

Magmatic Differentiation

It is the process by which the magma is able to separate to form either a new magma or a rock of different composition from its original magma.

Partial Melting

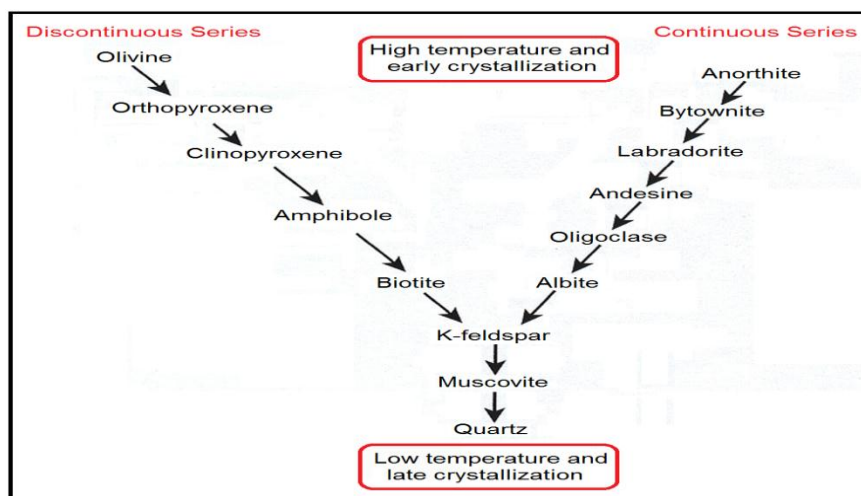
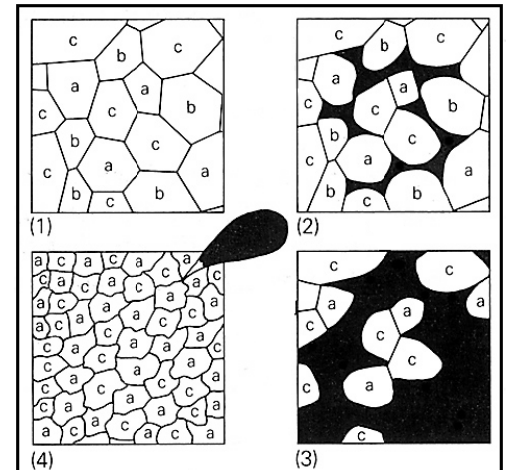
It is the process of separating the molten portion as a liquid from the residual solid.

The first drops of the melt are formed in the interstitial spaces of the solid rock's minerals of course due to increase in temperature. These interstitial drops of melt begin to accumulate and move out of the rocks due to overburden pressure similarly as squeezing by hand a sponge full of water.

Because the mantle is composed of many different minerals, it does not melt uniformly. As minerals with lower melting points turn into liquid magma, those with higher melting points remain as solid crystals. This is known as partial melting. As magma slowly rises and cools into solid rock, it undergoes physical and chemical changes in a process called magmatic differentiation.

Partial melting also occurs as existing crustal rocks melt in the presence of heat from magmas. In this process, existing rocks melt, allowing the magma formed to be more felsic and less mafic than the pre-existing rock.

According to Bowen's Reaction Series, each mineral has a unique melting and crystallization temperature. Since most rocks are made of many different minerals, when they start to melt, some minerals begin melting sooner than others. This is known as partial melting and creates magma with a different composition than the original mantle material.



Bowen's Reaction Series. Minerals that crystallize at higher temperatures are at the top (olivine) and minerals that crystallize at lower temperatures are at the bottom (quartz).

Methods of Magmatic Differentiation

After this simple explanation of the partial melting, we start to explain simply also the methods of magmatic differentiation :

(1) Crystal fractionation : includes :

- (a) Flow differentiation
- (b) Filter pressing
- (c) Congelation crystallization
- (d) Crystal Settling/Floating

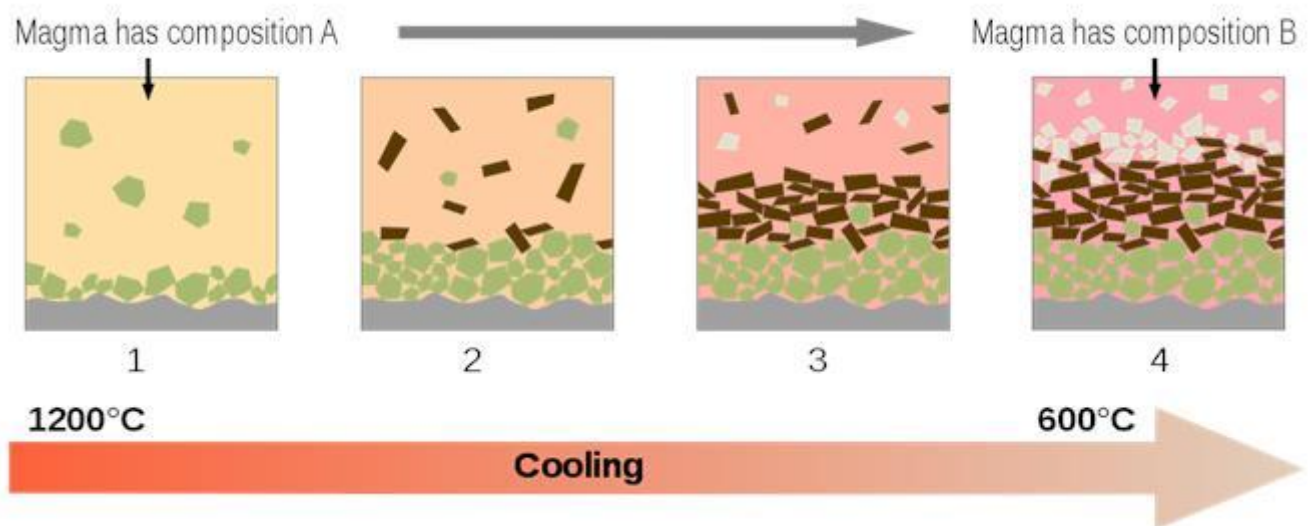
(2) Affecting processes on the chemistry of the parent magma : includes :

- (a) Liquids immiscibility
- (b) Diffusion and gas transfer
- (c) Magma Mixing or Hybridization
- (d) Assimilation

(1) Crystal fractionation

It is a process by which crystallization of minerals begins to form finally the igneous rocks after settling at the bottom of the magmatic chambers and solidification after cooling.

Crystal fractionation is as one of known processes of magma differentiation, and it is simply also called fractionation, which means separation of crystals from magma partially (step by step).

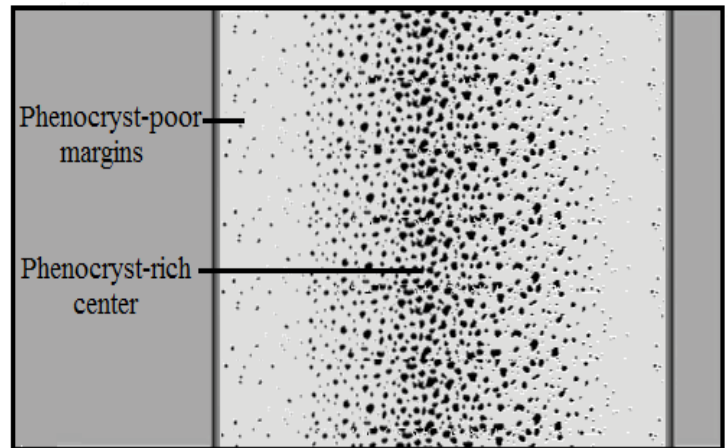


Schematic diagrams showing the principles behind fractional crystallization in a magma. While cooling, the magma evolves in composition because different minerals crystallize from the melt.

1: olivine crystallizes; 2: olivine and pyroxene crystallize; 3: pyroxene and plagioclase crystallize; 4: plagioclase crystallizes. At the bottom of the magma reservoir, a cumulate rock forms.

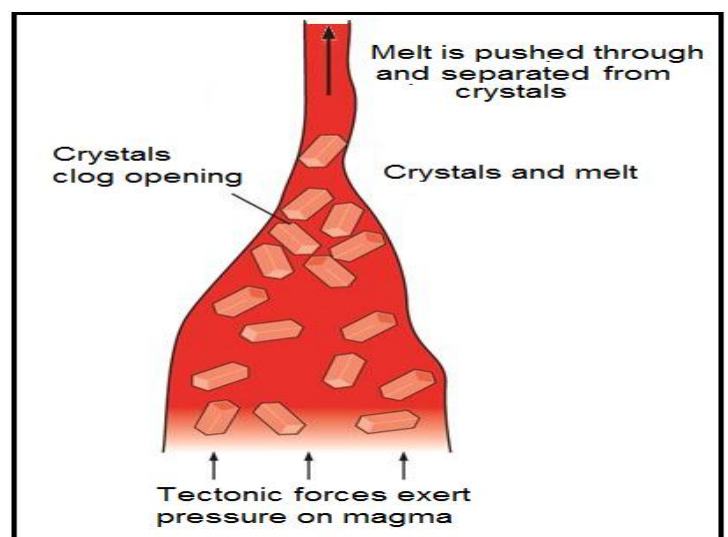
(a) Flow differentiation

Dikes and sills display gradational variations in the concentration of phenocrysts. The velocity of the flowing magma through a dike and sills will be higher in the center of this narrow channel than at its edges, where frictional forces are strong and the magma that carries crystals will cool rapidly at the walls of channel. Accordingly, larger phenocrysts will tend to migrate towards the center of the channel and the smaller phenocrysts to the walls.



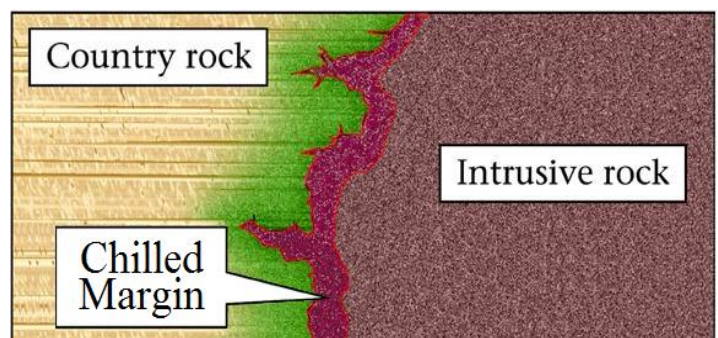
(b) Filter pressing

This is very important process for separation of minerals in the final stages of crystallization, in which the interstitial liquid (melt) is squeezed outside the place of cumulated crystals (similar to squeezing water from sponge). This squeezed liquid goes upwards the magmatic chamber and injected there to form the upper layer of the dyke. Squeezing occurs either due to internal pressing of the cumulated crystals on the intercumulus residual melt, or externally due to distortion after stresses occurred on the magmatic chamber.



(c) Congelation crystallization

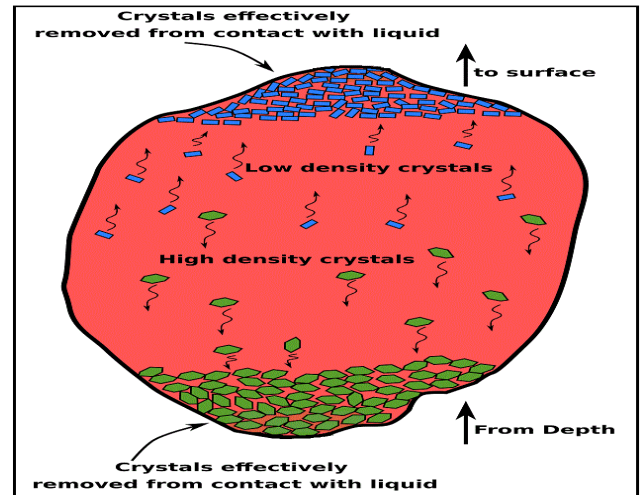
This process occurs in plutonic magma that suffers very slow cooling causing congealed enveloping layers of magma from inside start at the its contact margins as thin layer called a ***chilled margin*** which is considered to represent the parent magma.



(d) Crystal Settling/Floating

In general, crystals forming from a magma will have different densities than the liquid.

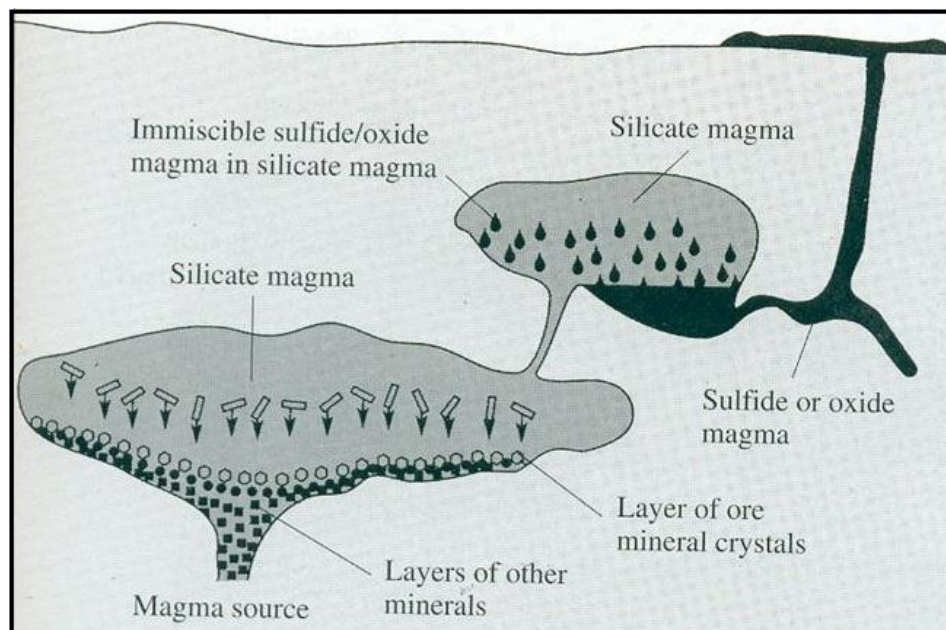
- 1) If the crystals (olivine, pyroxene) have a higher density than the liquid, they will tend to sink or settle to the floor of the magma body.
- 2) If the crystals (feldspar) have a lower density in the magma, they will tend to float or rise upward through the magma.



(2) Affecting processes on the chemistry of the parent magma : includes :

(a) Liquids immiscibility

One example is immiscibility of sulfides and silicate melt, therefore, sulfide minerals (e.g. pyrite) formed separately in the interstitial spaces of silicate minerals (e.g. olivine, pyroxene and plagioclase) in a basaltic magma rich. The sulfides are economically valuable even they are of small quantities.

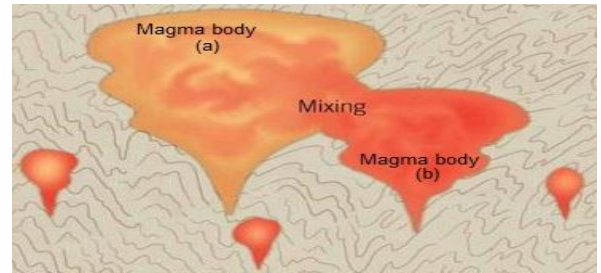


(b) Diffusion and gas transfer

Diffusion is very slow transfer of elements inside the magmatic chamber in long period of time. Diffusion causes formation of mineral phase after making element zonation in the magma by help of water. Gas transfer causes accumulation of some elements at the last stages of crystallization in the upper part of magmatic chamber. These gas phases are called volatiles which are very important in forming minerals of large crystals such as tourmaline.

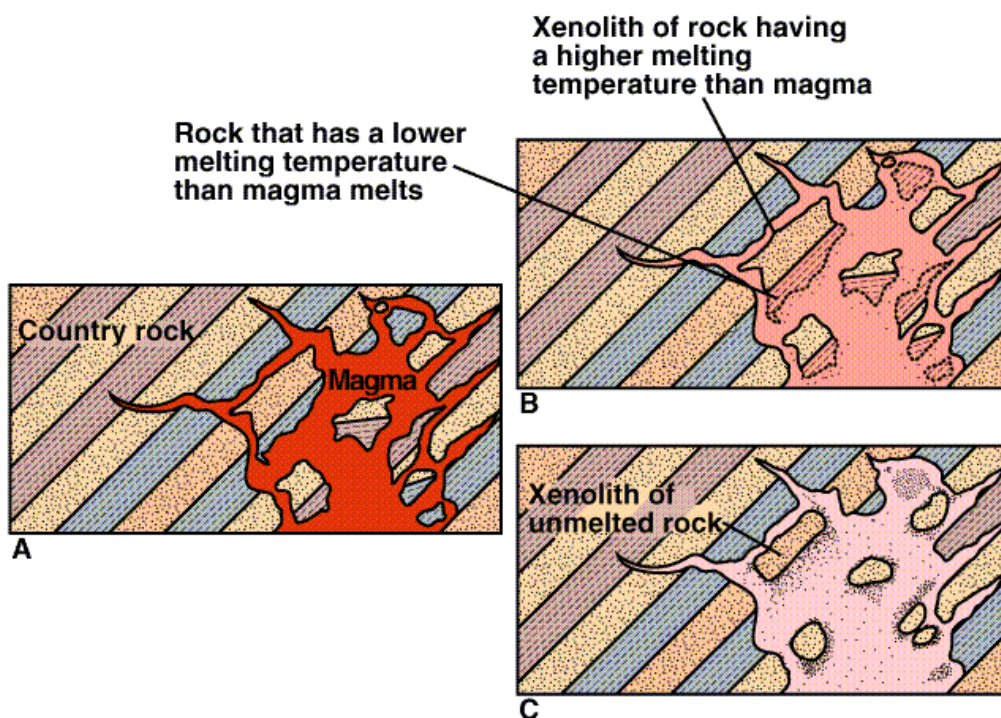
(c) Magma Mixing or Hybridization

Hybridization is mixing of two magmas that are compositionally different in long period of time, and the new mixed magma is called (hybrid magma). Resulting magma is of a composition intermediate between the parents.



(d) Assimilation

Assimilation is a process of an embrace and digestion of adjacent surrounding rocks that the magma penetrates them. The surrounding rocks are different composition broken as blocks during magma ascent and pulled upwards. When the blocks completely melt inside the magma (i.e. assimilated), the resulting igneous rocks from such magma are called (Contaminated rocks). If digested blocks remain stable and do not altered, they are called (Xenoliths), most xenoliths are pulled by this mechanism from deep mantle.



Petrogenesis

Magma Generation

According to the geophysical evidences, the only liquidus region in the Earth is the outer core that composed of iron and nickel with sulfur. The magma cannot travel from this region at 2900 km depth to reach the Earth's surface; it is impossible. Therefore, the mantle and the crust are the sources of magmas that derived from one of them or both.

Magmas are formed essentially as a result of a great change in pressure (P) and temperature (T) as well as chemical composition (X). Peridotites as upper mantle-forming rocks play an important role in magma generation, where they are considered as an important source for basaltic magma after their partial melting. Peridotites are also responsible for generation alkaline magmas but in lesser amount than basaltic magmas.

Before explanation of magma generation, it is very important to understand the main factors controlling this process in the following section "Mechanism of melting".

Mechanism of melting

1) Increase of temperature

It is mostly clear method that temperature increase will lead to melt the solid rocks of the upper mantle peridotites. To achieve this great difference, a great internal heat energy is needed.

- a) The first source of this great internal heat energy is thought to be obtained from ***nuclear fission of the main three radiometric elements (U, Th, K)*** that present in the rocks. But then after, it is found that this process of nuclear fission needs thousands or millions of years.
- b) It is believed nowadays that other extraordinary heat flow comes from the outer core to the upper mantle and even to the Earth's surface known as ***mantle plumes***.
- c) The heat energy resulting from ***plate tectonic activities*** of the Earth's crust due to two possibilities:
 - (1) Subduction of the cold oceanic crust beneath the continental crust. This subduction will give heat energy due to friction happened between them.
 - (2) The heat that is derived from the partial melting of peridotite causing melting of upper continental crust (sialic).

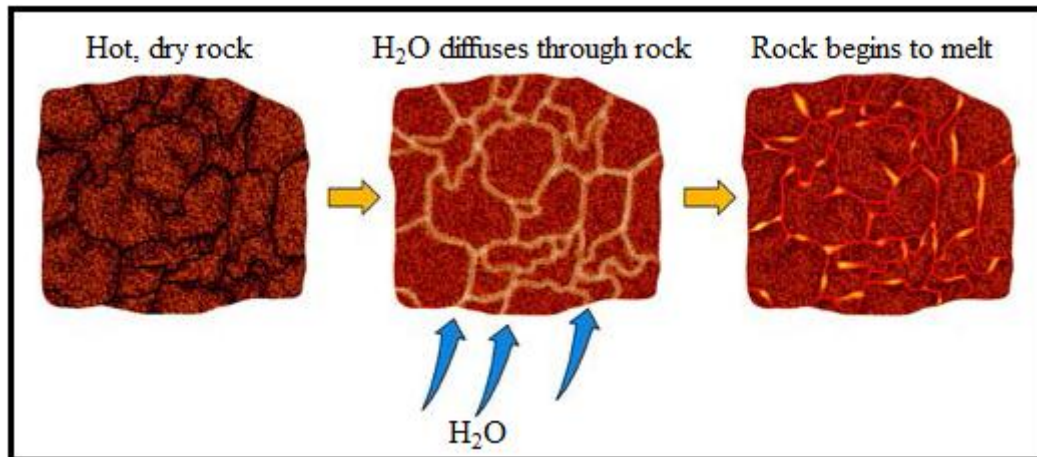
2) Decompression

Removing the pressure from compressed solid rock will cause its melting when the temperature is close to the melting temperature.

The melting of mantle material that occurs when the material rises into a region of lower pressure, allowing it to cross from its solidus to its liquidus. To create about 30% partial melting as postulated for oceanic rift source regions, the mantle would have to rise roughly 60 km.

3) Role of water pressure in chemical composition

Partial melting occurs as a result of probable changes in the chemical composition (X) the most effective change is that of water pressure (PH_2O). The hydrous minerals (as mica, amphibole, and chlorite) in the subducted oceanic crust will release their water content. This released water will move upward to emplaced mantle peridotite that override the subducted oceanic crust then undergoes partial melting.



Hereunder, short explanation is given for the generation of the most two famous magmas : the basaltic and granitic.

(1) Generation of Basaltic Magma

The basaltic magma is the consequent result of the partial melting of the mantle peridotite, which formed of olivine phase (in higher percentage), then orthopyroxene (in lesser percentage than olivine), then clinopyroxene (in lesser percentage than orthopyroxene), in addition to aluminous phases (such as garnet, spinel, or plagioclase) .

The first phases to be melted are (clinopyroxene and aluminous phases) leaving harzburgite (olivine and orthopyroxene). If the melting continues, the orthopyroxene will melt leaving dunite (olivine). The resultant magma is basaltic in composition.

Peridotite source rock =====>> **Basaltic partial melt + Crystalline residuum**
(olivine + orthopyroxene + aluminous phases)

(1) Generation of Granitic Magma

The main process responsible for generating a granitic magma is the partial melting of the rocks of the lower continental crust. As there no large granitic bodies appeared in the oceanic crust, so the idea of generation a granitic magma by differentiation of mantle peridotites is not accepted. On the other hand, the presence of many great granitic bodies as batholiths in the continental crust emphasizes the impression that the granitic magmas are the results of partial melting of the upper continental crust (sialic). This is affirmed by many evidences, amongst them are :

- 1) Abundance of heat energy that enough to produce sialic magma. This heat energy is from the released heat of the ascending hot magma such as basaltic magma that comes from mantle penetrating the layers of the continental crust.
- 2) Presence of deep faults among which as conduits for ascending very hot materials that will be in contact with pre-existing molten rocks of the continental crust.
- 3) Evolution of a mafic magma generates residual felsic liquids.