INTRODUCTION TO IGNEOUS ROCKS

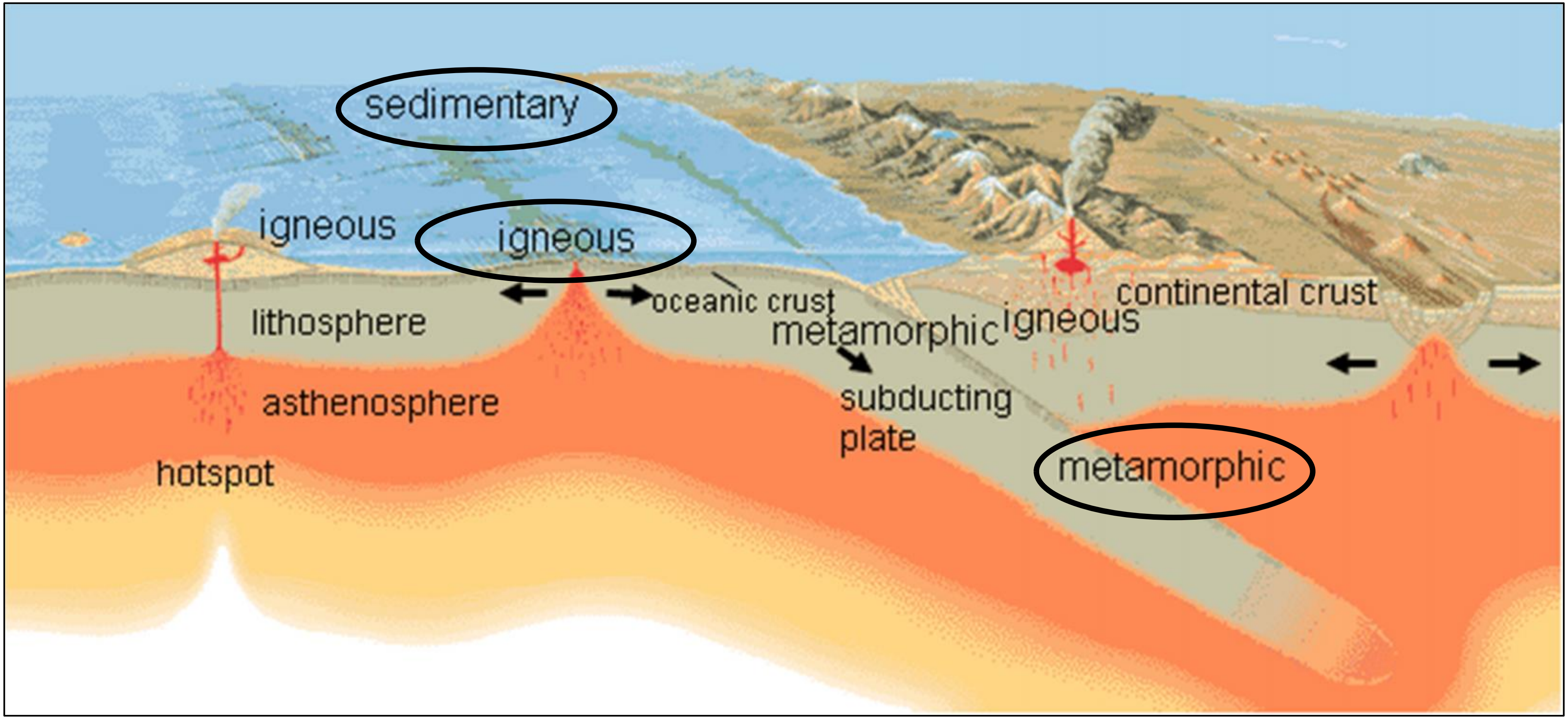
What is a rock?

- Elements are chemically combined to form minerals
- Minerals are physically combined to form rocks.

- **A rock is a naturally occurring aggregate of minerals and/or other rock fragments**

- Three basic types of rocks
  - Igneous
  - Metamorphic
  - Sedimentary

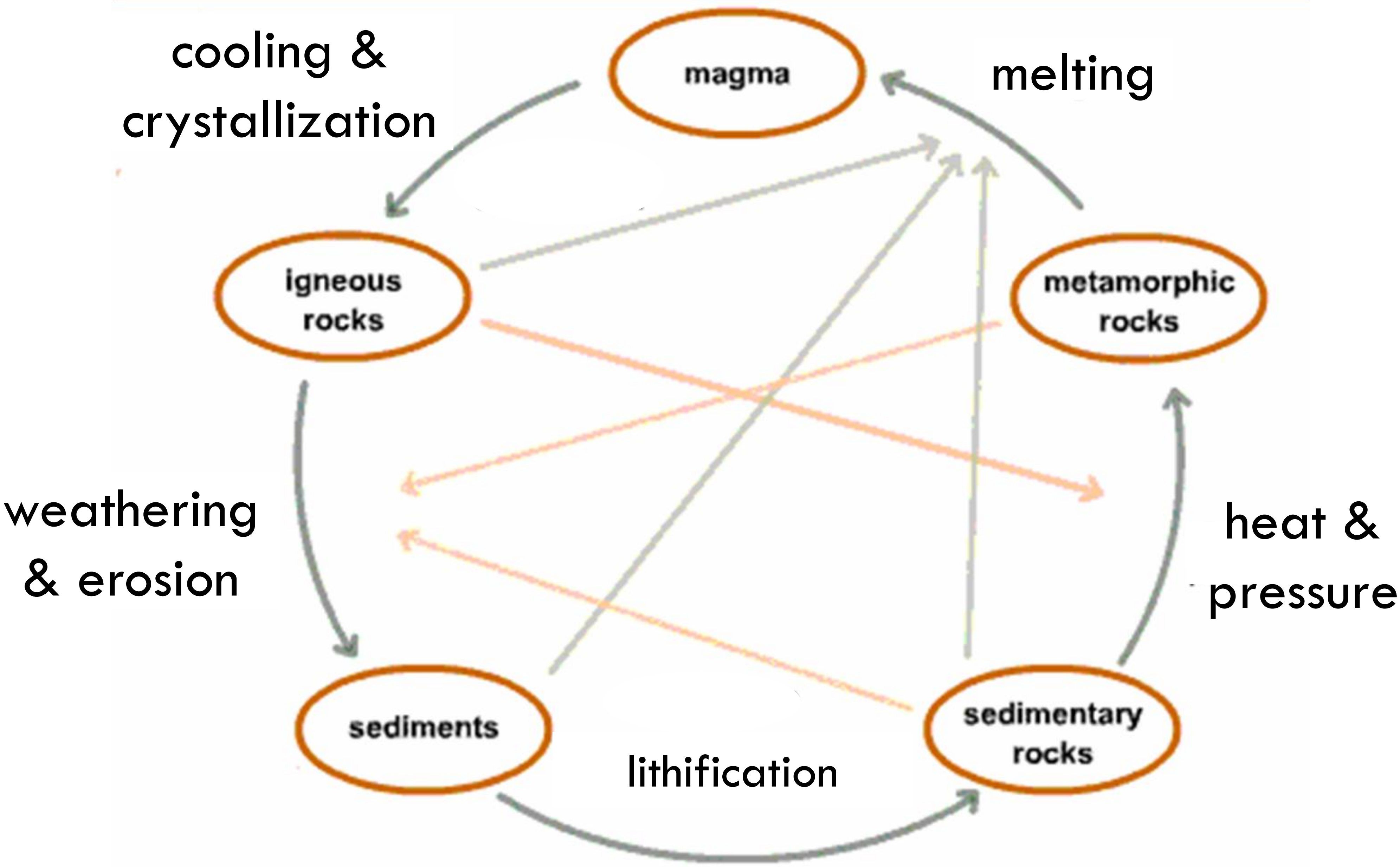
Distribution of different rocks



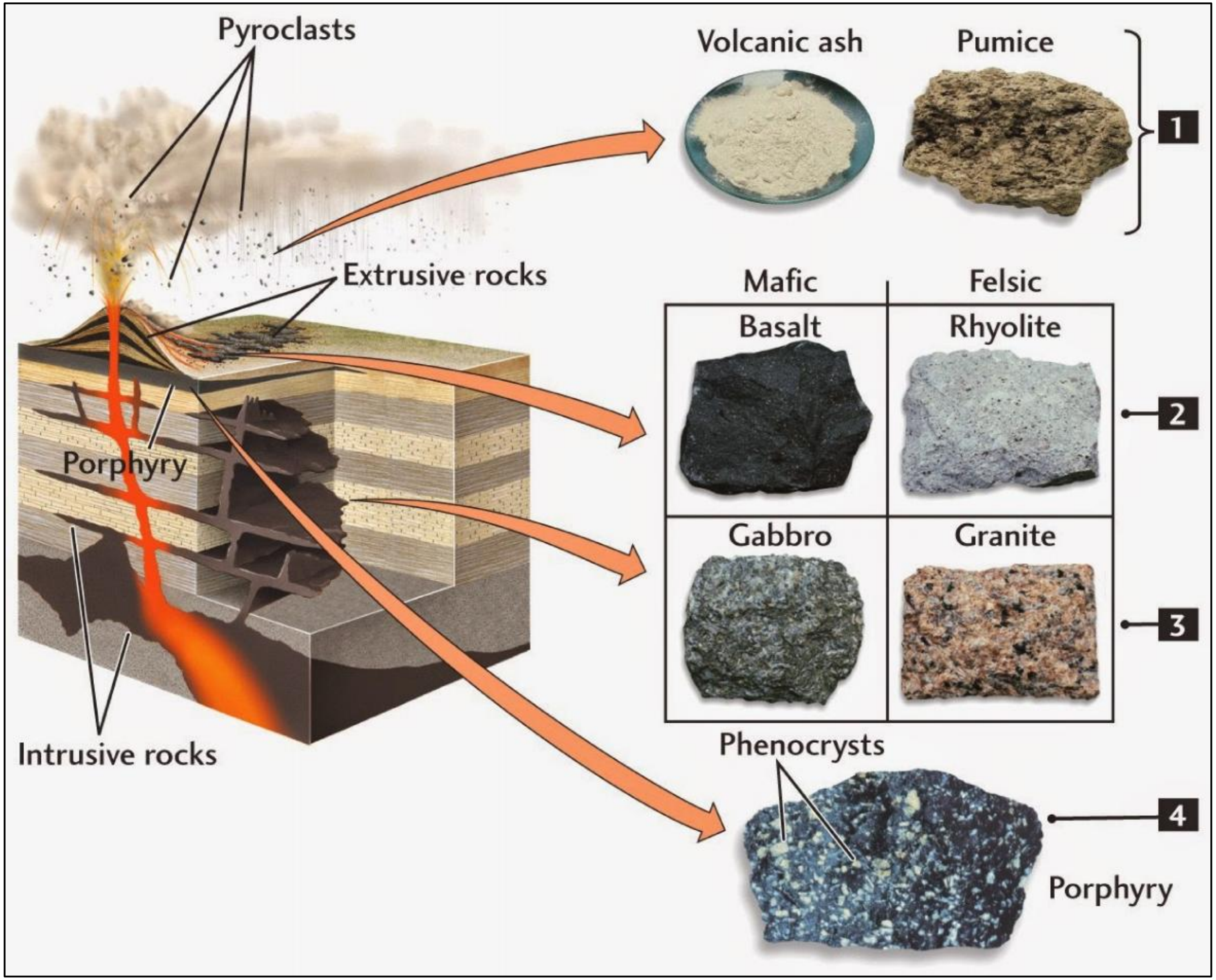
Rock cycle

- Earth is a dynamic planet with the surface and interior in a constant state of flux.
  - Internal changes alter the surface by moving the Earth’s plates, building mountains.
  - Seas advance and retreat over the continents brining in new materials and taking other materials away.
  - Rocks are continually being changed by Earth’s forces.
  - Igneous, sedimentary, or metamorphic rock are just temporary stages in the continuing changes that all rocks undergo.

Rock cycle


cooling &
crystallization
magma
melting
igneous rocks
metamorphic rocks
weathering
& erosion
heat &
pressure
sediments
lithification
sedimentary rocks

Igneous rocks



General characteristics of magma

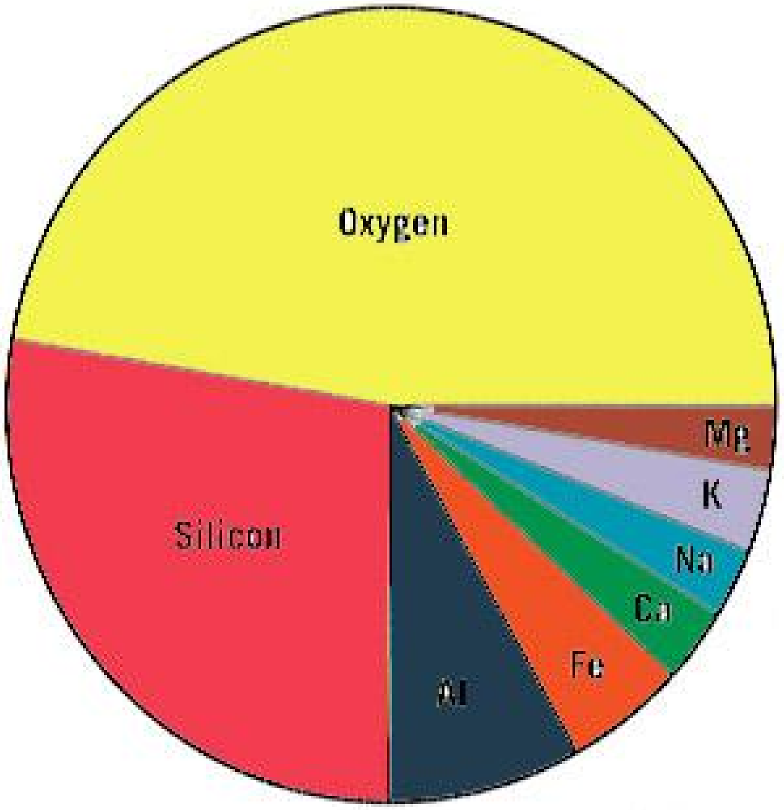
- Igneous rocks form as molten rock cools and solidifies
- General characteristics of magma:
  - Parent material of igneous rocks
  - Forms from partial melting of rocks
  - Magma at surface is called lava
- Rocks formed from lava = extrusive, or volcanic rocks
- Rocks formed from magma at depth = intrusive, or plutonic rocks

Characteristics of magma (1)

- **Types of Magma :** based on chemical composition of the magma :
  - Basaltic magma -- SiO_2 45-55 wt%, high in Fe, Mg, Ca, low in K, Na
  - Andesitic magma -- SiO_2 55-65 wt%, intermediate. in Fe, Mg, Ca, Na, K
  - Rhyolitic magma -- SiO_2 65-75%, low in Fe, Mg, Ca, high in K, Na

Average composition of the Earth's Crust (by weight, elements, and volume)

	Weight percent*	Atom percent	Ionic† radius (Å)	Volume percent
O	46.60	62.55	1.36	~ 94
Si	26.72	21.22	0.26 [4]	
Al	8.13	6.47	0.39 [4]	
Fe	5.00	1.92	0.78 [6]	
Ca	3.63	1.94	1.00 [6]	~ 6% in total
Na	2.83	2.64	1.02 [6]	
K	2.59	1.42	1.51 [8]	
Mg	2.09	1.84	0.72 [8]	
	98.59	100.00		



Characteristics of magma (2)

- **Temperature of Magmas:** difficult to measure (due to the danger involved), but laboratory measurement and limited field observation indicate that the eruption temperature of various magmas:
  - Basaltic magma - 1000 to 1200°C
  - Andesitic magma - 800 to 1000°C
  - Rhyolitic magma - 650 to 800°C.

Characteristics of magma (3)

- **Viscosity of Magmas: *Viscosity*** is the resistance to flow (opposite of fluidity).
- Viscosity depends on primarily on the composition of the magma, and temperature.
  - Higher SiO_2 (silica) content magmas have higher viscosity than lower SiO_2 content magmas (viscosity increases with increasing SiO_2 concentration in the magma).
  - Lower T magmas have higher viscosity than higher T magmas (viscosity decreases with increasing temperature of the magma).

Characteristics of magma (4)

- **Gases in Magmas:** At depth in the Earth nearly all magmas contain gas dissolved in the liquid, but the gas forms a separate vapor phase when pressure is decreased as magma rises toward the surface.
- Gas gives magmas their explosive character, because volume of gas expands as pressure is reduced. The composition of the gases in magma are:
  - Mostly H_2O (water vapor) with some CO_2 (carbon dioxide)
  - Minor amounts of Sulfur, Chlorine, and Fluorine gases
- The amount of gas in a magma is also related to the chemical composition of the magma. Rhyolitic magmas usually have higher dissolved gas contents than basaltic magmas.

Summary table

Summary Table					
Magma Type	Solidified Rock	Chemical Composition	Temperature	Viscosity	Gas Content
Basaltic	Basalt	45-55 SiO_2 %, high in Fe, Mg, Ca, low in K, Na	1000 - 1200 °C	10 - 10^3 PaS	Low
Andesitic	Andesite	55-65 SiO_2 %, intermediate in Fe, Mg, Ca, Na, K	800 - 1000 °C	10^3 - 10^5 PaS	Intermediate
Rhyolitic	Rhyolite	65-75 SiO_2 %, low in Fe, Mg, Ca, high in K, Na.	650 - 800 °C	10^5 - 10^9 PaS	High

Igneous rock bodies

Plutonic rock bodies

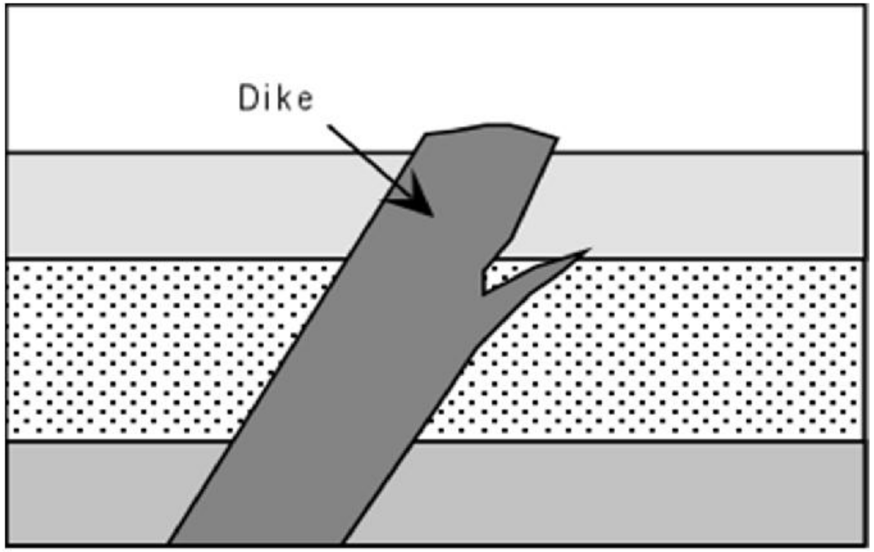
Volcanic rock bodies

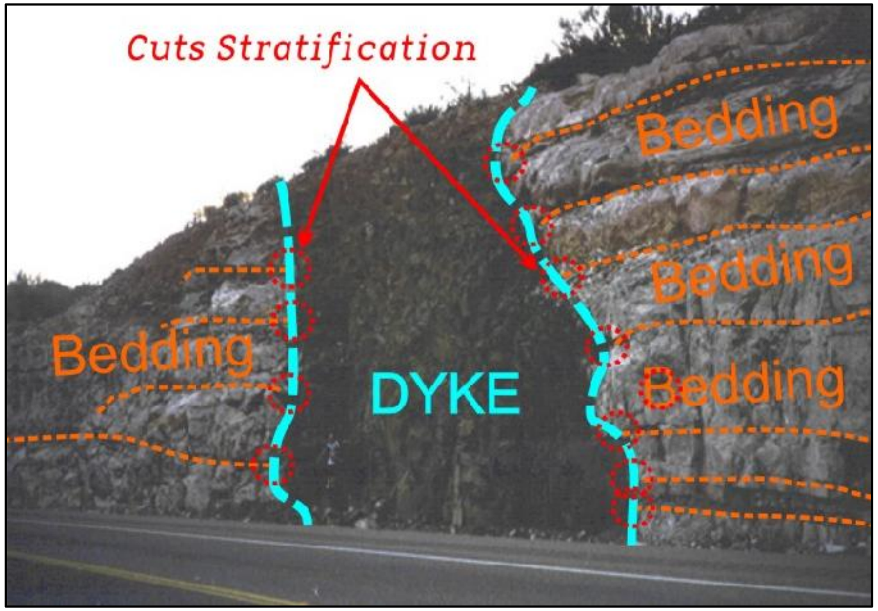
Plutonic / Intrusive rock bodies – Hypabyssal intrusions

- Hypabyssal intrusions
  - Intrusions that intrude rocks at shallow levels of the crust are termed hypabyssal intrusions.
  - Shallow generally refers to depths less than about 1 km.
  - Hypabyssal intrusions always show sharp contact relations with the rocks that they intrude.
  - Types
    - Dikes
    - Sills
    - Laccoliths

Hypabyssal igneous structures - Dyke

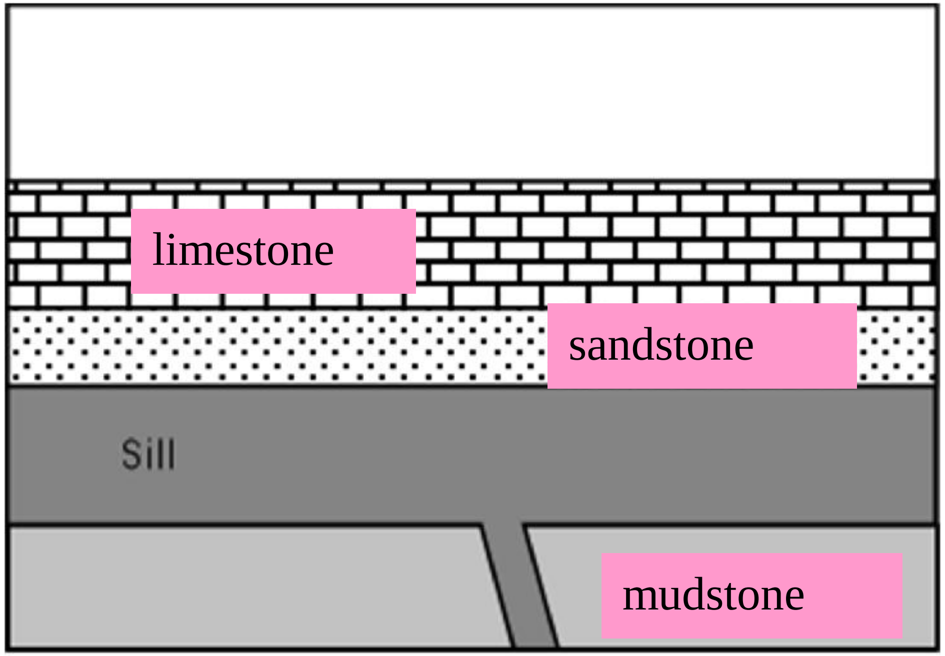
- They are discordant
- Cut across the bedding of the rocks in which they intrude
- Vertical to steeply inclined and sheetlike body (extensive in lateral dimension)
- Thickness vary widely from an inch upto hundred of feet
- Injected through fractures, joints, and weak planes





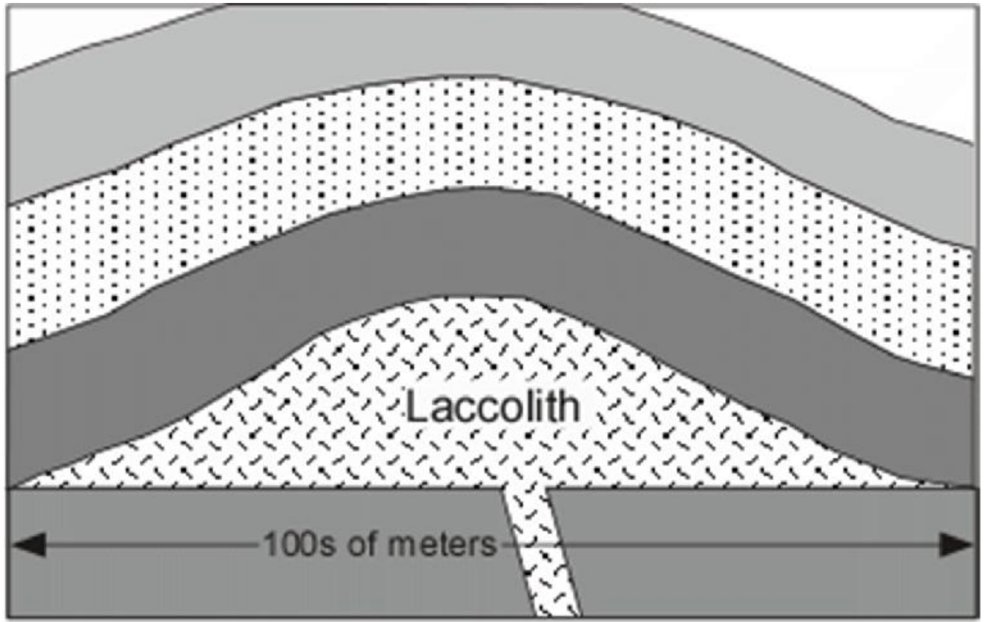
Hypabyssal igneous structures - Sill

- Sills are relatively thin tabular sheet like body that penetrates parallel to the bedding planes
- Laterally it may extends for 100s of km and upto 10 km in width



Hypabyssal igneous structures - Lacolith

- It is a concordant body, with flat bottom and convex upward. It is dome shaped.
- When viscous magma is injected rapidly along the bedding, as it cannot spreads, it pushes up the overlying layers and keep on piling up.
- Results in uplifting & folding of the overlying rock layers.

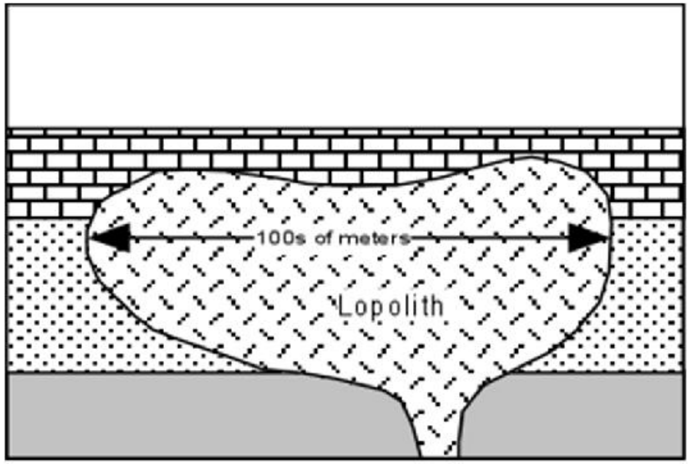


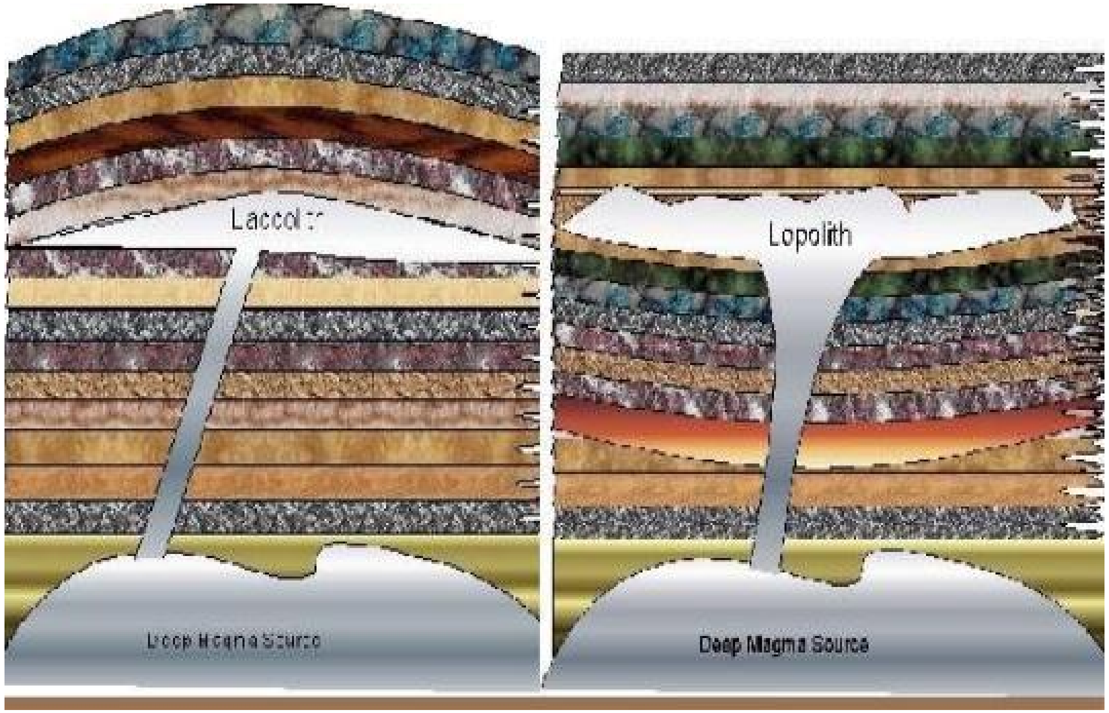
Plutonic / Intrusive rock bodies – Plutonic bodies

- Plutonic intrusions:
  - Plutons are generally much larger intrusive bodies that have intruded much deeper in the crust.
  - Although they may show sharp contacts with the surrounding rocks into which they intruded, at deeper levels in the crust the contacts are often gradational.
  - Types:
    - Lopoliths
    - Batholiths
    - Stocks

Plutonic bodies - Lopoliths

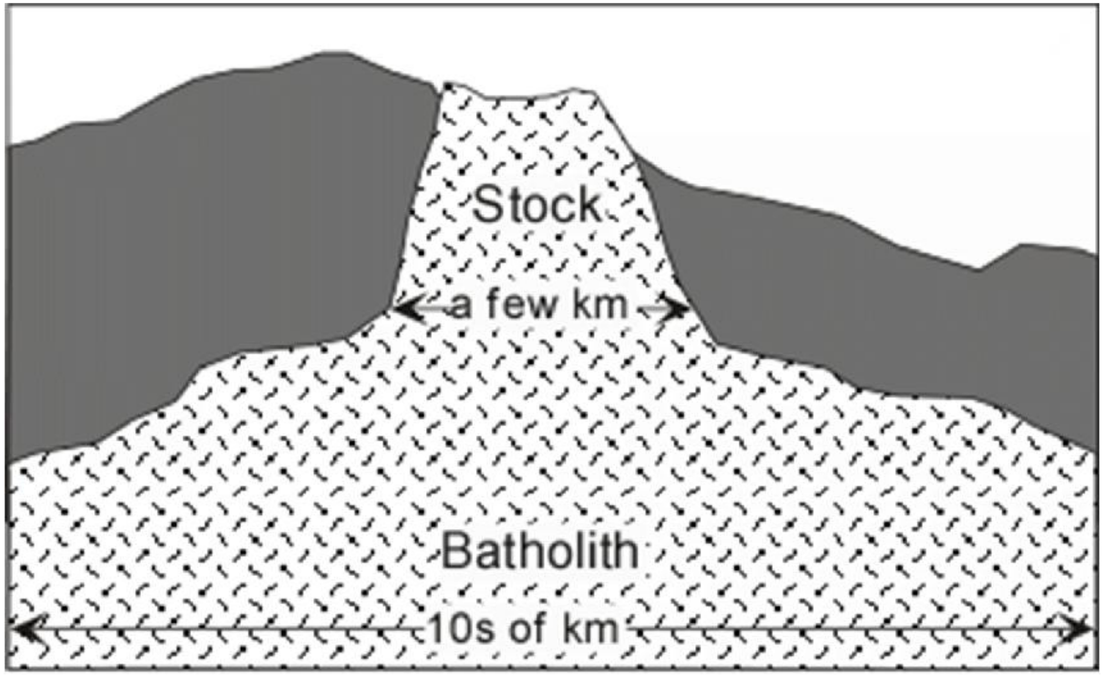
- Plutons that usually show a concave downward upper surface.
- Resulted from the reduction in volume that occurs when magmas crystallize, with the weight of the overlying rocks causing collapse of into the space once occupied by the magma when it had a larger volume as a liquid.





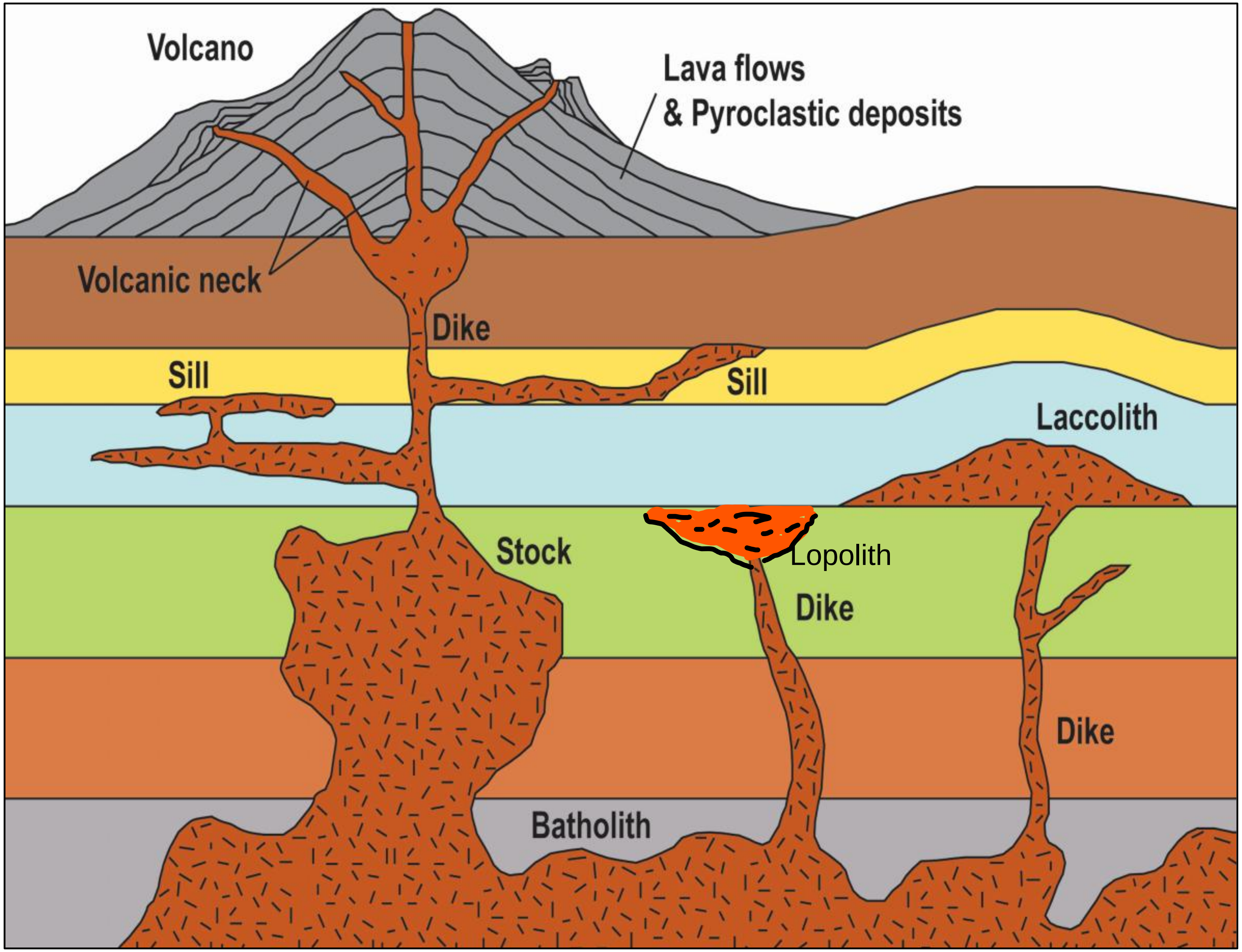
Plutonic bodies – Batholiths & Stocks

- **Batholiths**
  - very large intrusive bodies, usually so large that there bottoms are rarely exposed.
- **Stocks**
  - smaller bodies that are likely fed from deeper level batholiths. Stocks may have been feeders for volcanic eruptions,



Plutonic / Intrusive igneous rock bodies - Summary

- Hypabyssal
  - Dikes
  - Sills
  - Laccoliths
- Plutons
  - Lopoliths
  - Batholiths
  - Stocks

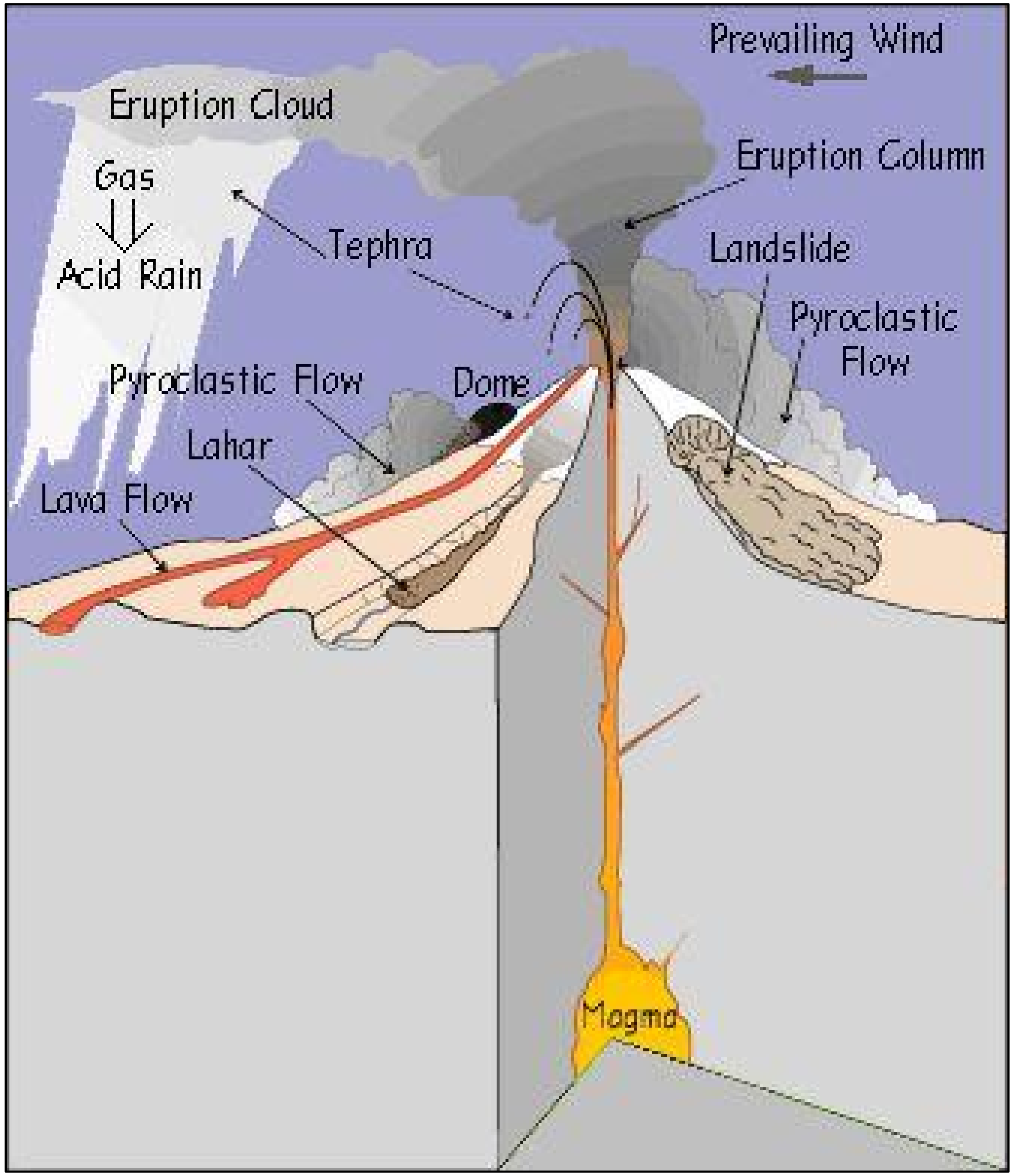


Volcanic Eruptions

- In general, magmas that are generated deep within the Earth begin to rise because they are less dense than the surrounding solid rocks.
- As they rise they may encounter a depth or pressure where the dissolved gas no longer can be held in solution in the magma, and the gas begins to form a separate phase.
- When a gas bubble forms, it will also continue to grow in size as pressure is reduced and more of the gas comes out of solution. In other words, the gas bubbles begin to expand.
- If magma has a low viscosity, then the gas can expand relatively easily. When the magma reaches the surface, the gas bubble will simply burst, the gas will easily expand to atmospheric pressure, and a non-explosive eruption will occur, usually as a lava flow.
- If magma has a high viscosity, then the gas will not be able to expand easily. Thus, pressure will build inside the gas bubble(s). When the magma reaches the surface, the gas bubbles will have a high pressure inside, which will cause them to burst explosively on reaching atmospheric pressure. This will cause an explosive volcanic eruption.

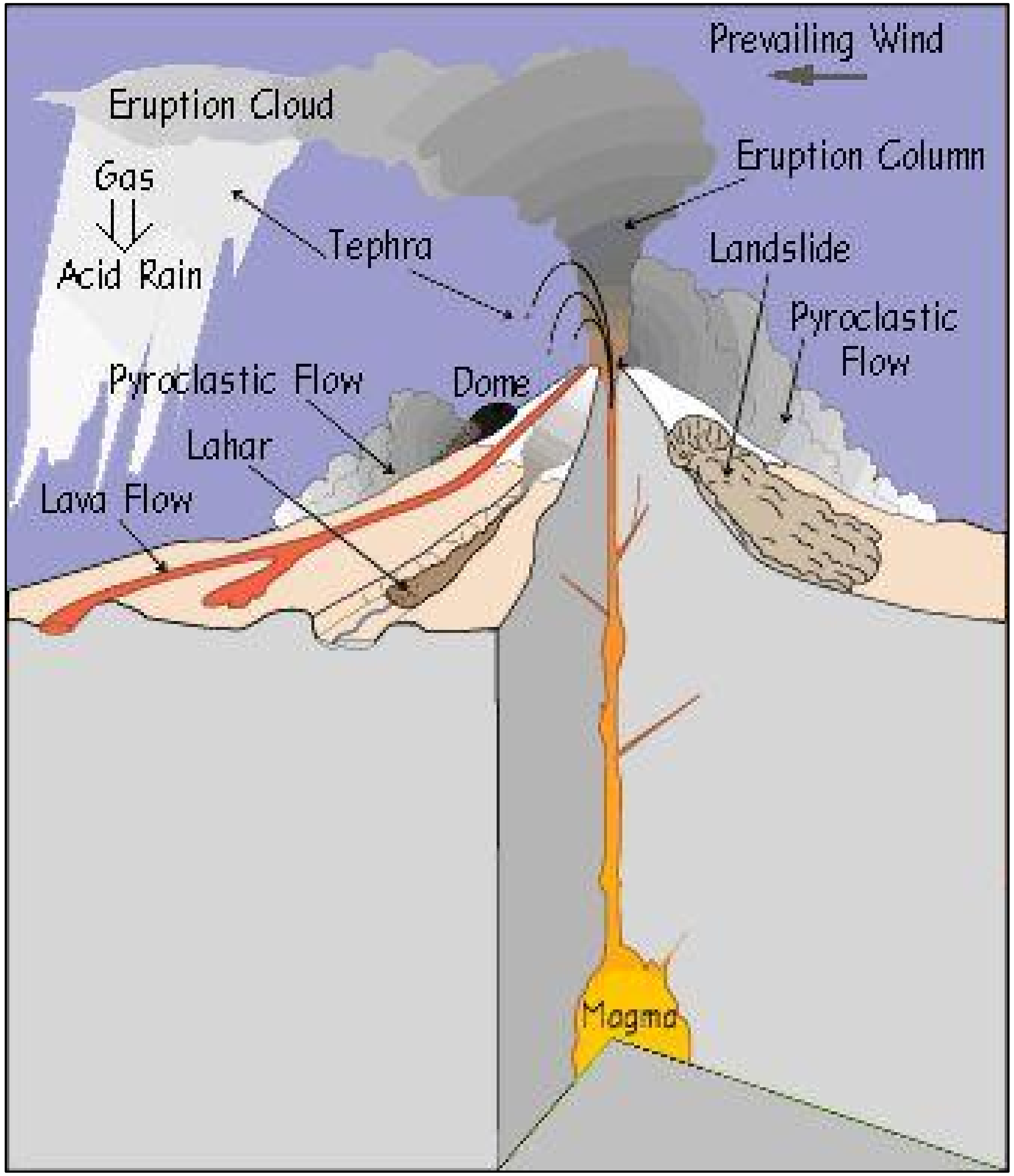
Explosive Eruptions - Pyroclasts

- **Pyroclasts** – Explosive bursting of bubbles will fragment the magma into clots of liquid that will cool as they fall through the air. These solid particles become ***pyroclasts (meaning – hot*** fragments) and ***tephra or volcanic ash, which refer to sand- sized or smaller fragments.***



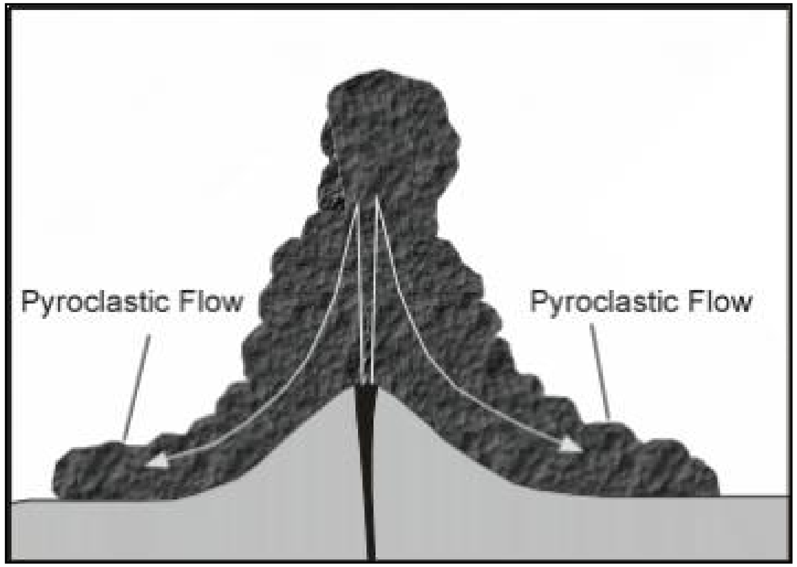
Explosive Eruptions – Eruption column

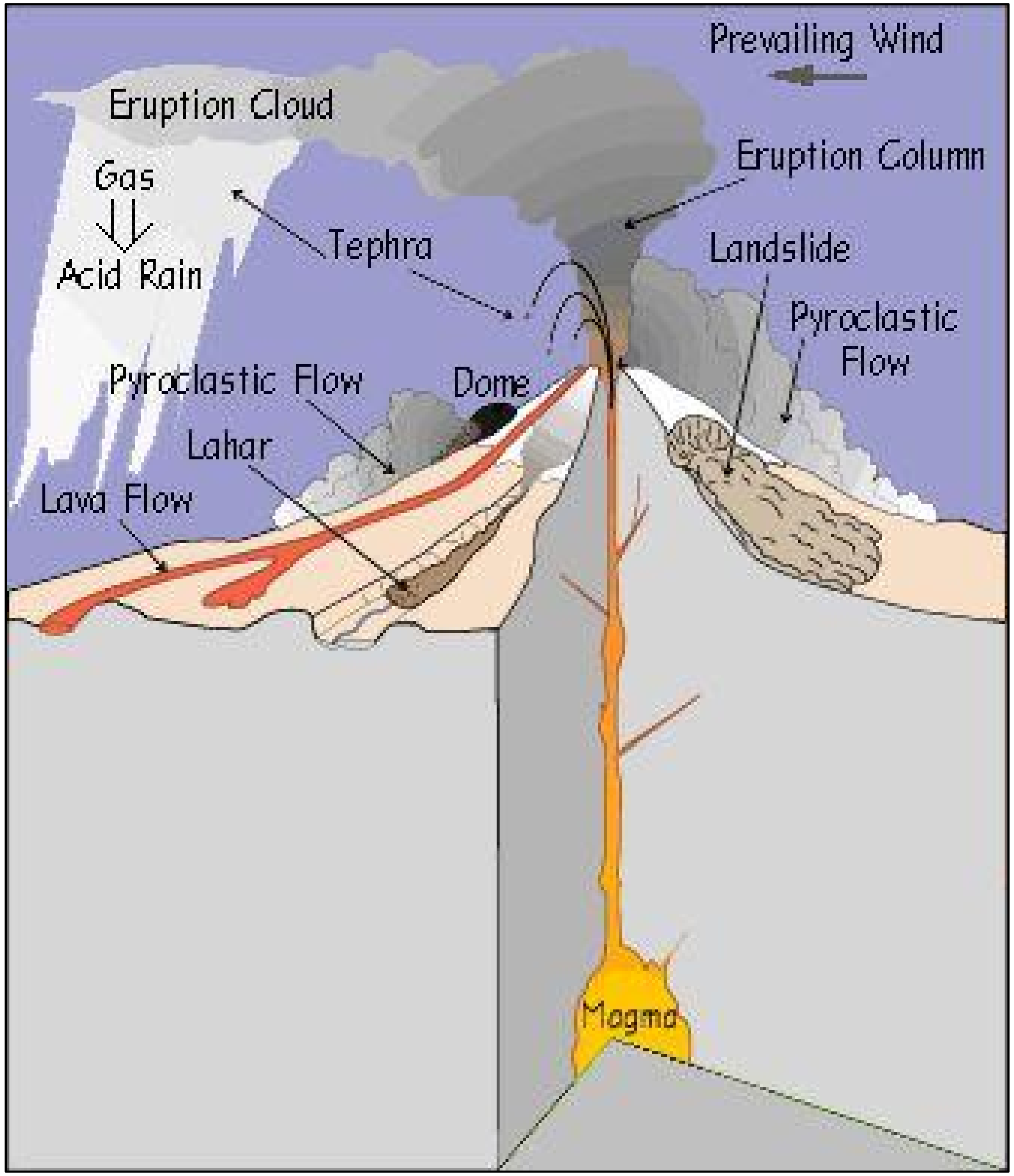
- Clouds of gas and tephra that rise above a volcano produce an **eruption column** that can rise up to 45 km into the atmosphere.
- Eventually the tephra in the eruption column will be picked up by the wind, carried for some distance, and then fall back to the surface as a **tephra fall or ash fall.**



Explosive Eruptions – Pyroclastic flow

- If the eruption column collapses a **pyroclastic flow will occur,** wherein gas and tephra rush down the flanks of the volcano at high speed. This is the most dangerous type of volcanic eruption.



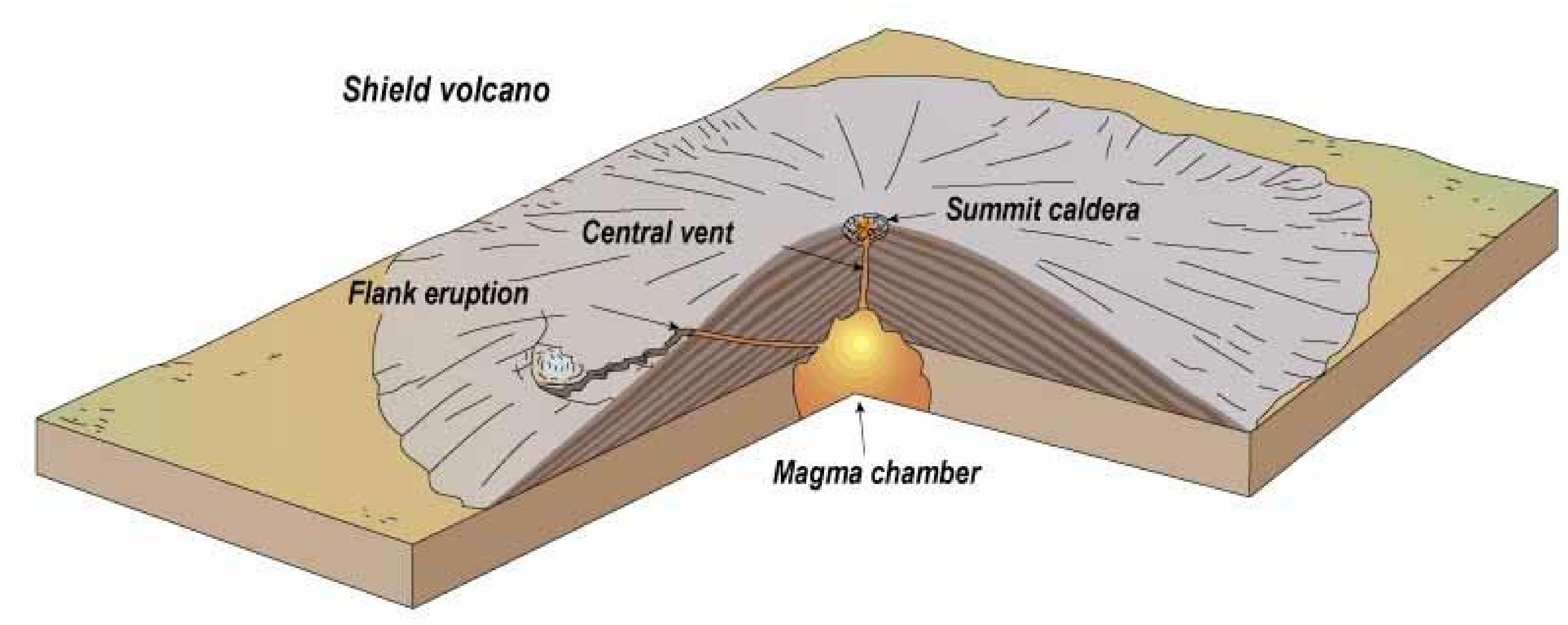


Non-explosive eruptions

- Non-explosive eruptions are favored by low gas content and low viscosity magmas (basaltic to andesitic magmas).
- If the viscosity is low, non-explosive eruptions usually begin with fire fountains due to release of dissolved gases.
- Lava flows are produced on the surface, and these run like liquids down slope, along the lowest areas they can find.
- Lava flows produced by eruptions under water are called ***pillow lavas.***
- If the viscosity is high, but the gas content is low, then the lava will pile up over the vent to produce a ***lava dome or volcanic dome.***

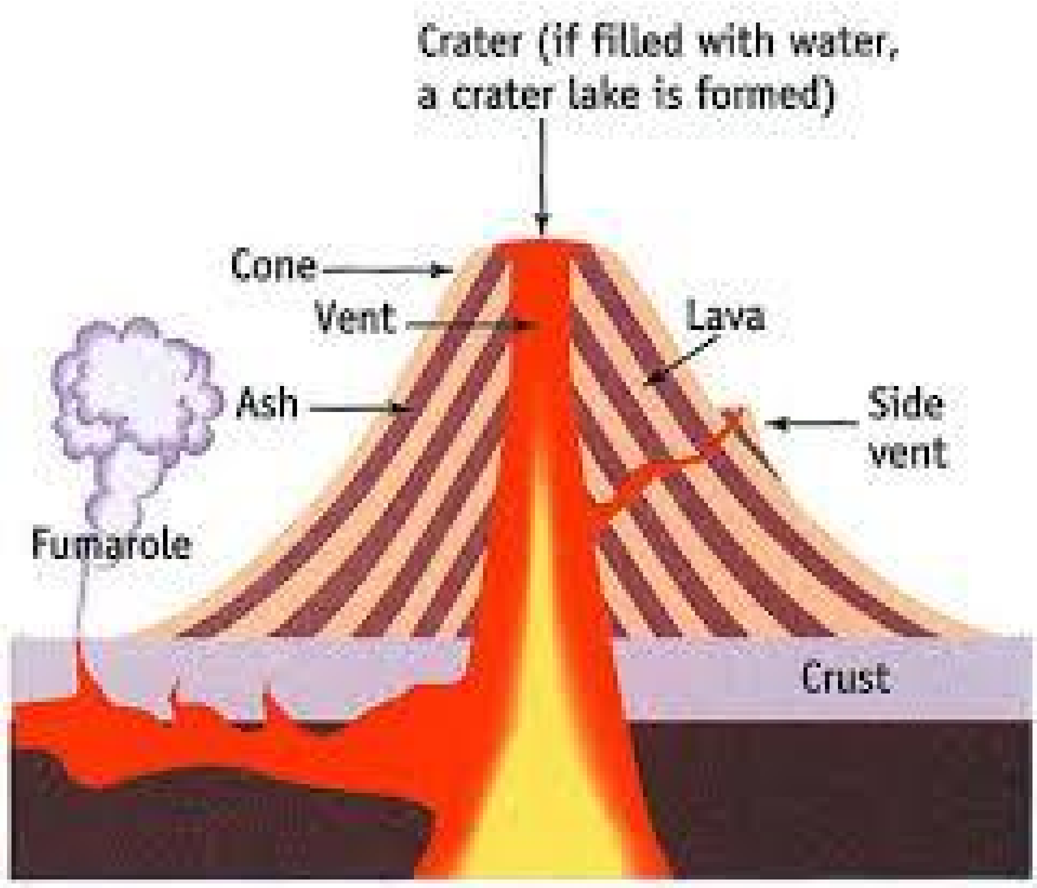
Volcanic landforms - **Shield Volcanoes**

- A shield volcano is characterized by gentle upper slopes (about 5°) and somewhat steeper lower slopes (about 10°).
- Most shields are formed by low viscosity basaltic magma that flows easily down slope away form a summit vent.



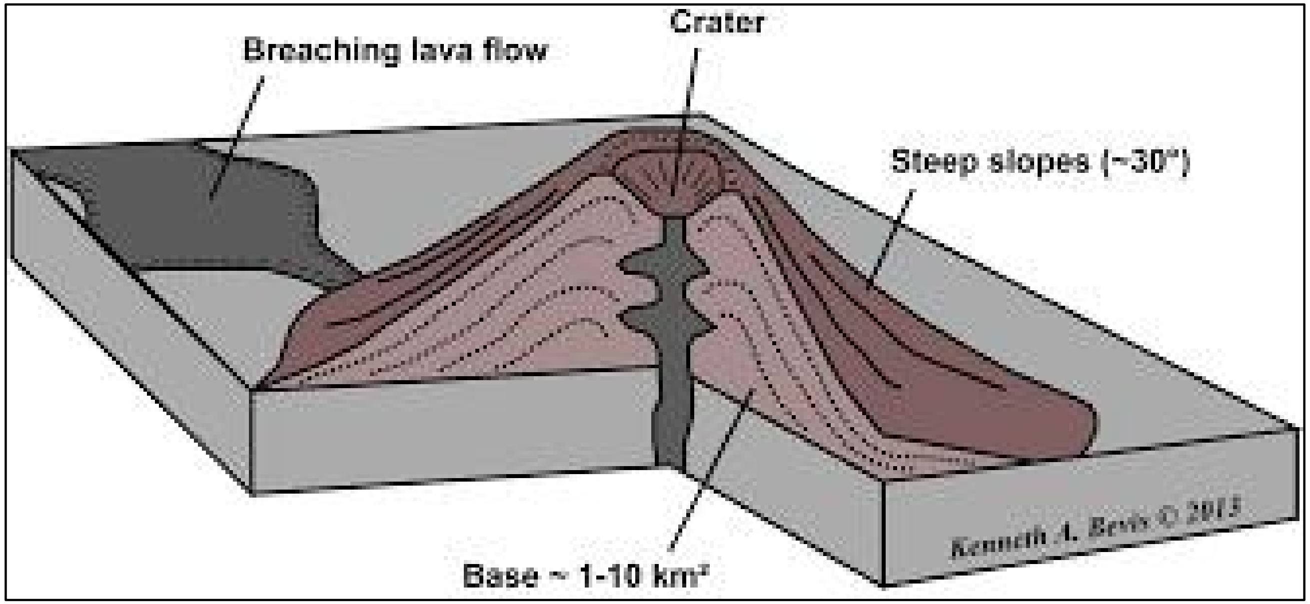
Volcanic landforms – Composite Volcanoes

- Have steeper slopes than shields, with slopes of 6 - 10° low on the flanks to 30° near the summit.
- Inter-layering of lava flows and pyroclastic material, which is why they are sometimes called composite volcanoes.
- Lavas and pyroclastics are usually andesitic to rhyolitic in composition, more explosive
- Sometimes have a crater at the summit, that is formed by explosive ejection of material from a central vent.



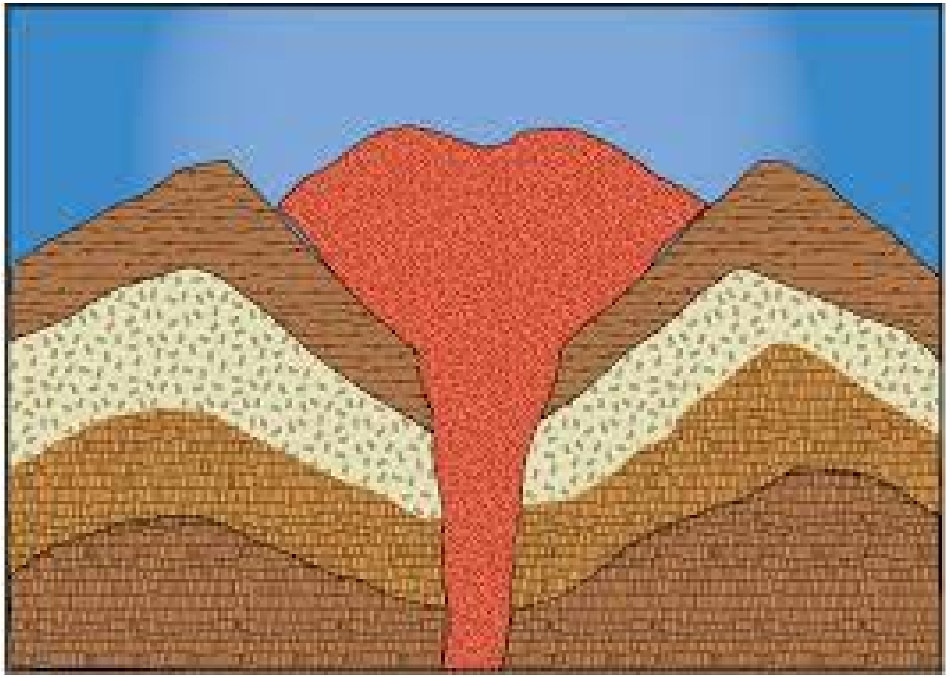
Volcanic landforms – **Tephra Cones**

- Tephra cones are small volume cones consisting predominantly of tephra, usually basaltic to andesitic material.
- On young cones, a depression at the top of the cone, called a crater, is evident, and represents the area above the vent from which material was explosively ejected. Craters are usually eroded away on older cones.



Volcanic landforms – **Volcanic Domes**

- Result from the extrusion of highly viscous, gas poor andesitic and rhyolitic lava. Since the viscosity is so high, the lava does not flow away from the vent, but instead piles up over the vent.

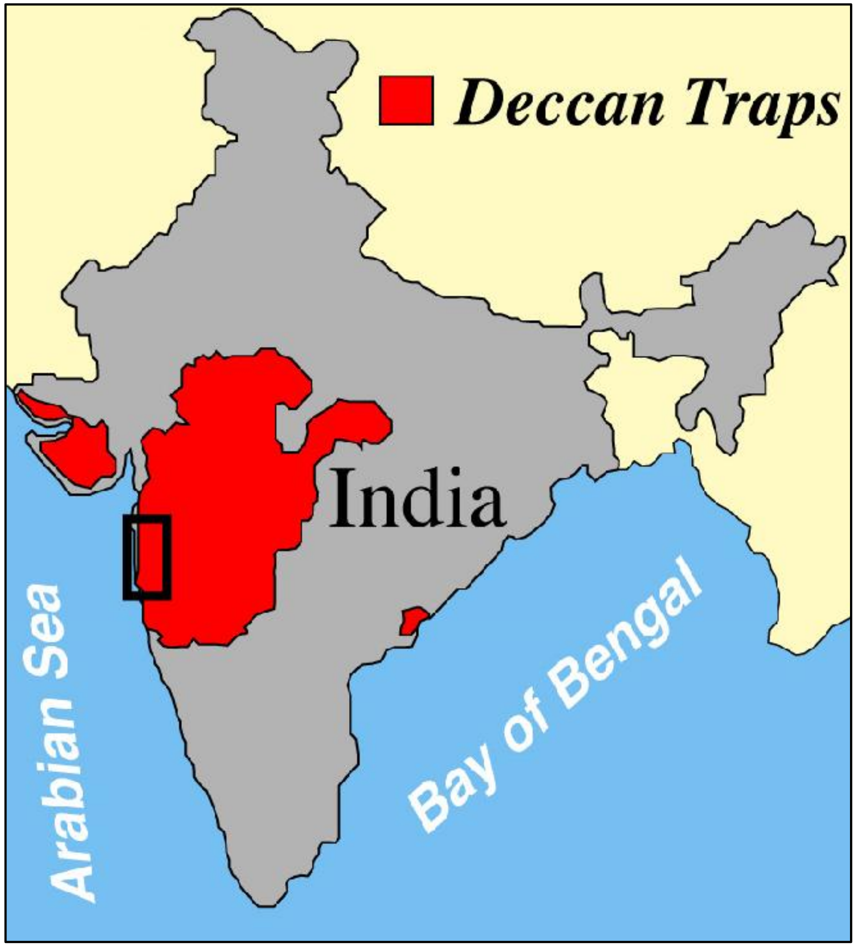


Volcanic landforms – **Craters & Calderas**

- Craters are circular depressions, usually less than 1 km in diameter, that form as a result of explosions that emit gases and tephra.
- Calderas are much larger depressions, circular to elliptical in shape, with diameters ranging from 1 km to 50 km. Calderas form as a result of collapse of a volcanic structure.
- Calderas are often enclosed depressions that collect rain water and snow melt, and thus lakes often form within a caldera

Volcanic landforms – **Flood Basalts**

- Plateau or Flood basalts are extremely large volume outpourings of low viscosity basaltic magma from fissure vents. The basalts spread huge areas of relatively low slope and build up plateaus.



Igneous Rock Texture

Igneous textures

- Texture is used to describe the overall appearance of a rock based on the size, shape, and arrangement of interlocking minerals

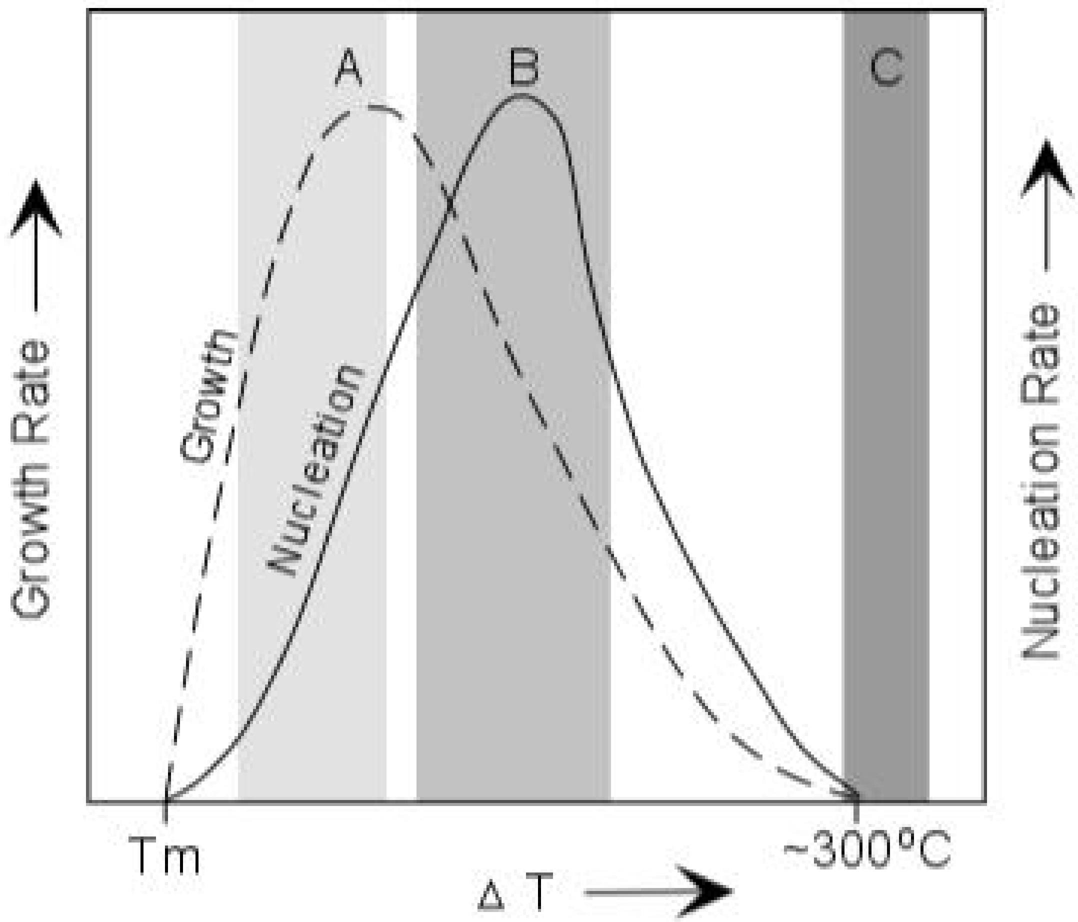
- Factors affecting crystal size
  - Rate of cooling
    - Slow rate = fewer but larger crystals
    - Fast rate = many small crystals
    - Very fast rate forms glass
  - % of silica (SiO_2) present
  - Dissolved gases

Crystallization from magma

- For a crystal to form in a magma enough of the chemical constituents that will make up the crystal must be at the same place at the same time to form a nucleus of the crystal.
- Once a nucleus forms, the chemical constituents must diffuse through the liquid to arrive at the surface of the growing crystal.
- The crystal can then grow until it runs into other crystals or the supply of chemical constituents is cut off.

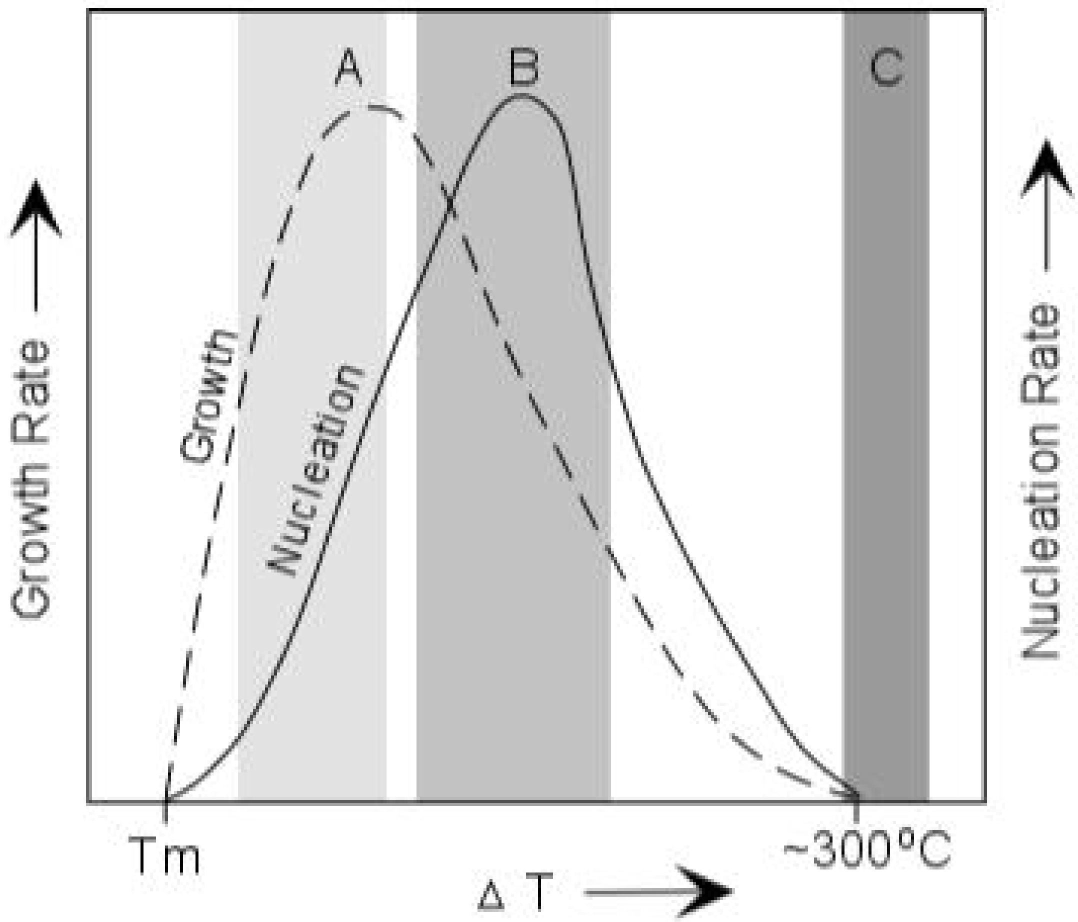
Rate of Cooling

- the rate of crystal growth and nucleation depends on how long the magma resides at a specified degree of undercooling ($T = T_m - T$), and thus the rate at which temperature is lowered below the crystallization temperature



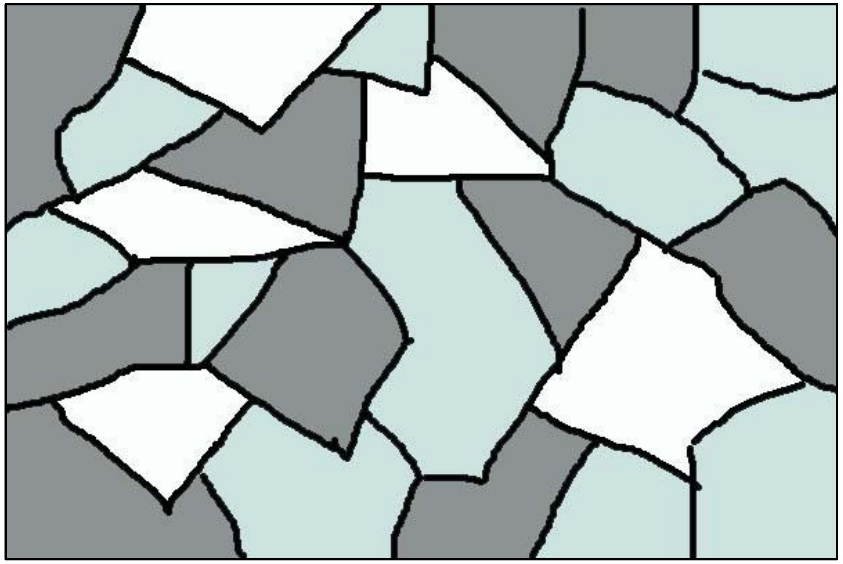
Rate of Cooling: Case I

- Let's talk about A
- Nucleation rate is low
  - Only few crystals will form
- Growth rate is moderate
  - Those few crystals will grow large
- Results in an igneous rock with few but large crystals.
- **Phaneritic** texture



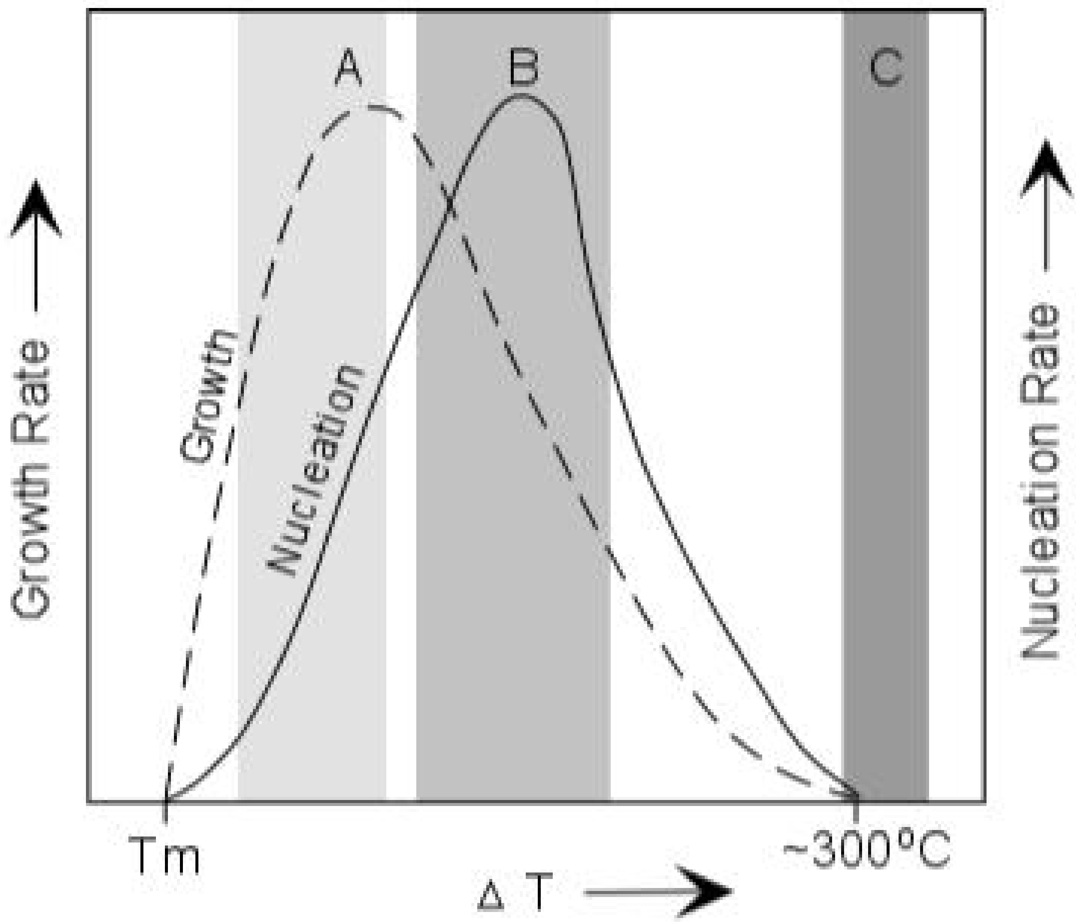
Igneous textures - Phaneritic

- Phaneritic (coarse-grained) texture
  - Slow cooling
  - Large, visible crystals



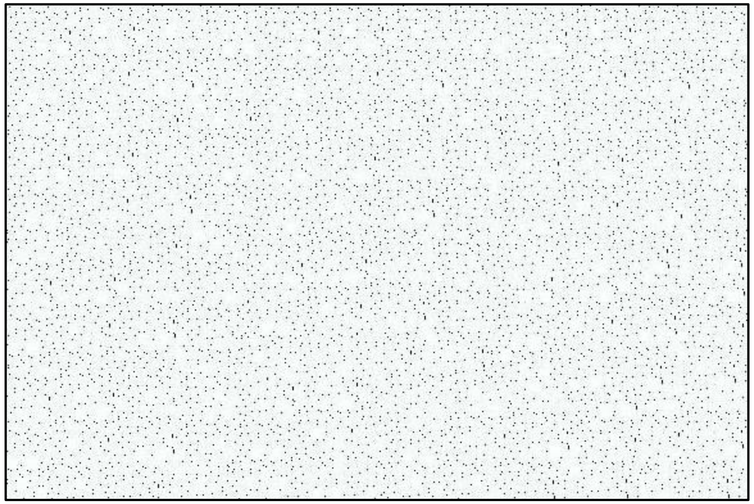
Rate of Cooling: Case II

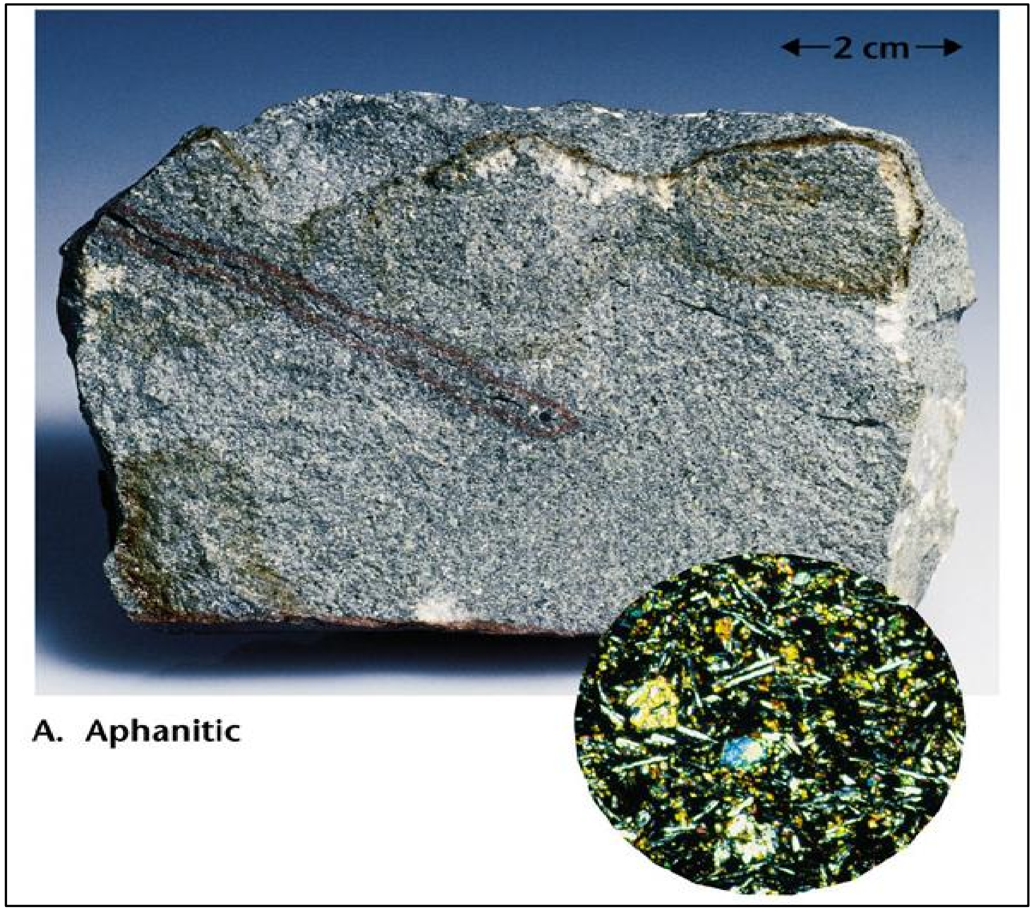
- Let's talk about B
- Nucleation rate is high
  - Lots of crystals will form
- Growth rate is also high
  - crystals will grow fast
- Result will be an igneous rock with numerous small crystals.
- **Aphinitic** texture



Igneous textures - Aphanitic

- Aphanitic (fine-grained) texture
  - Rapid rate of cooling
  - Microscopic crystals
    - May contain vesicles (holes from gas bubbles)

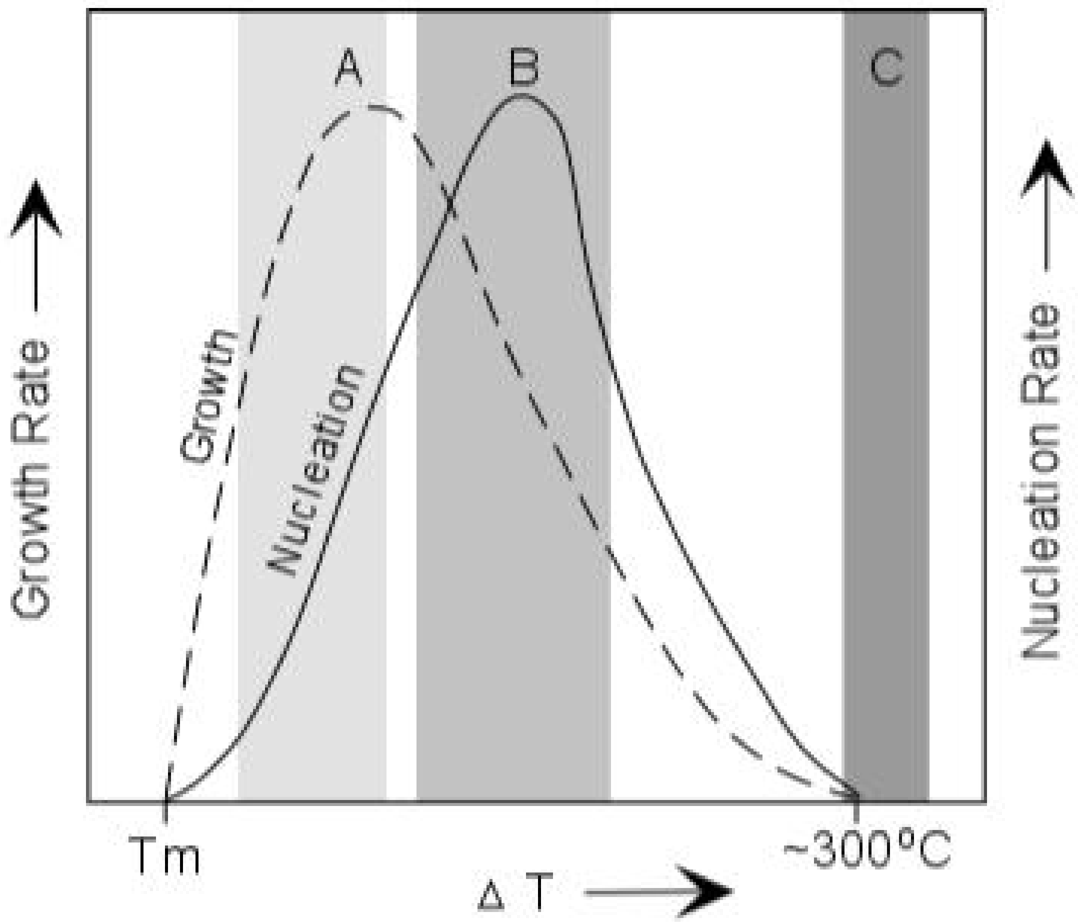




A. Aphanitic

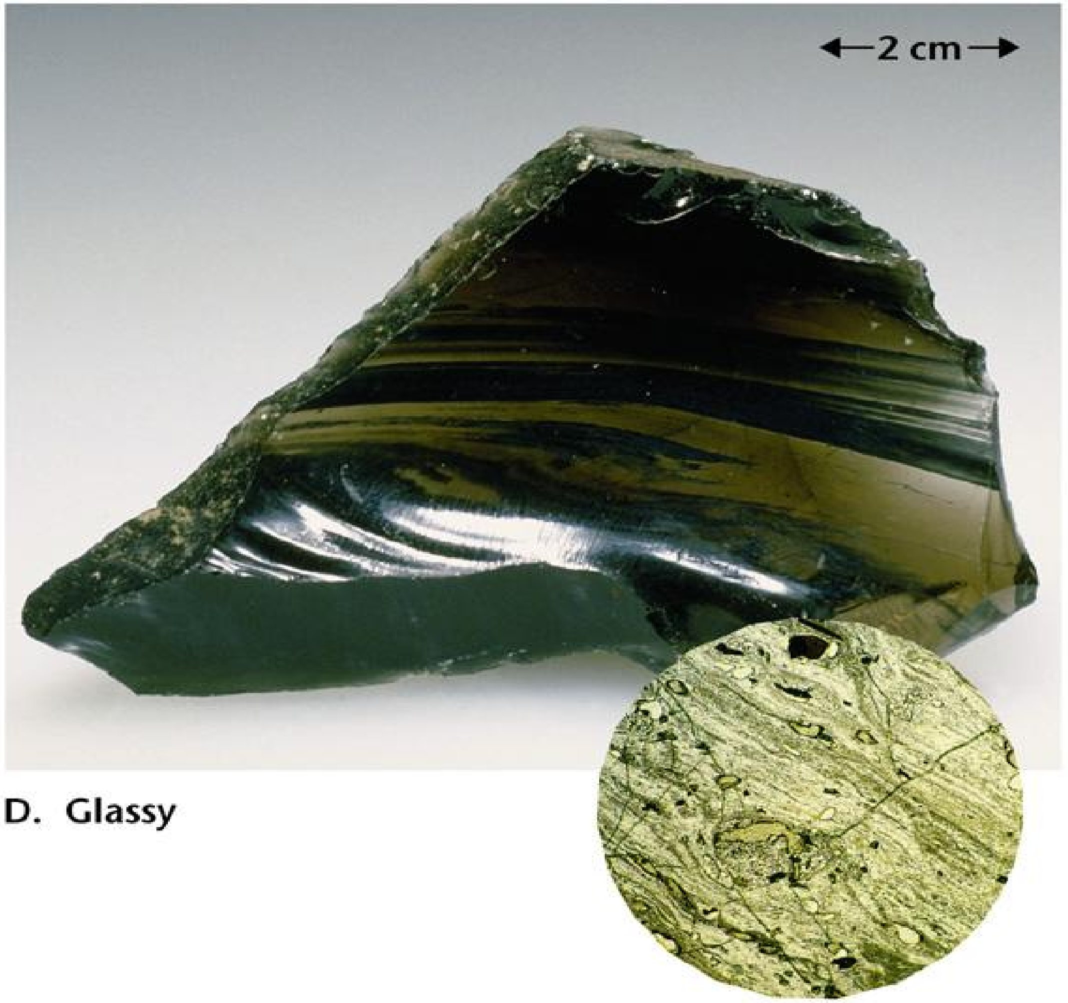
Rate of Cooling: Case III

- Let's talk about C
- Nucleation rate is very low
  - Very few crystals will form
- Growth rate is also low
  - crystals will not grow large
- Result will be an igneous rock with very few small crystals.
- **Glassy** texture



Igneous textures - Glassy

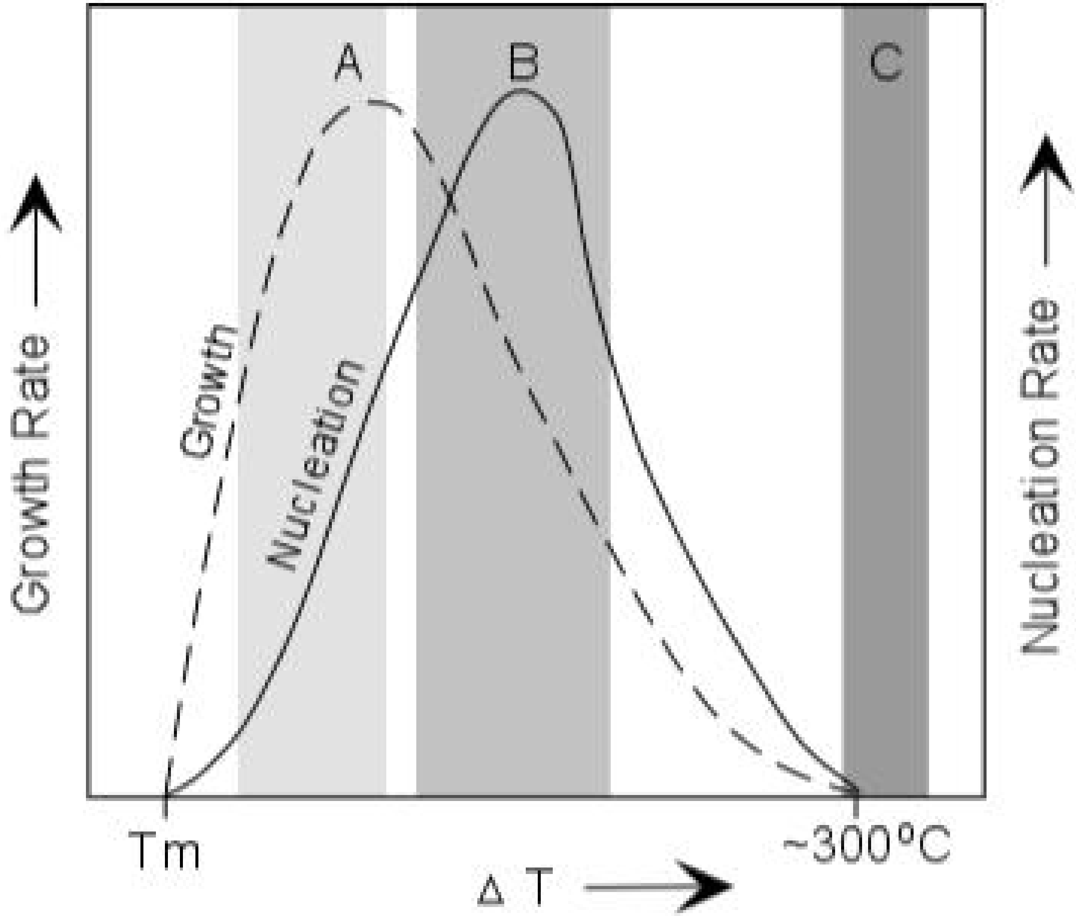
- Glassy texture
  - Very rapid cooling of lava
  - Resulting rock is called obsidian



D. Glassy

Rate of Cooling: Case IV

- Let's talk about an intermediate situation
- Slow cooling
  - Few large crystals
- Followed by fast cooling
  - Many smaller crystals
- Result will be an igneous rock with two distinct grain sizes.
- **Porphyritic** texture



Igneous textures - Porphyritic

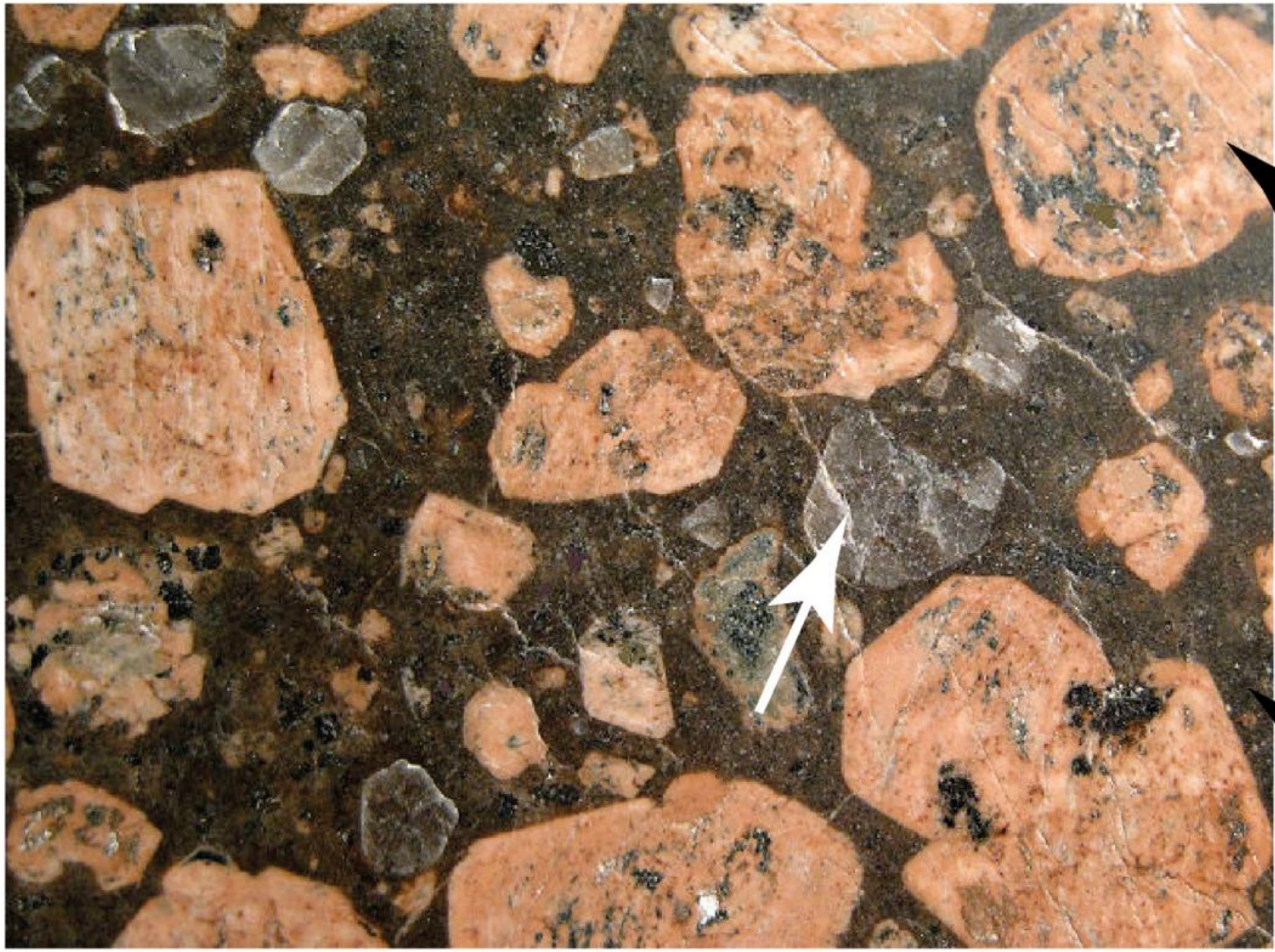


Photo: R. Weller/ Cochise College

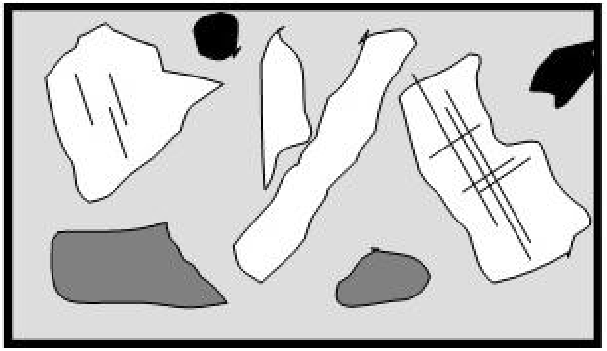
Potassium feldspar phenocryst
(formed in the magma chamber)

Groundmass
(formed after eruption)

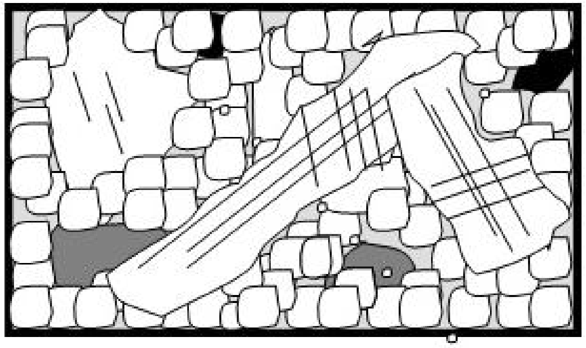
Quartz phenocryst
(formed in the magma chamber)

Igneous textures - Porphyritic

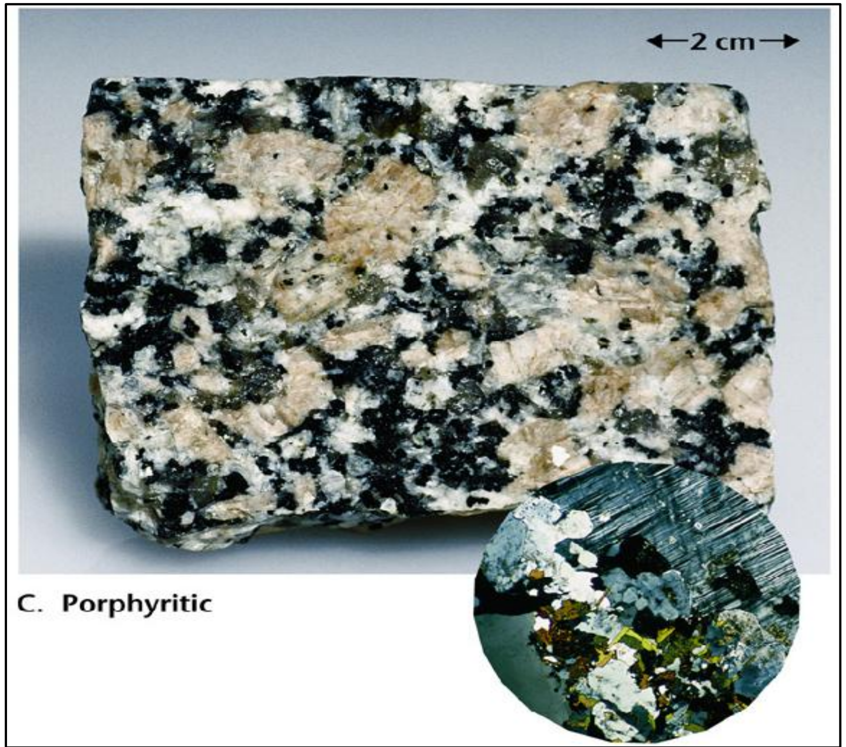
- Porphyritic texture



Porphyritic – matrix grains not visible



Porphyritic – fine-grained matrix



C. Porphyritic

Igneous textures - Pegmatitic

- Pegmatitic texture
  - Exceptionally coarse grained
  - Form in late stages of crystallization of granitic magmas

Igneous textures - Pyroclastic

- Pyroclastic texture
  - Fragmental appearance produced by violent volcanic eruptions
  - Often appear more similar to sedimentary rocks

Summary of igneous textures

- Phaneritic: crystals visible with naked eye
  - *Plutonic* or *intrusive rocks*
- Aphanitic: crystal too small for naked eye
  - *Volcanic* or *extrusive rocks*
- Porphyritic: two different, dominant grain sizes
  - Large xtals = *phenocrysts*; small xtals = *groundmass*
- Pegmatitic: very large xtals (cm to 10s of cm); i.e., *slowly* cooled
  - *Forms veins or layers within plutonic body*
- Pyroclastic: composed of disaggregated igneous material
- Glassy: non-crystalline; cools very fast (e.g., obsidian)
  - *Volcanic rocks*

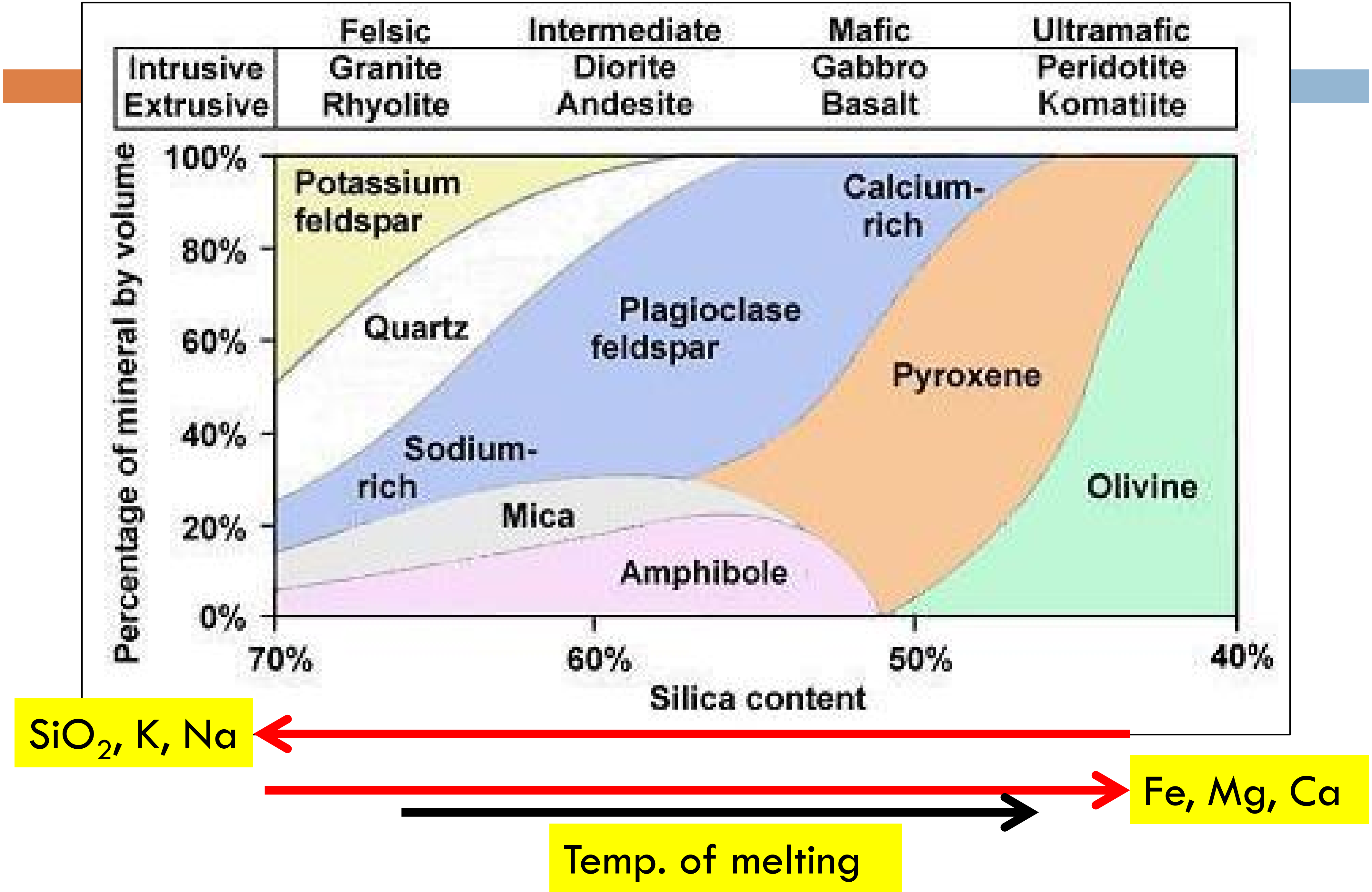
Igneous compositions

- Igneous rocks are composed primarily of silicate minerals
  - Dark (or ferromagnesian) silicates
    - Olivine, pyroxene, amphibole, and biotite mica
  - Light (or nonferromagnesian) silicates
    - Quartz, muscovite mica, and feldspars
- Silica content as an indicator of composition
  - Exhibits a considerable range in the crust
    - 45% to 70%
- Silica content influences magma behavior
  - Granitic magmas = high silica content and viscous
  - Basaltic magmas = much lower silica content and more fluid-like behavior

Classification of common igneous rocks

Composition	**Phaneritic**	**Aphanitic**	**Color index (% dark minerals)**
Felsic	Granite Syenite Monzonite	Rhyolite Trachyte Latite	10 15 20
Intermediate	Granodiorite Diorite	Dacite Andesite	20 25
Mafic	Gabbro	Basalt	50
Ultramafic	Peridotite		95

Mineralogy of common igneous rocks



Igneous composition

- Felsic / Acidic compositional group
  - dominated by K-feldspar, Na Plagioclase, quartz, and biotite
  - usually light in color
  - typical of continental crust (Granite and Rhyolite)

- Mafic / Basic compositional group
  - Dominated by Ca-Plagioclase, pyroxene, olivine, amphibole
  - Usually dark in color
  - Higher density than granitic rocks
  - Typical of oceanic crusts (and the Moon, Mars, and Venus!) (Basalt, Gabbro)

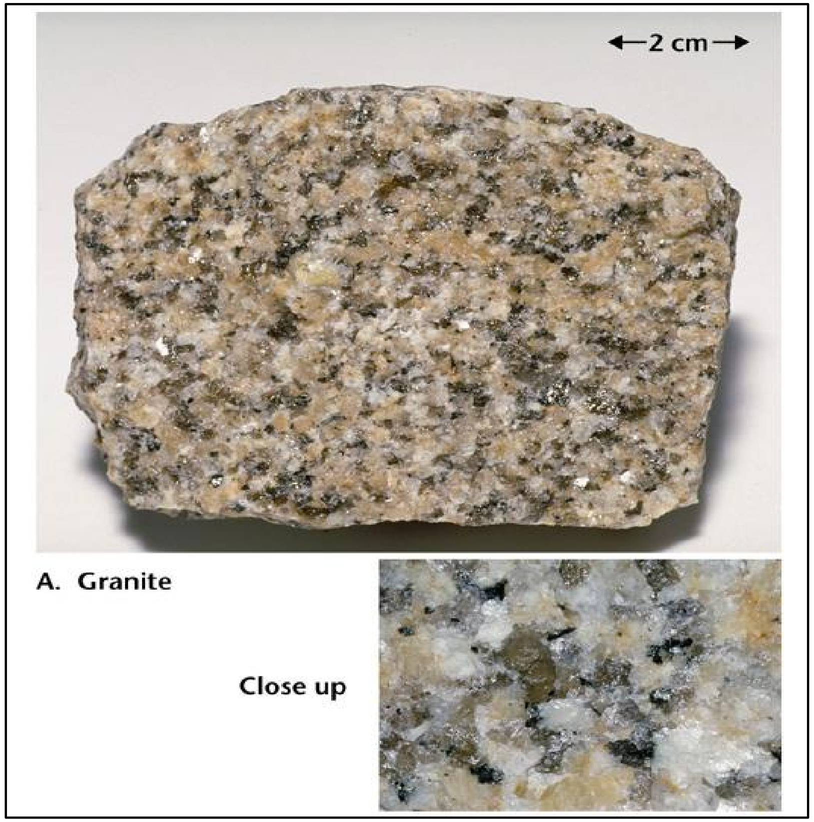
Igneous composition

- <u>Intermediate compositional group</u>
  - dominated by plagiocase, amphibole, pyroxene, biotite, quartz
  - intermediate color
  - Andesite and diorite

- <u>Ultramafic / Ultrabasic compositional group</u>
  - Dominated by olivine, minor amounts of pyroxene and Ca-plagioclase
  - Rarely seen on Earth's surface
  - Major constituent of Earth's Mantle
  - Peridotite

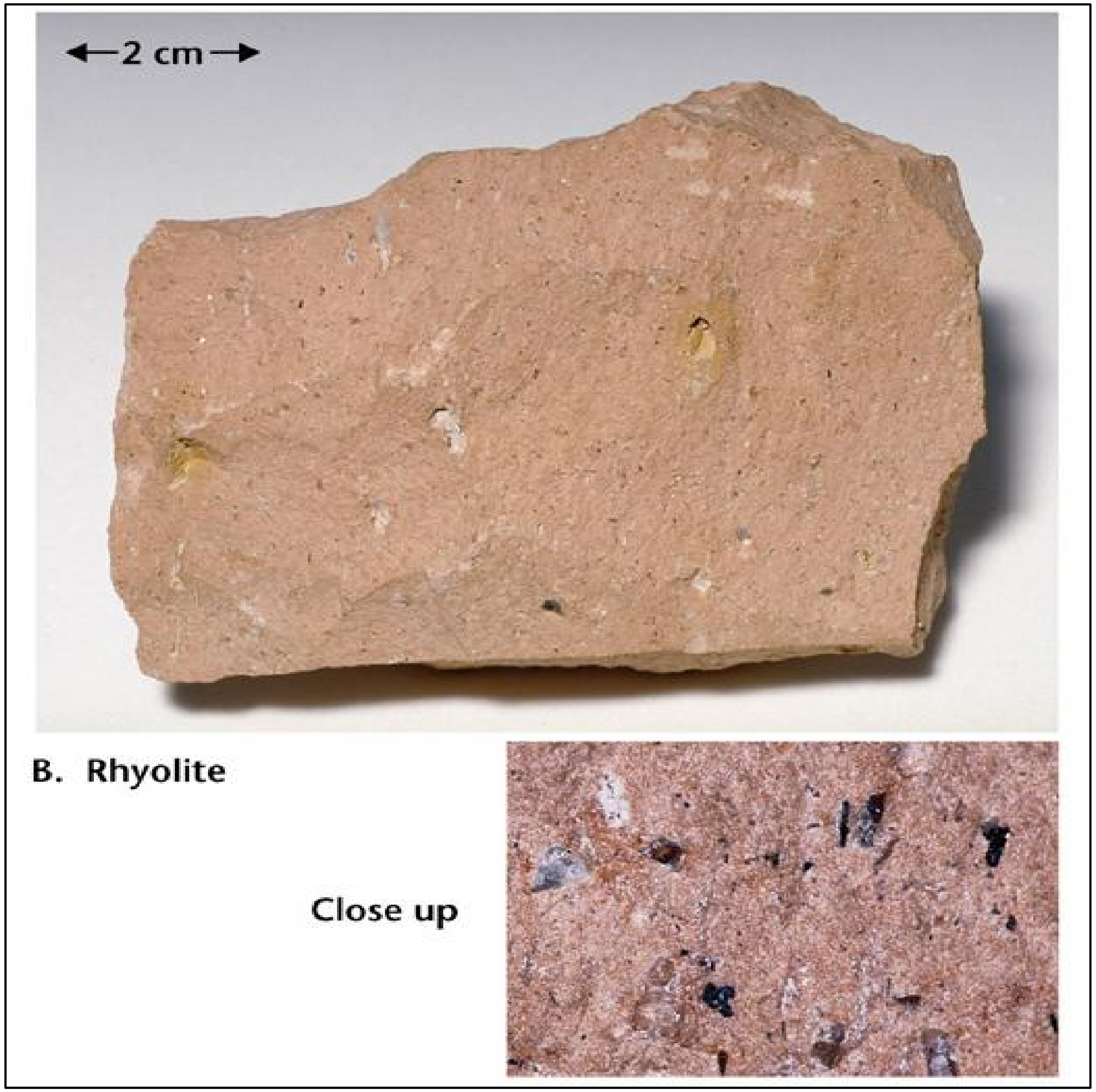
Common Igneous rocks – Felsic rocks

- Granite
  - Intrusive / Plutonic
  - Phaneritic
  - Over 25% quartz, about 65% or more feldspar
  - Very abundant - often associated with mountain building
  - The term granite includes a wide range of mineral compositions



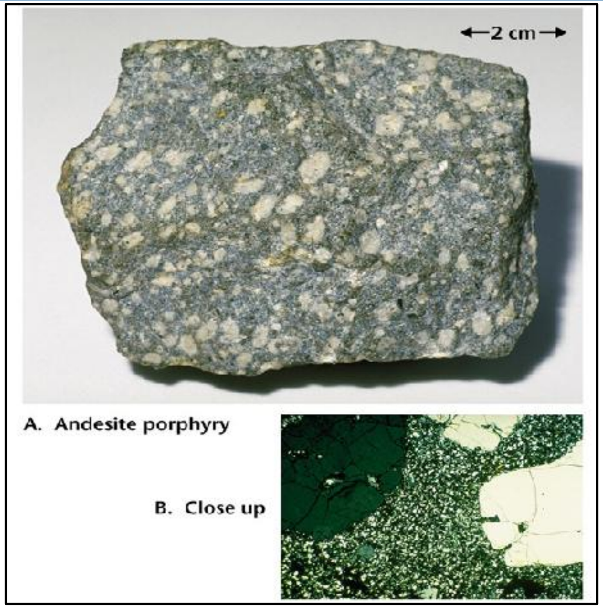
Common Igneous rocks
– Felsic rocks

- Rhyolite
  - Extrusive equivalent of granite
  - May contain glass fragments and vesicles
  - Aphanitic texture
  - Less common and less voluminous than granite

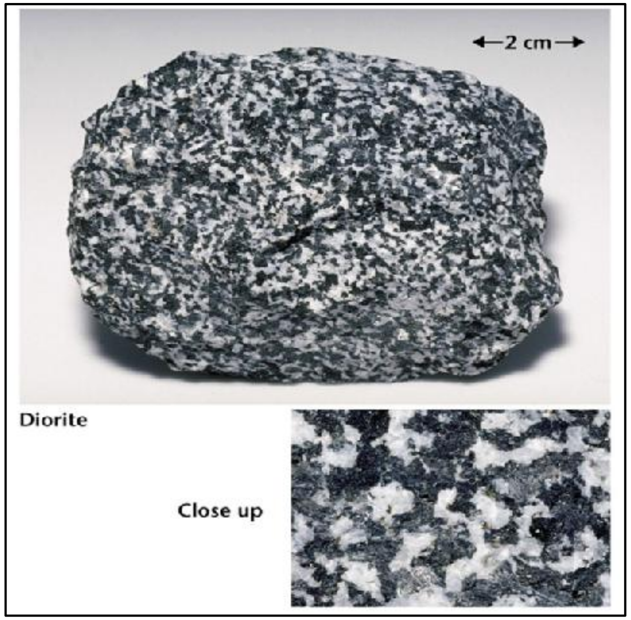


Common Igneous rocks – intermediate rocks

- **Andesite**
  - Volcanic origin
  - Aphanitic texture



- **Diorite**
  - Plutonic equivalent of andesite
  - Coarse grained



Common Igneous rocks – mafic rocks

- **Basalt**
  - Volcanic origin
  - Aphanitic texture
  - Composed mainly of pyroxene and calcium-rich plagioclase feldspar
  - Most common extrusive igneous rock

A. Basalt

Common Igneous rocks – mafic rocks

- Gabbro
  - Intrusive equivalent of basalt
  - Phaneritic texture consisting of pyroxene and calcium-rich plagioclase
  - Significant % of the oceanic crust

Summary of Igneous Rocks

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