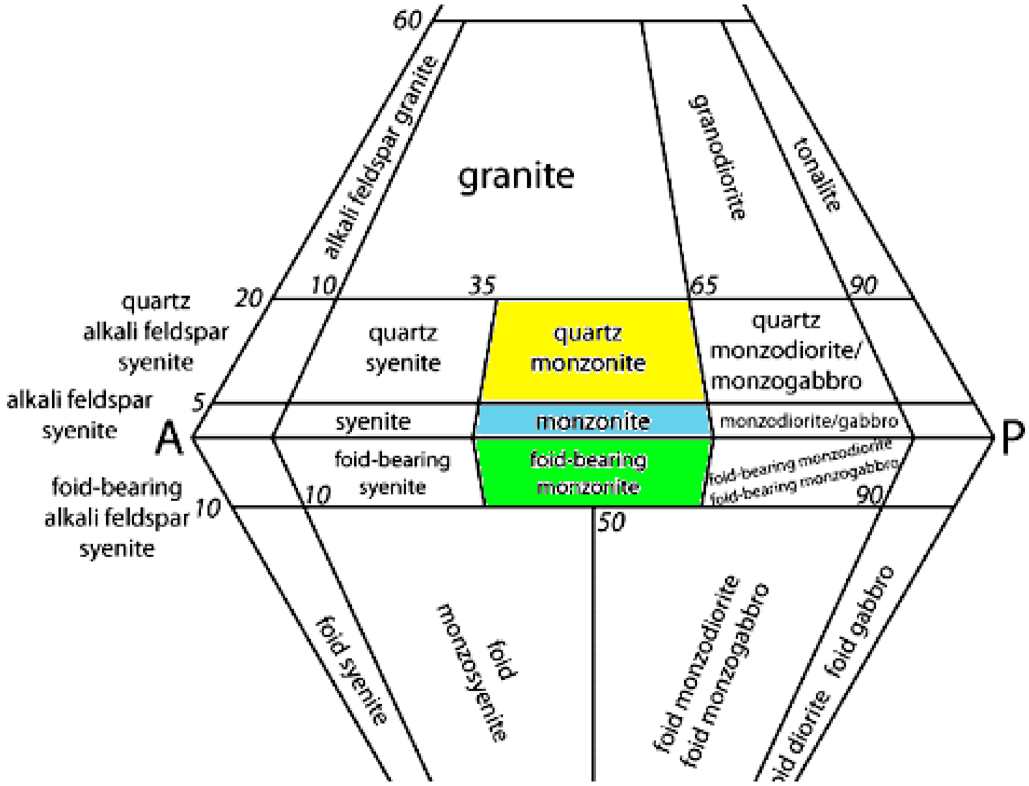


Figure 12: Monzonite -latite family

2 - Quartz monzonite

Quartz monzonite (**adamellite)** is an intrusive, felsic, igneous rock that has an approximately equal proportion of alkali feldspar (mainly orthoclase) and plagioclases.

It is typically a light colored phaneritic (coarse-grained) to porphyritic rock. The plagioclase is typically intermediate to sodic in composition (andesine to oligoclase). Quartz is present in significant amounts. Biotite and/or hornblende constitute the dark minerals.

Because of Quartz monzonite is a rock similar to granite in general character, its coloring and appearance but different in mineralogical and chemical composition, it is often confused with granite, but whereas granite contains more than 20% quartz, quartz monzonite contains only 5% to 20% quartz. Chemically, granite contains more of the alkali metals sodium and potassium and less calcium than quartz monzonite and granite also contains more silica.

Quartz monzonite differs from **granodiorite** by containing more alkali feldspar, usually more biotite and less hornblende, and oligoclase instead of andesine as the plagioclase mineral.

3 - Monzogabbro

Monzogabbro is a coarse-grained igneous rock consisting of essential plagioclase feldspar, pyroxene, and orthoclase with or without biotite. Plagioclase of **labradorite** composition is the dominant feldspar and making up 60–90% of the total feldspar. The presence of orthoclase feldspar distinguishes this rock from a gabbro. Monzogabbro rock contains between 0 to 5 % quartz and no feldspathoid minerals.

4 - Monzodiorite

Monzodiorite is consisting essential of plagioclase, biotite, orthoclase, and hornblende, with or / without pyroxene. Plagioclase is the dominant feldspar making up 60–90% of the total feldspar and varying from **oligoclase** to **andesine** in composition.

The presence of the considerable amount of orthoclase distinguishes this rock from a normal diorite.

The principal difference between monzodiorite and monzogabbro is based on the type of plagioclase: plagioclase varies from oligoclase to andesine in composition in **monzodiorite**, whereas plagioclase is labradorite in **monzogabbro**.

5 -Latite

Latite also called **trachyandesite**: it is extrusive igneous rock. Usually, the colour of latite is white, yellowish, pinkish, or gray.

Latite is a volcanic igneous rock that typically occurs as porphyry, which is characterized by the presence of large phenocrysts of plagioclase and K-feldspar in nearly equal proportions.

Latites contain calcium-rich plagioclase (andesine or oligoclase) and K-feldspar (sometimes sanidine) as phenocrysts (they also contain phenocrysts of pyroxene, and sometimes biotite and hornblende) in a fine-grained matrix of orthoclase feldspar and pyroxenes.

Biotite, hornblende, pyroxene and scarce olivine, or quartz are common accessory minerals in Latites.

Latites are the volcanic equivalents of monozonites and, as such, they are members of the calc-alkaline magma series.

Latite is chemically intermediate between trachyte and andesite. Quartz in latite is less than five percent and is absent in a feldspathoid-bearing latite, and olivine is absent in a quartz-bearing latite. When quartz content is greater than 5 % (become rich in quartz) the rock is classified as quartz latite.

Peridotites family

Peridotites are a group of ultrabasic igneous rocks containing more than 40 vol% olivine with or without orthopyroxene and clinopyroxene. Accessory phases include spinel, plagioclase, ilmenite, chromite and magnetite.

Peridotite is a dense, coarse-grained ultrabasic igneous rock, consisting mostly of the minerals olivine and pyroxene. Its composition varies, depending on the mineral content of the rock.

Generally, peridotite is rich in magnesium, with appreciable amounts of iron, and less than 45% silica. It is therefore described as ultramafic or ultrabasic rock. Magnesium rich olivine forms a large part of the peridotite and therefore it has high magnesium content.

Peridotites can also form as cumulates in layered ultrabasic intrusions; peridotites from these layered igneous complexes vary widely, reflecting the relative proportions of pyroxenes, plagioclase, and chromite. Cumulate peridotites often have cumulate textures and exhibit preferred crystal orientation.

It is thought that peridotites originated as cumulate rocks formed by the precipitation of olivine and pyroxenes from basaltic or ultramafic magmas. These magmas are ultimately derived from the upper mantle.

The rocks of the peridotite family are uncommon at the surface and are highly unstable, because olivine reacts quickly with water at typical temperatures of the upper crust and at the Earth's surface. This hydration reaction of the peridotites involves considerable increase in volume with deformation of the original textures.

Many surface outcrops of the peridotites have been at least partly altered to serpentinite, a process by which the pyroxenes and olivines are converted to green serpentine.

Peridotites are scarce in much of the Earth's crust, and there are a few places on Earth where mantle rocks have been uplifted to the surface

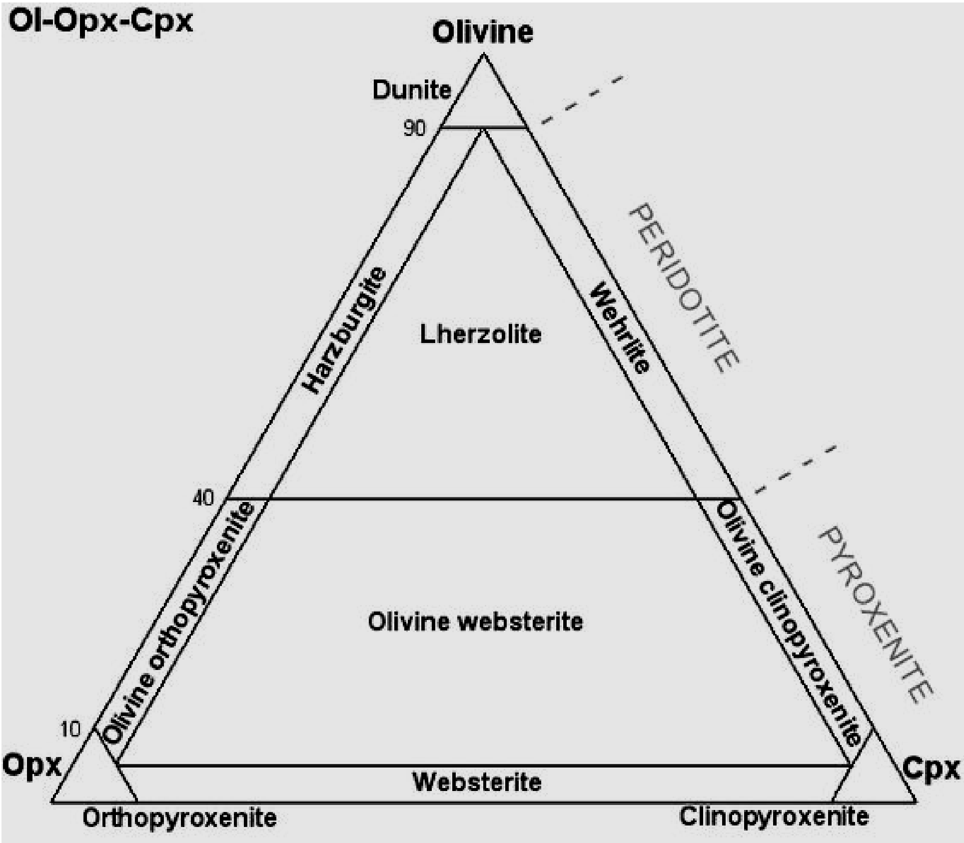


Figure 13: Peridotites family

Mineral chemistry of peridotites

Olivine in peridotites is usually magnesian ($Fo_{60–95}$); it also carries appreciable **Ni** (500–5,000 ppm.) with variable amounts of **Co**.

Orthopyroxene in peridotites is also generally magnesian (En_{60-95}) with variable amounts of **Cr** and **Ni**.

Some peridotites carry high-**Al** pyroxene. Clinopyroxenes are invariably calcic and both augitic and diopsidic species are common; high **Al-**clinopyroxenes species are widespread in peridotites, with high contents of **Ni**, **Co**, and **Cr.**

Amphiboles are usually aluminous, with **Mg : Fe^{2+}** ratios **>** 1. Micas can be either biotite or phlogopite. Spinels show wide compositional variation, but fall between the end-members. The **Mg : Fe^{2+}** ratio in **Spinels** is usually >1, but the **Cr** : **Al** show wide variation, with defining high **Cr**. Feldspars are calcic plagioclase (**An**$_{60-95}$).

Sulfides may be locally important in peridotites with variable amounts of **Co** and **Cu**. Platinide group elements may also be important.

Rock types of Peridotites

1 - Dunite

Dunite is light green intrusive igneous rock of ultramafic composition and with phaneritic (coarse-grained) texture. Dunite usually forms sills (tabular bodies intruded between other rocks) but may also occur as lenses (thin-edged strata) or pipes (funnels, more or less oval in cross section). The mineral assemblage is greater than **90% olivine**, with **minor amounts of other minerals** such as pyroxene, chromite, and magnetite. Dunite is the olivine-rich endmember of the peridotite group of mantle-derived rocks.

Dunite is rarely found within continental rocks, but where it is found, it typically occurs at the base of ophiolite sequences where slabs of mantle rock from a subduction zone have been thrust onto continental crust during continental collisions (orogeny).

Dunite typically undergoes retrograde metamorphism in near-surface environments and is altered to serpentinite.

Dunite may also form by the accumulation of olivine crystals on the floor of large basaltic magma chambers. These "cumulate" dunites typically occur in thick layers in layered intrusions, associated with cumulate layers

2- Pyroxenite

Pyroxenite is an ultramafic igneous rock that more than 90% of the rock is composed of magnesium- and iron-rich minerals like pyroxenes and olivine. It is an ultramafic igneous rock consisting essentially of the pyroxene group, such as augite, diopside, hypersthene, or enstatite.

Pyroxenites are classified into clinopyroxenites, orthopyroxenites. Pyroxenites dominated by orthopyroxene are termed **orthopyroxenites**, those dominated by clinopyroxene are known as **clinopyroxenites**, and those with similar abundances of orthopyroxene and clinopyroxene are known as **websterites**.

The principal accessory minerals, in addition to olivine and feldspar, are chromite, spinels, magnetite, and rutile.

Pyroxenites are closely allied to gabbros and norites, from which they differ by the absence of feldspar, and they are also closely allied to peridotites. They are distinguished from peridotites which containing more than 40% olivine. This connection is indicated also by their mode of occurrence

There are **four** types of pyroxenites that are: **clinopyroxenite**, **orthopyroxenite**, **olivine websterite** and the **websterite**.

Pyroxenites are also found as layers within masses of peridotite. These layers typically are a few centimetres to a meter or so in thickness. Pyroxenites that occur as xenoliths in basalt and in kimberlite have been interpreted as fragments of such layers.

3 - Peridotite

Peridotite is coarse-grained ultramafic igneous rock, consisting mostly of the minerals olivine and pyroxene.

There are three types of peridotite that are:

A - Harzburgite

Harzburgite is a variety of peridotite consisting mostly of the two minerals, olivine and orthopyroxene , with small amounts of clinopyroxene; it is named for occurrences in the **Harz Mountains** of Germany. It commonly contains a few percent chromium-rich spinel as an accessory mineral, which found commonly as xenoliths in kimberlite.

B - Wehrlite

Wehrlite is an ultrabasic igneous rock dominated by essential olivine and clinopyroxene with or without small amounts of orthopyroxene. Accessory minerals include spinel, ilmenite, chromite and magnetite.

Wehrlite occurs as xenoliths within the sequence of ophiolites. It can occur in both xenoliths and veins or dykes in ophiolites. Wehrlite can also form as cumulates within layered intrusions associated with gabbro and norite.

C- Lherzolite

Lherzolite is coarse-grained, ultrabasic rock consisting of essential magnesium-rich olivine (40 to 90%), chromium-magnesium clinopyroxene (Cr-diopside), magnesium orthopyroxene (enstatite). Accessory minerals include spinel, ilmenite, chromite and magnetite

Plagioclase can occur in lherzolites and other peridotites that crystallize at relatively shallow depths, but at greater depth plagioclase is unstable and is replaced by spinel

Economic value of peridotite

Peridotite is also sought for its economic value. The sulfide ores of **nickel** and **platinum** and the **chromite** are often found associated with peridotite. When hydrated at low temperatures, peridotite rocks become serpentine, which may include chrysotile **asbestos** and **talc**.

Peridotite is a source of valuable ores and minerals, including chromite, platinum, and nickel. Diamonds are also obtained from mica-rich peridotite (kimberlite) in South Africa.

Layered intrusions with cumulate peridotite are typically associated with sulfide or chromite ores and nickel ores.

Most of the platinum used in the world today is mined from the Bushveld Igneous Complex in South Africa and the Great Dyke of Zimbabwe associated with layered intrusion cumulate peridotites. Chromite bands commonly associated with peridotites are the world's major ores of chromium.

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