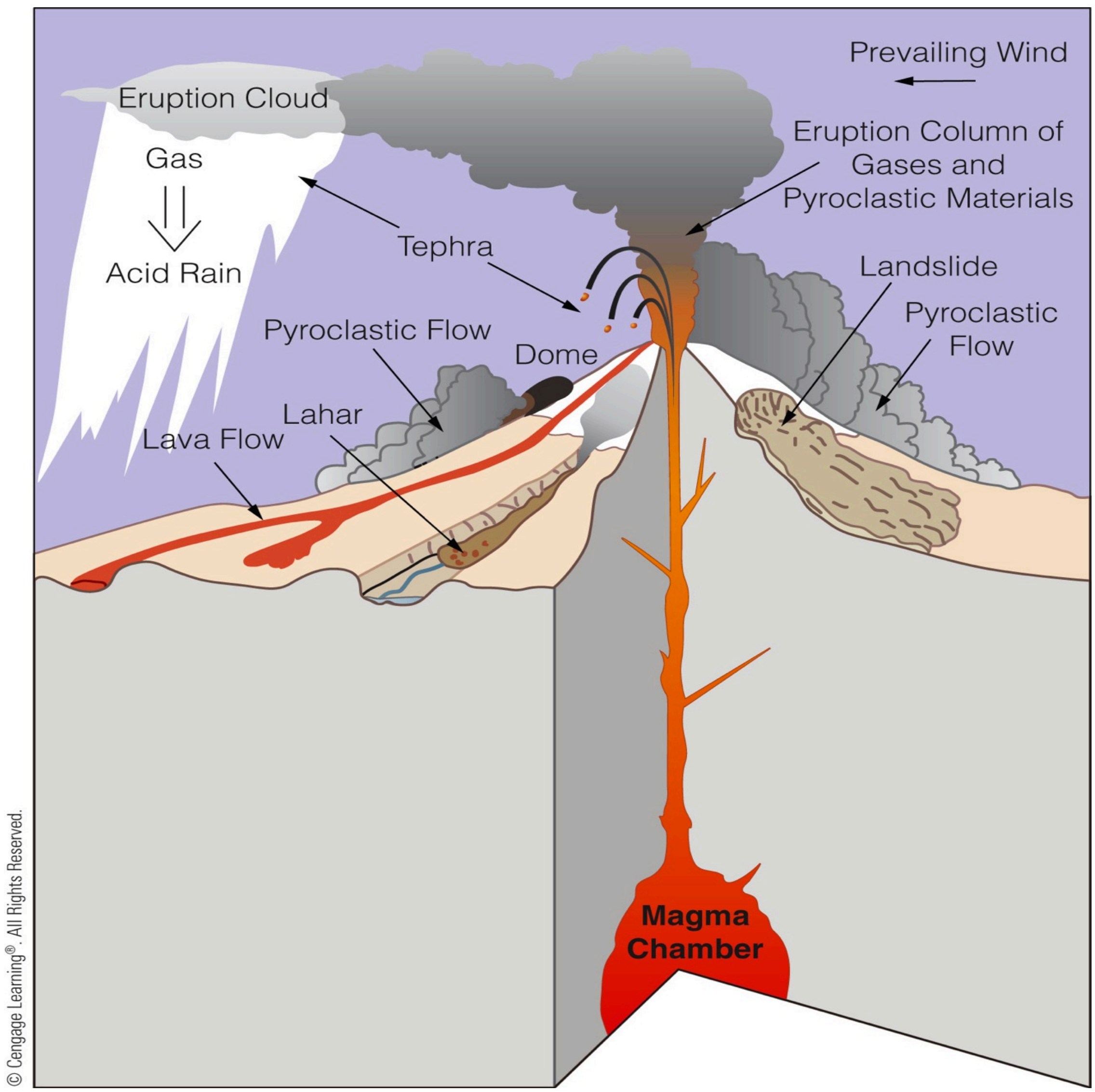
Igneous Rock

Magma - Molten rock under the surface
Temperature = 700º – 2400ºC (1300-4300 F)

Lava - magma at the surface
- lava flows
- pyroclastic materials ejected particles
- Temperature = 700º – 1300ºC (1300-2400 F)



Magma Chamber – Large pool of magma in the lithosphere

- Most all magma consists of silicon and oxygen (silicate) and the other 6 common elements. Total of 8 elements.
- Composition of the magma is determined by presence of these elements
- Igneous rock type is determined by the magma composition

(elements present) ➔ (magma composition) ➔ (igneous rock type)

Aluminum =	Al
Iron =	Fe
Calcium =	Ca
Sodium =	Na
Potassium =	K
Magnesium =	Mg

- magma rises to the surface because it is <u>less dense</u> than the surrounding material. Why is it less dense?

Igneous Rock - when magma or lava solidifies
- **extrusive** igneous rock: magma that cools at or near the surface
- **intrusive** igneous rocks: magma that cools and crystallizes below the surface
- 95% of the crust is made of igneous rock

Composition of Magma - defined by silica content

Felsic
- Silica <u>rich</u> magma
- more than 65% silica; abundant sodium, potassium, aluminum
- example: super volcanoes – Yellowstone National Park

Mafic
- Silica <u>poor</u> magma
- 45% to 52% silica; abundant calcium, iron, magnesium
- example: Hawaiian Islands

Intermediate - Compositions between felsic and mafic
- example: Mount St. Helens

TABLE 4.1 The Most Common Types of Magmas and Their Characteristics

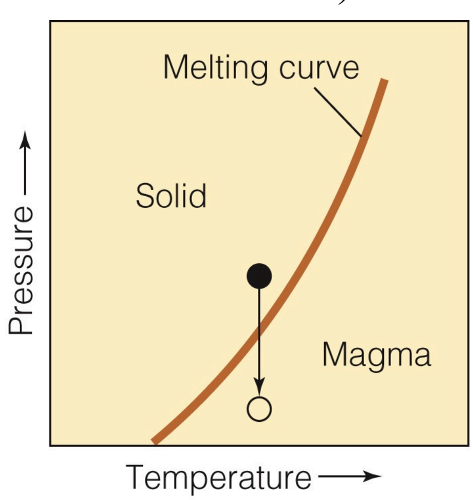
Type of Magma	Silica Content (%)	Sodium, Potassium, and Aluminum	Calcium, Iron, and Magnesium
Ultramafic	<45	↓	Increase
Mafic	45–52	↓	↑
Intermediate	53–65	↓	↑
Felsic	>65	Increase	↑

Magma Formation: forms from melting preexisting crust or mantle rock

- 4 main factors that can cause melting
    1. Temperature
    2. Pressure
    3. Water
    4. Mineral content

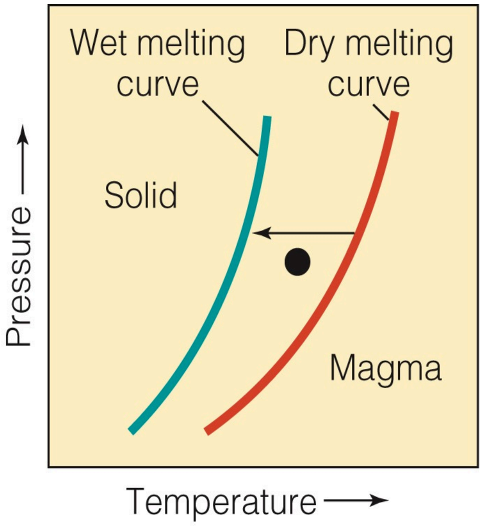
- Temperature & Pressure increase with depth
    Geothermal Gradient: 25 ^{o}C/km (75 ^{o}F /mile)

- An *increase* in pressure ➡ *increases* the melting point (temp needed to melt the rock)



As pressure decreases, even when temperature remains constant, melting takes place. The black circle represents rock at high temperature. The same rock (open circle) melts at lower pressure.

- An *<u>increase</u>* in water ➡ *<u>decreases</u>* the melting point (temp needed to melt the rock)



If water is present, the melting curve shifts to the left because water provides an additional agent to break chemical bonds. Accordingly, rocks melt at a lower temperature (green melting curve) if water is present.

- Mineral content: different minerals have different melting points.
  - minerals **crystalize** (form) at different temps as magma solidifies
  - minerals **melt** at different temps as rock melts
    - **partial melting**: when sum minerals melt in a rock whereas other minerals remain solid in that same rock

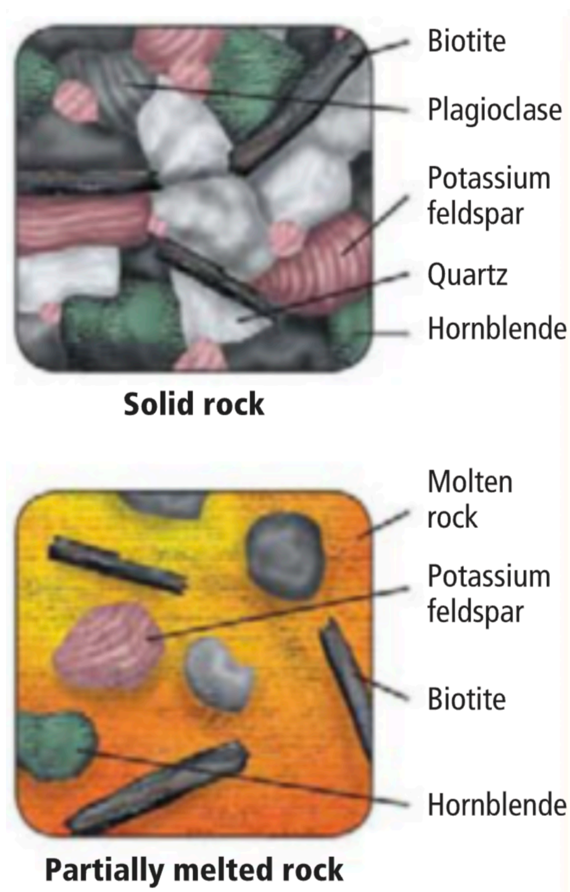


Figure 3 As the temperature increases in an area, minerals begin to melt.
Determine ***What can you suggest about the melting temperature of quartz based on this diagram?***

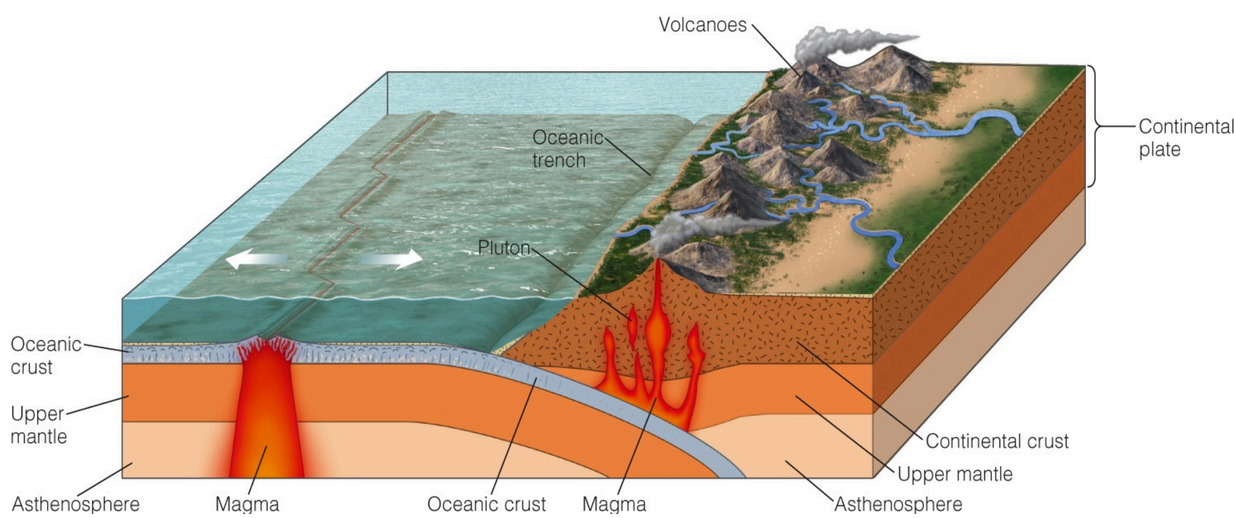
Places on Earth Where Magma Forms

- Spreading Ridges

- Melting is initiated by a pressure decrease at spreading ridges
- Presence of water also decreases melting temperature
- Partial melting explains how mafic magmas are derived from an ultramafic source

- Subduction Zones

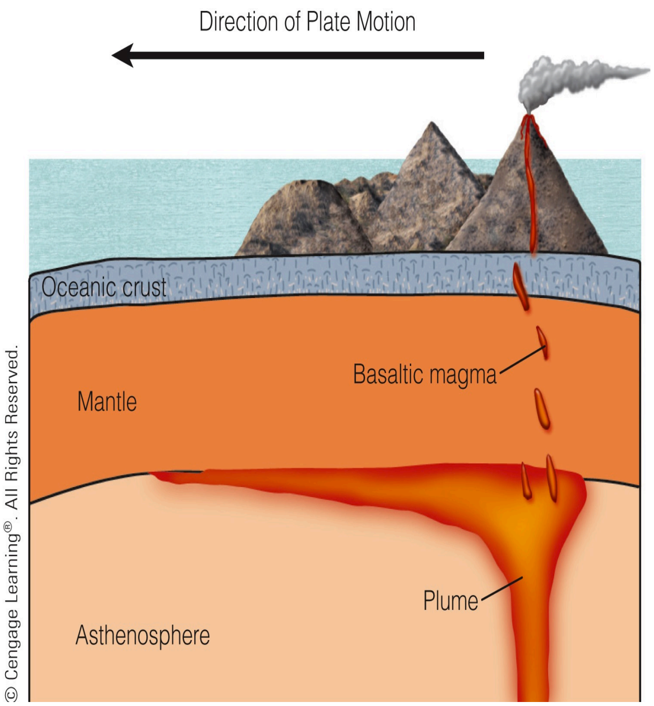
- Partial melting of a mafic crust results in intermediate and felsic magmas
- Melting of sediments and contamination with silica rich continental crust rocks also change the magma composition



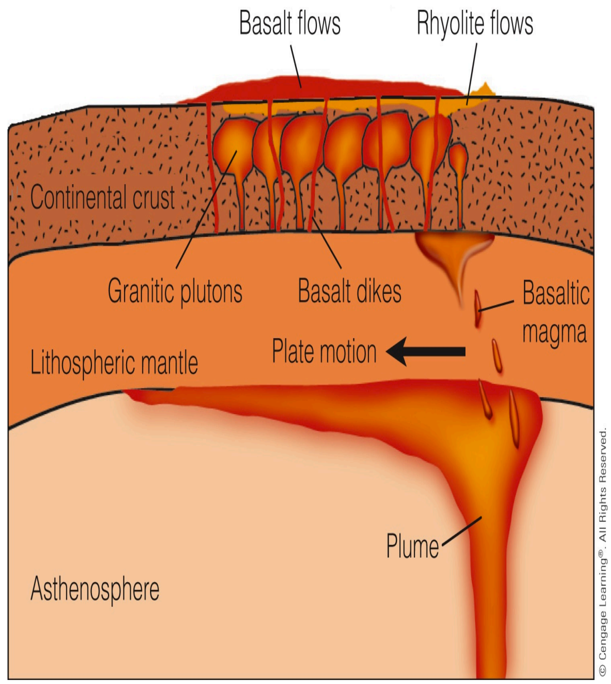
The Origin of Magma: Magma forms beneath spreading ridges, because as plates separate, pressure is reduced on the hot rocks and partial melting of the upper mantle begins. Invariably, the magma formed is mafic. Magma also forms at subduction zones where water from the subducted plate aids partial melting of the upper mantle. This magma is also mafic, but as it rises, melting of the lower crust makes it more felsic.

- Hot Spots

- Hot mantle rock rises
- Decrease in pressure melts mantle rock, creating magma



A mantle plume beneath oceanic crust with a hot spot. Rising magma forms a series of volcanoes that become younger in the direction of plate movement.

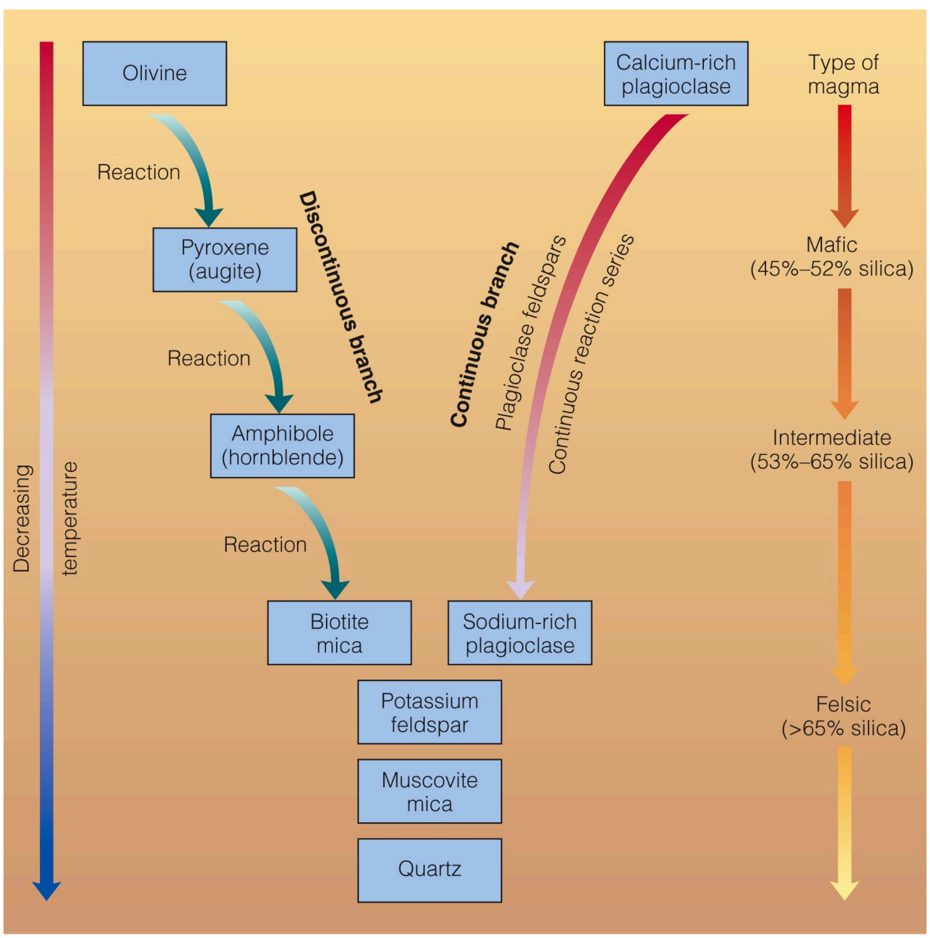


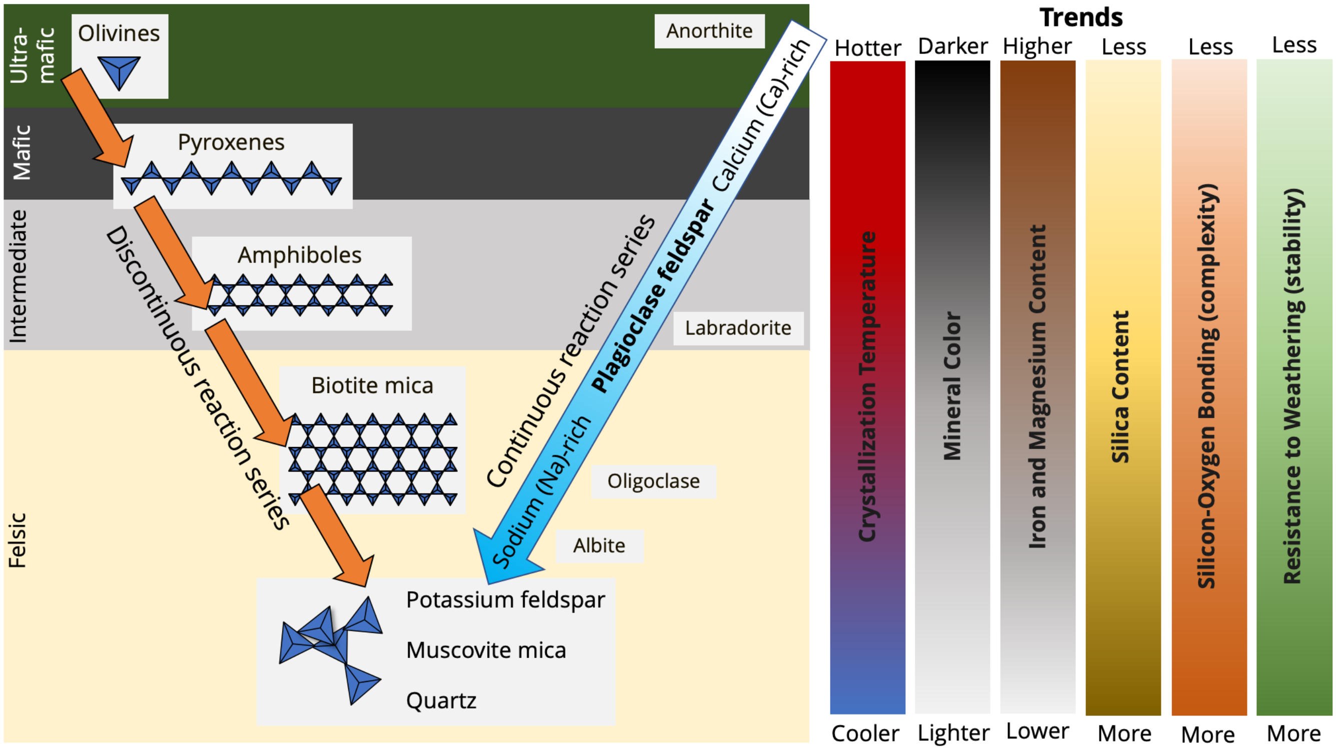
A mantle plume with an overlying hot spot yields flood basalts, and some of the continental crust melts to form felsic magma.

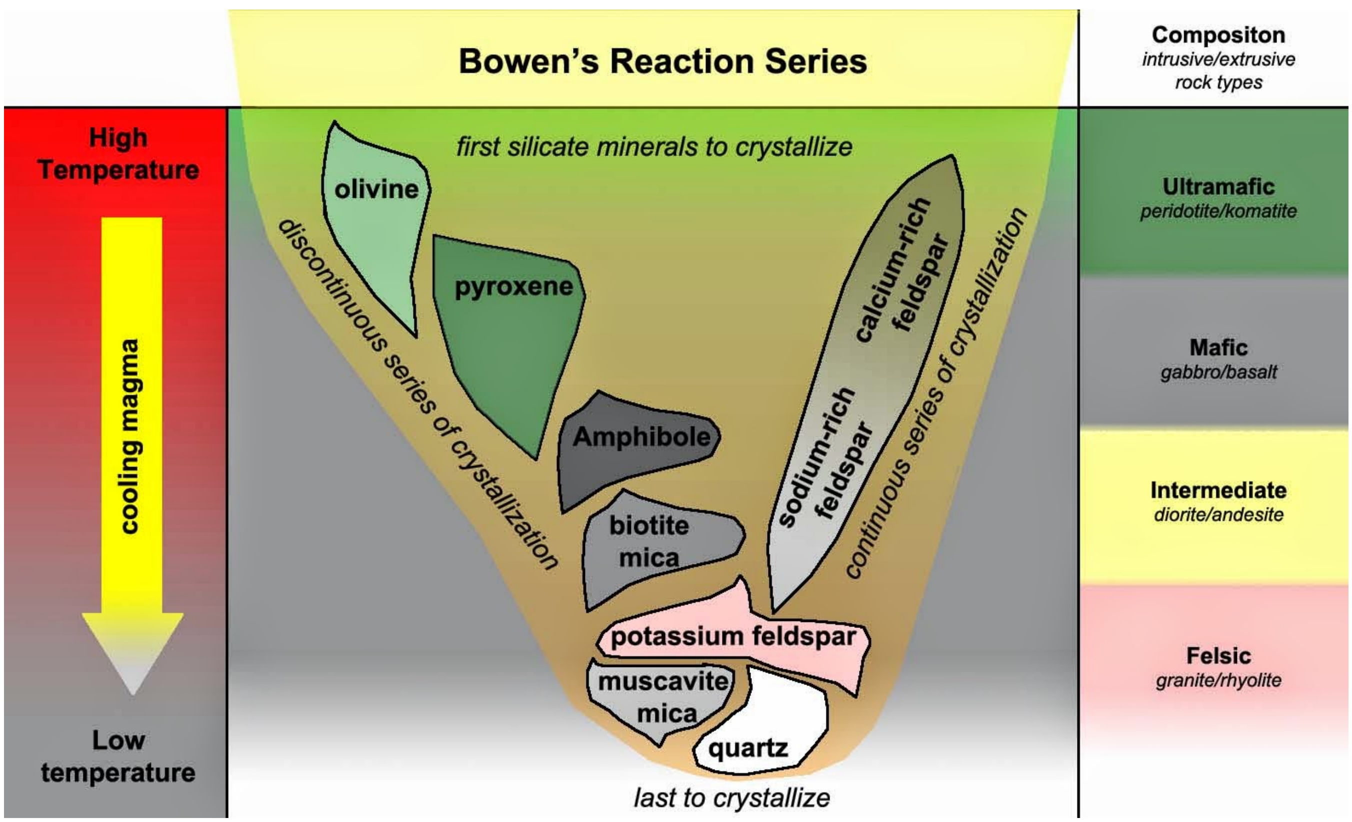
Bowen's Reaction Series: predicts the pattern and the sequence of mineral formation in magma chambers and lava as they cool.

- shows how mafic, intermediate, and felsic magmas could form from ultramafic magma

- **Discontinuous branch <u>or</u> Iron and Magnesium Rich minerals**
  - the previously formed mineral will *<u>discontinue</u>* its formation and then the next mineral in the series will start to form. When they discontinue, they will react with the magma and be converted into the next mineral in the series. Olivine is converted into augite and so on.
- **Continuous branch <u>or</u> Plagioclase Feldspar minerals**
  - gradual change from one type of mineral to the next.
  - These minerals are not converted. Once formed they are now permanent.
  - first plagioclases to form are Ca-rich. As the magma continues to cool, Na-rich plagioclases start to form.
  - the last feldspars to form are Potassium feldspars (K-spar).



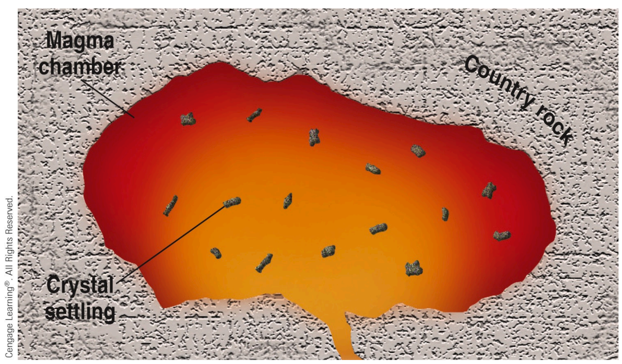

Ultra-mafic
Mafic
Intermediate
Felsic
Olivines
Pyroxenes
Amphiboles
Biotite mica
Potassium feldspar
Muscovite mica
Quartz
Discontinuous reaction series
Continuous reaction series
Calcium (Ca)-rich
Plagioclase feldspar
Sodium (Na)-rich
Anorthite
Labradorite
Oligoclase
Albite
Trends
Hotter
Crystallization Temperature
Cooler
Darker
Mineral Color
Lighter
Higher
Iron and Magnesium Content
Lower
Less
Silica Content
More
Less
Silicon-Oxygen Bonding (complexity)
More
Less
Resistance to Weathering (stability)
More


Bowen's Reaction Series
Compositon
intrusive/extrusive rock types
High Temperature
cooling magma
Low temperature
first silicate minerals to crystallize
olivine
pyroxene
Amphibole
biotite mica
potassium feldspar
muscavite mica
quartz
calcium-rich feldspar
sodium-rich feldspar
discontinuous series of crystallization
continuous series of crystallization
last to crystallize
Ultramafic
peridotite/komatite
Mafic
gabbro/basalt
Intermediate
diorite/andesite
Felsic
granite/rhyolite

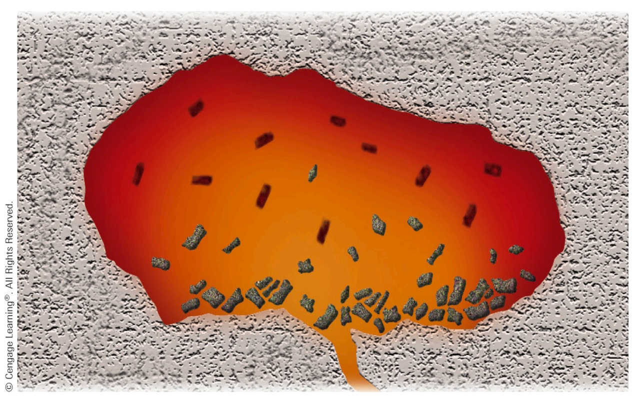
Chemical Changes in Magma

- **Fractional Crystallization**: when magma cools, it crystallizes (becomes solid rock) in reverse order of partial melting. The newly formed minerals may be removed from the remaining melt. As a result, the magma's composition changes and becomes more concentrated in silica.

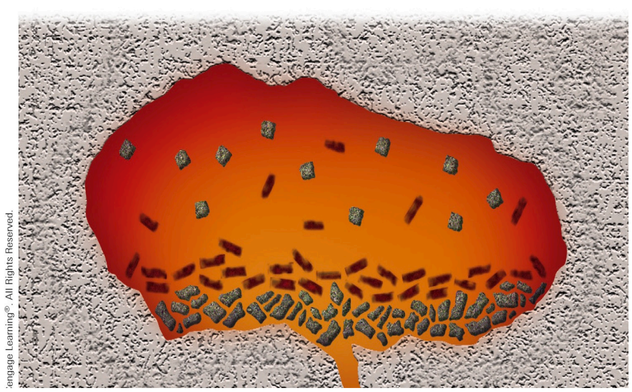
- **Crystal settling:** the physical separation of minerals by crystallization and gravity. Mafic minerals form first, leaving the melt richer in silica.



Early formed ferromagnesian, iron/magnesium rich, silicates such as olivine crystallize and because of their density settle to the bottom of the magma chamber.



Ferromagnesian silicates continue to form and settle.



The remaining melt becomes richer in silicon, sodium, and potassium because much of the iron and magnesium originally present is now in the ferromagnesian minerals that settled.

Classification of Igneous Rocks

- **Igneous Rocks** form from crystallizing from magma or lava or by explosive volcanic activity
- Classification is based on **texture** and **composition** (minerals present)
- Igneous rocks can form inside the earth or on the surface.

    - **Intrusive:** when magma crystallizes <u>*below*</u> the Earth's surface. Ex. Granite
    - **Extrusive:** when magma crystallizes <u>*on*</u> the Earth's surface. Ex. Basalt

- Igneous Rock **Textures**

    - Refers to the size, shape, and arrangement of mineral grains
    - Size relates to cooling rate, and indicates an intrusive or extrusive origin

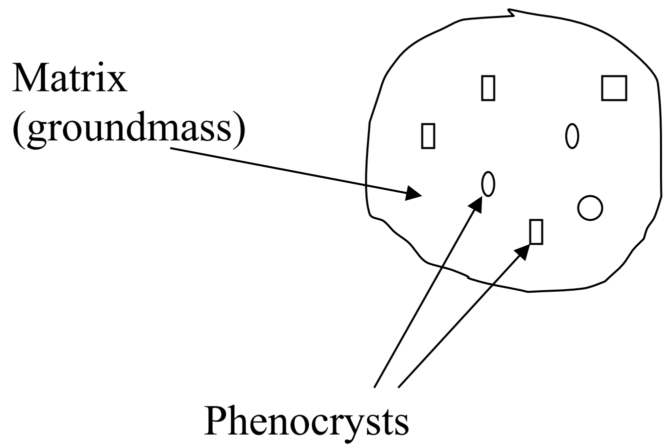
        - **Aphanitic**: fine-grained, to small to see, rapid cooling
        - **Phaneritic**: coarse grained, slow cooling
        - **Porphyritic**: phenocrysts (big crystals) and groundmass, two-stage cooling history
        - **Glassy**: no crystal structure/no grains visible
        - **Vesicular**: gas cavities
        - **Pyroclastic**: fragments generated by explosive volcanism. Fine grain ash that becomes consolidated and solid

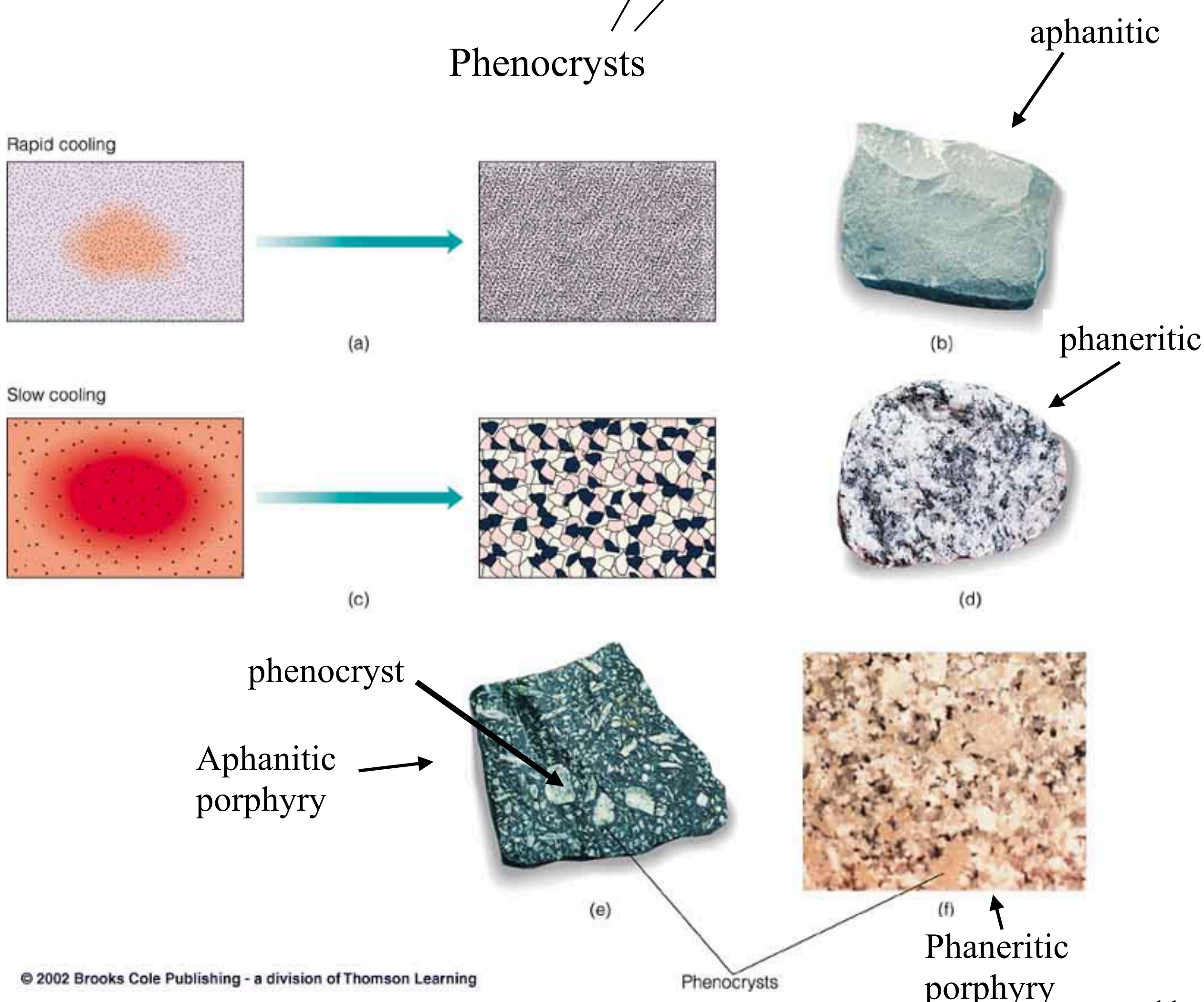
    - **Texture depends on:**

        1) rate of cooling
        2) rate of loss of volatiles (water, sulfur, gases.)
        3) amount of silica content (SiO_2) – the more silica the more viscous (thicker) the melt

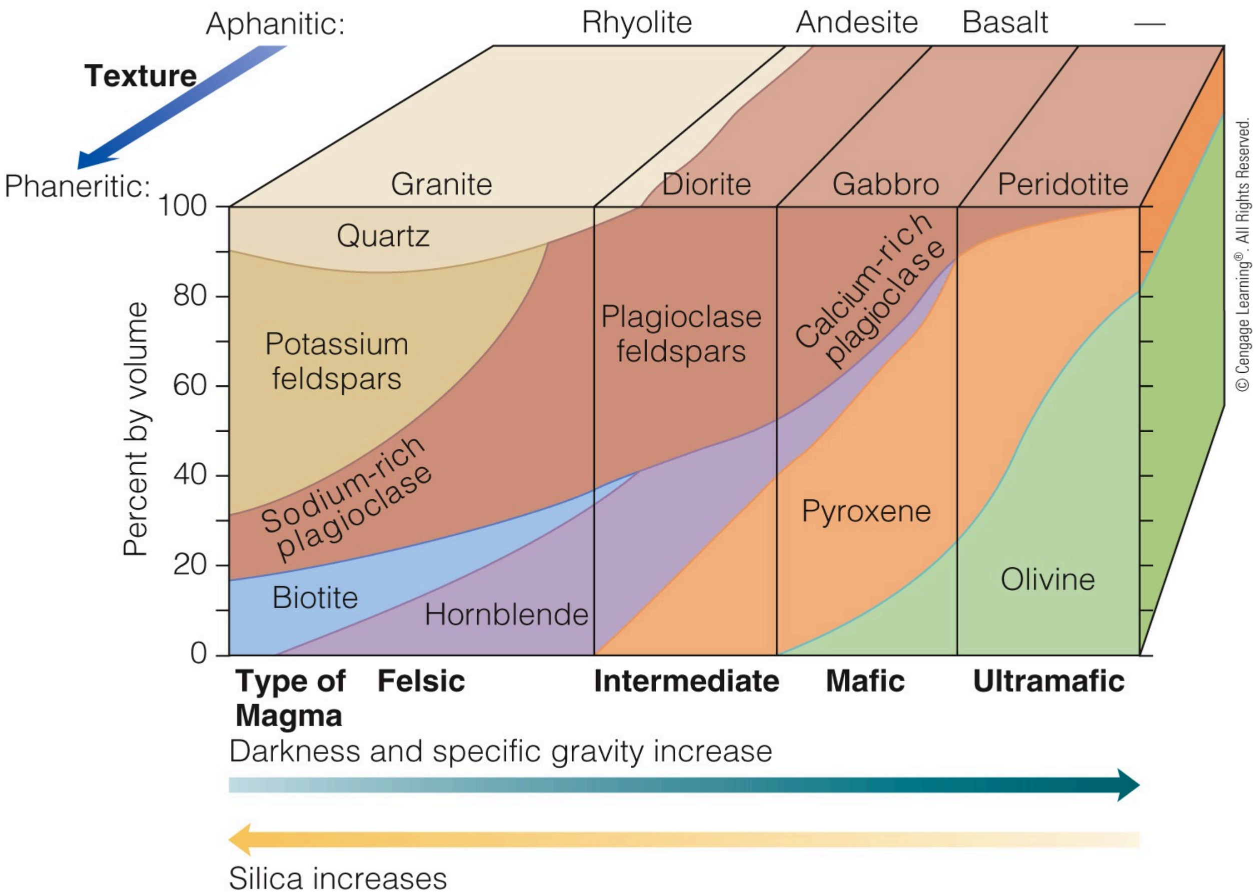
- Crystal size and Cooling

1) Slow cooling = Intrusive = coarse grained
   ex. granite
2) Rapid cooling = Extrusive = fine grained
   ex. Rhyolite
3) Very rapid cooling (quenching) = Glass
4) Slow to fast cooling = slow cooling followed by fast cooling. Porphyritic





- Chart shows relative proportions of chief mineral components and the textures of some common igneous rocks



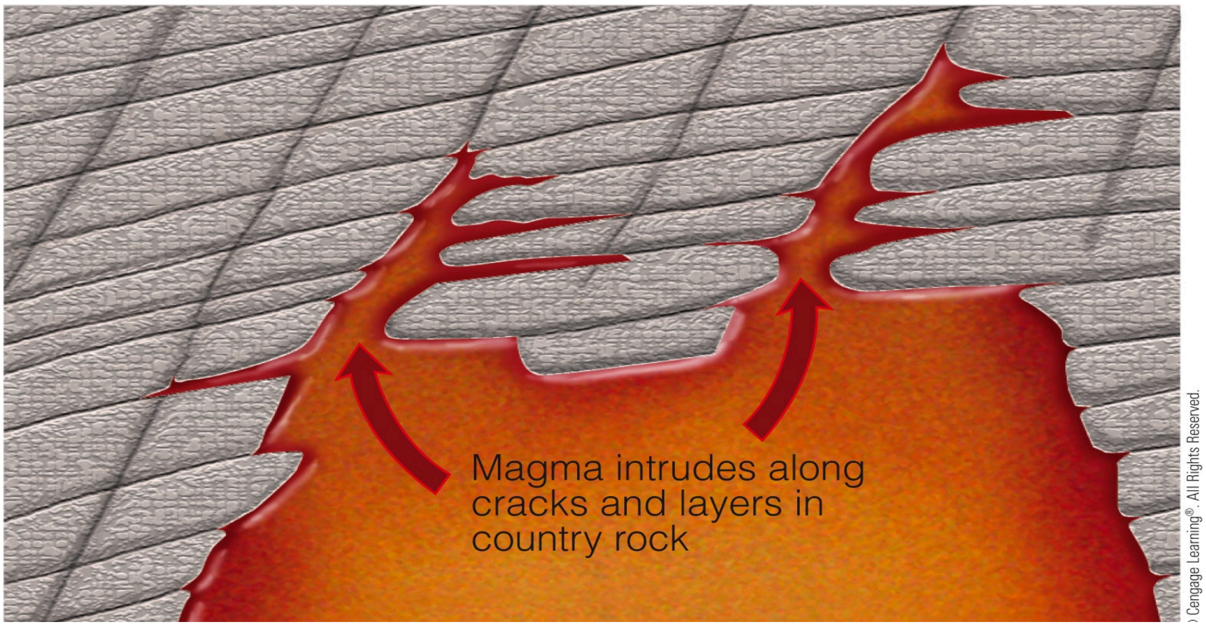
Classification of Igneous Rocks: This diagram shows the percentages of minerals, as well as the textures of common igneous rocks. For example, an aphanitic (fine-grained) rock of mostly calcium-rich plagioclase and pyroxene is basalt.

- Common Intrusive and Extrusive Igneous rocks

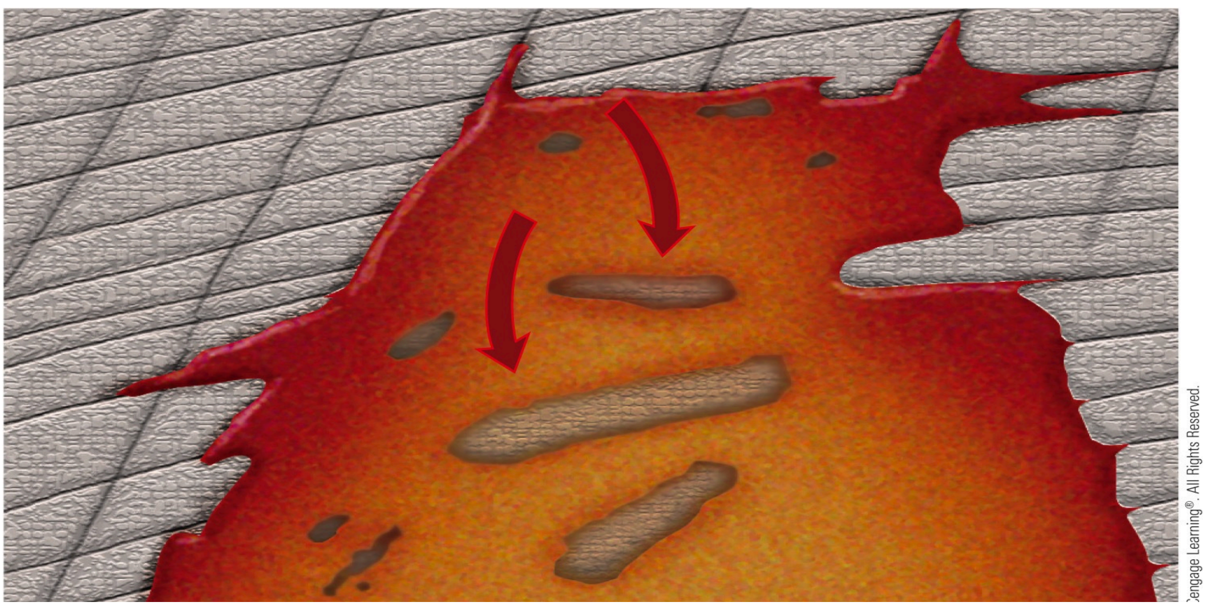
	Extrusive (Aphanitic texture)	**Intrusive** (Phaneritic texture)
Ultramafic		**Peridotite**: makes up the upper mantle. High in Mg & Fe; low in silica
	Mostly pyroxene (augite) & olivine	
Mafic	**Basalt**: makes up the upper part of the oceanic crust, lava flows, volcanoes	**Gabbro**
	Mostly Ca-plagioclase & Pyroxene (augite)	
Intermediate	**Andesite**	**Diorite**
	Mostly Ca & Na Plagioclase feldspars, Amphibole (hornblende) & Biotite	
Felsic	**Rhyolite**	**Granite**: basement rock for most continents-rk below sedimentary rock
	Made mostly of feldspar, quartz & muscovite	

- **Common Igneous Rocks for which texture is the main consideration**

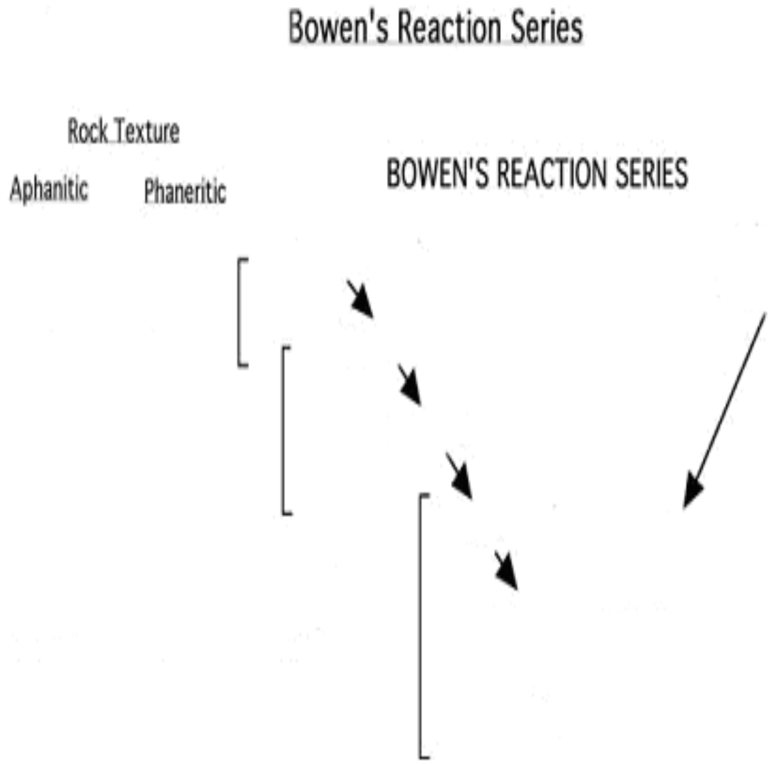
Composition		Felsic ⟷ Mafic
Texture	Vesicular	**Pumice** **Scoria**
	Glassy	**Obsidian**
	Pyroclastic or Fragmental	⟵ **Volcanic Breccia** ⟶ **Tuff/Welded tuff**



Stoping takes place when magma rises into the crust by detaching and engulfing pieces of country rock.



Some of the detached blocks may be assimilated, and some may remain as inclusions



Igneous Rock (texture)

Igneous Rock (composition)

<u>Mafic</u>

45-52%
Low Silica
Rich in Fe & Mg
High Melting Point
Low Viscosity (thin)
Low Water

<u>Felsic</u>

> 65%
High Silica
Low in Fe & Mg
Low Melting Point
High Viscosity (thick)
High Water

<u>Intrusive</u>

Coarse Grain
Phaneritic
Slow Cooling
Really Slow Cooling = Pegmatite
Ex. Gabbro, Diorite, Granite

<u>Extrusive</u>

Fine grain
Aphanitic
Fast Cooling
Really Fast Cooling = glass
Ex. Basalt, Andesite, Rhyolite