# Lecture 6 - Igneous Rocks and Volcanoes

# Learning objectives

- Understand and be able to predict where and why magma will be forming at different tectonic settings
- Understand the factors controlling magma composition and make predictions about the composition of magma at different tectonic settings
- Be able to explain the type of materials produced by igneous activity and classify types of igneous rock
- Assess the type of volcanic hazards likely to occur at different tectonic settings

# The Rock Cycle

Magma

Cooling and crystallization

Heating and burial

Igenous Rock

Metamorphic Rock

Heating and burial (pressure)

Uplift and Weathering

Weathering

Heating and burial (pressure)

Sediment

Weathering

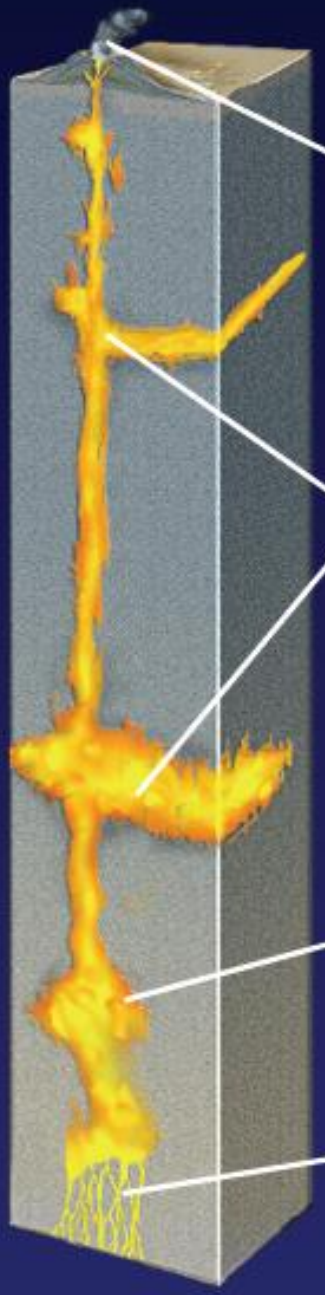
Sedimentary Rock

Cementation and compaction

# What is magma made of?

- Liquid portion = melt (mobile ions e.g. Si, O, Fe, Mg, Ca, Na)
- Solids = silicate minerals
- Dissolved gases (volatiles) in the melt, including water vapor ($H_2O$), carbon dioxide ($CO_2$), and sulfur dioxide ($SO_2$)

# Forming Igneous Rocks



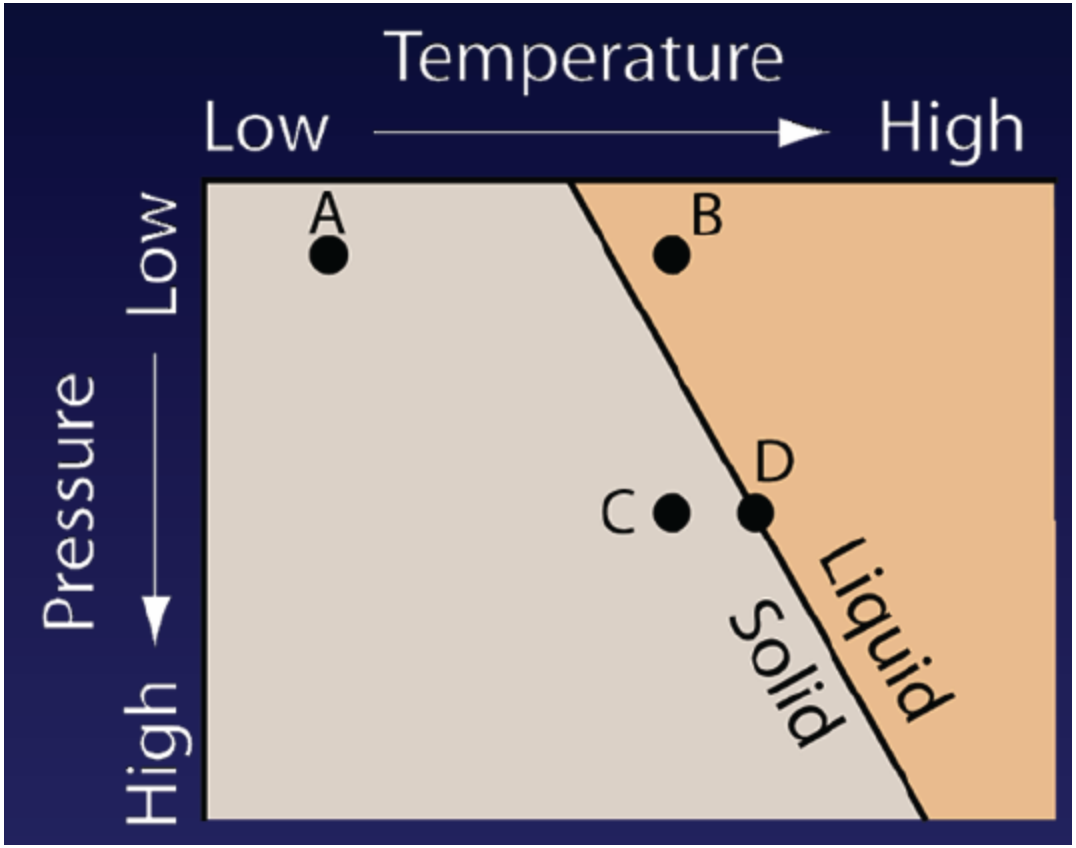
Eruption as lava or ash

Forms magma chamber (solidifies or rises)

Accumulates into rising magma body

Partial melting of source

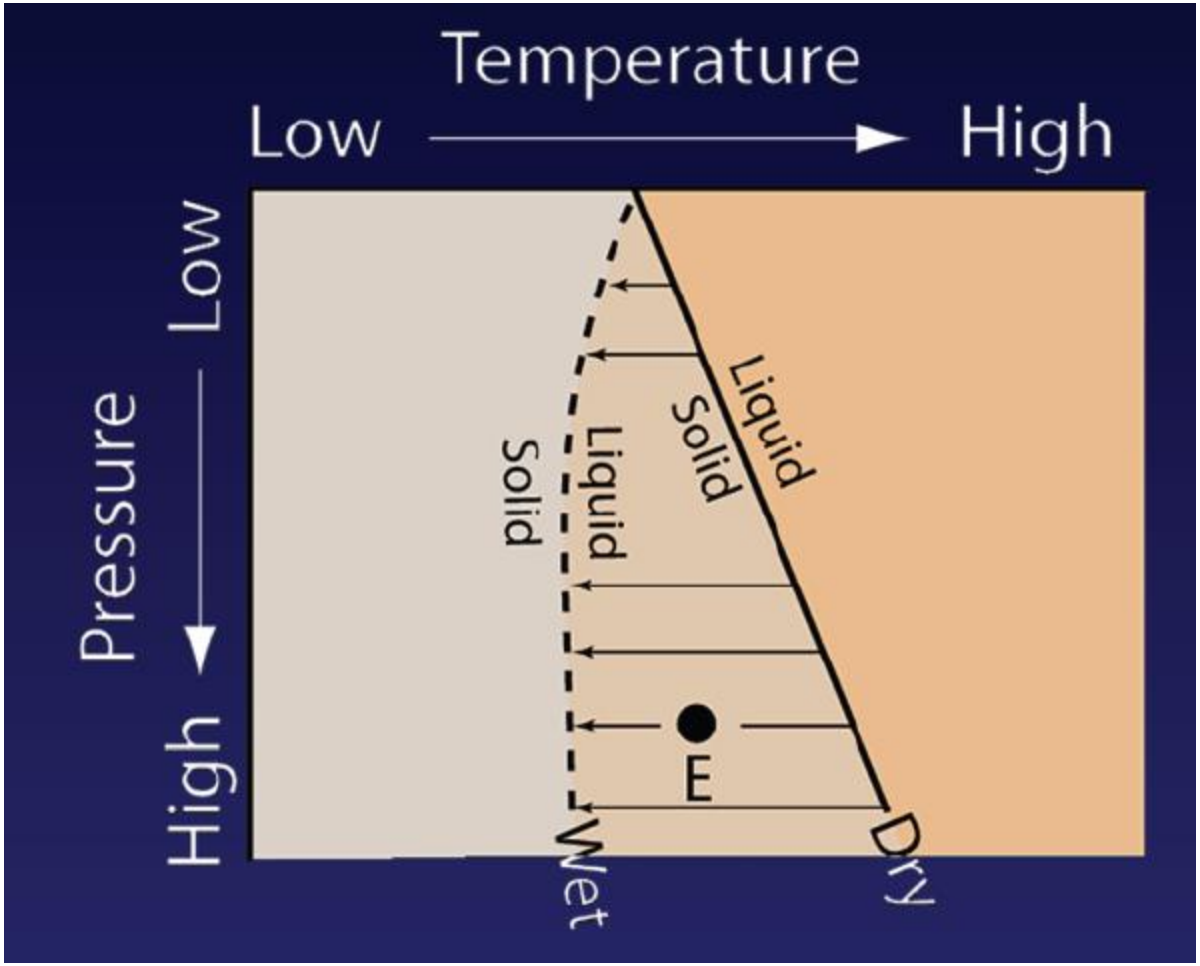
# Changing conditions to create melt




How could changing conditions cause a rock at point A to melt?

How could changing conditions cause a rock at point C to melt?

# Effect of water on melting



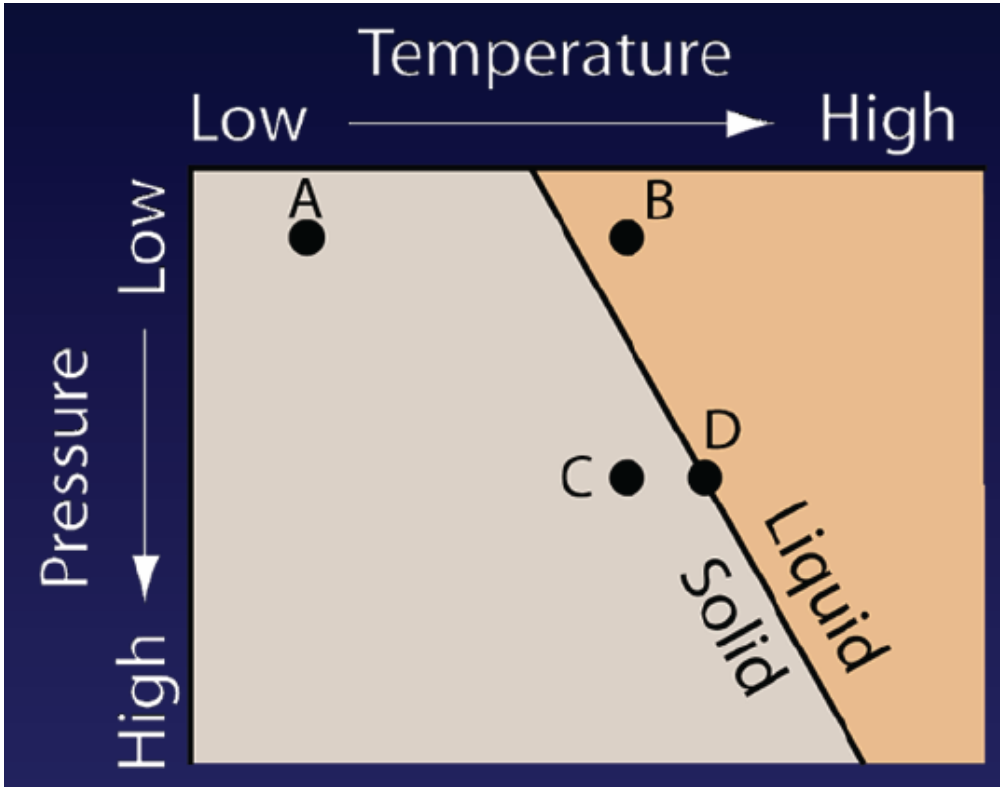

What happens to a hot, dry rock at point E when a small amount of water is added?

# Magma Formation

Magma forms in special settings that melt existing rocks.

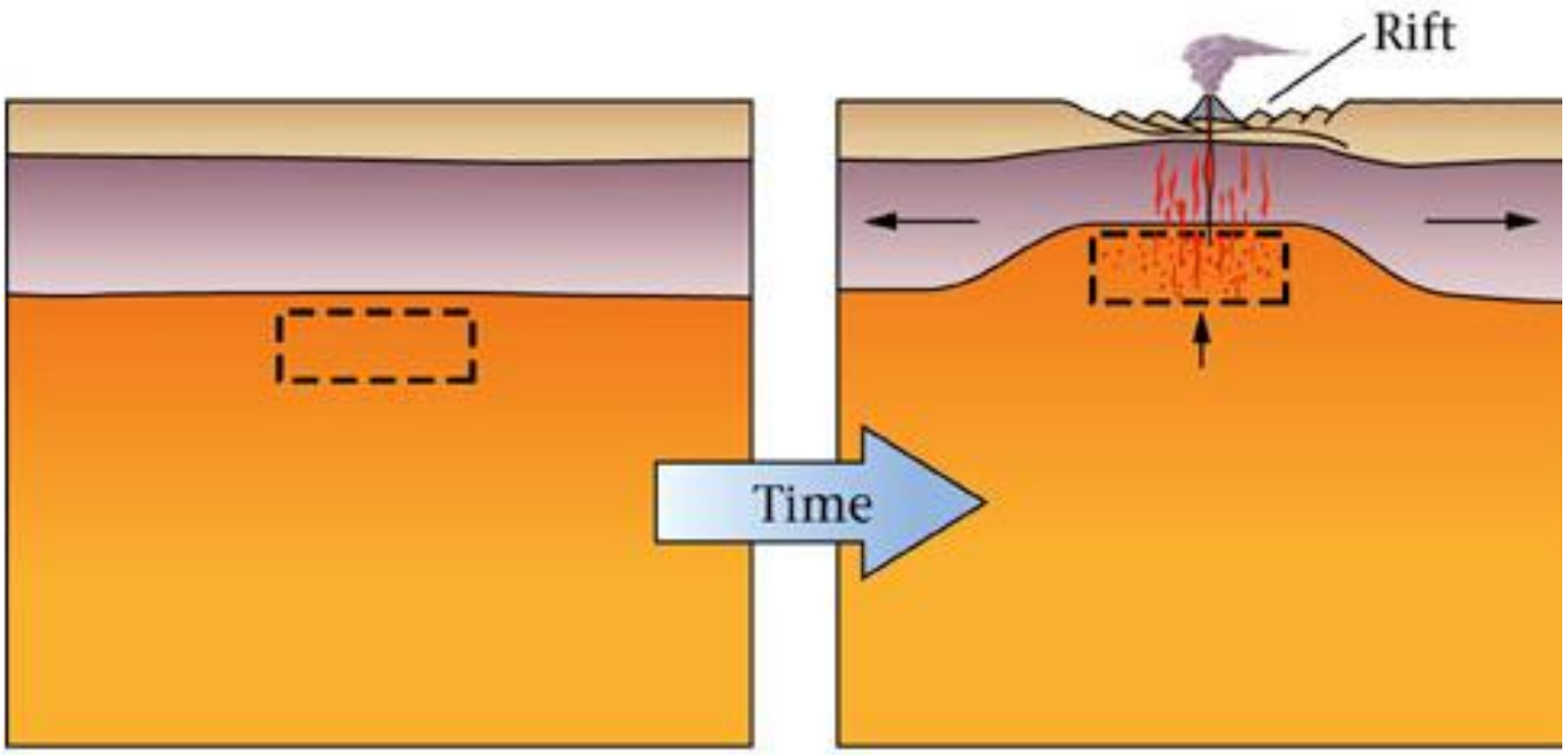
Melting is caused by…

1. Pressure decrease
2. Temp increase
3. Addition of water



# Magma Formation

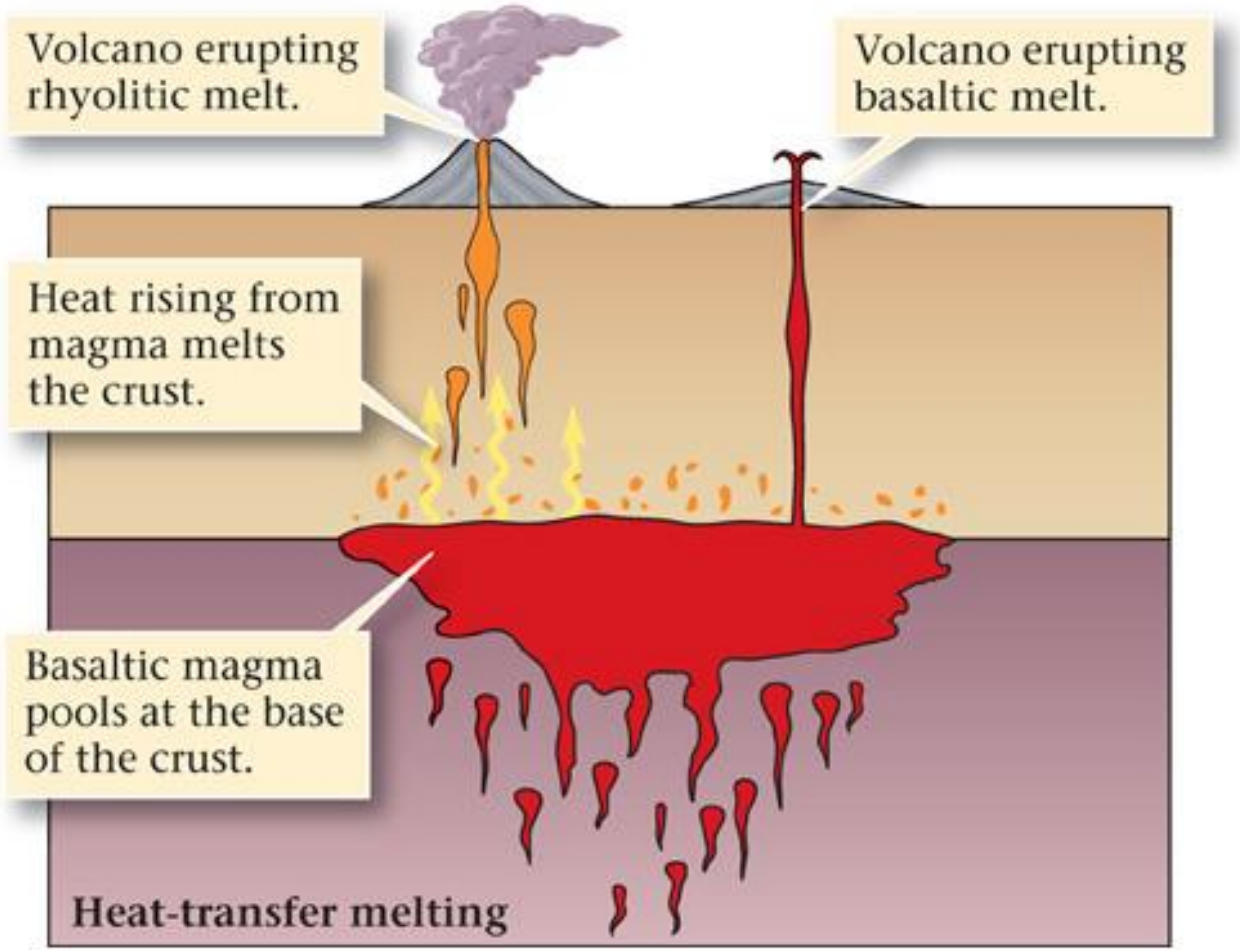
- **Pressure decrease**




Decompression melting beneath a rift

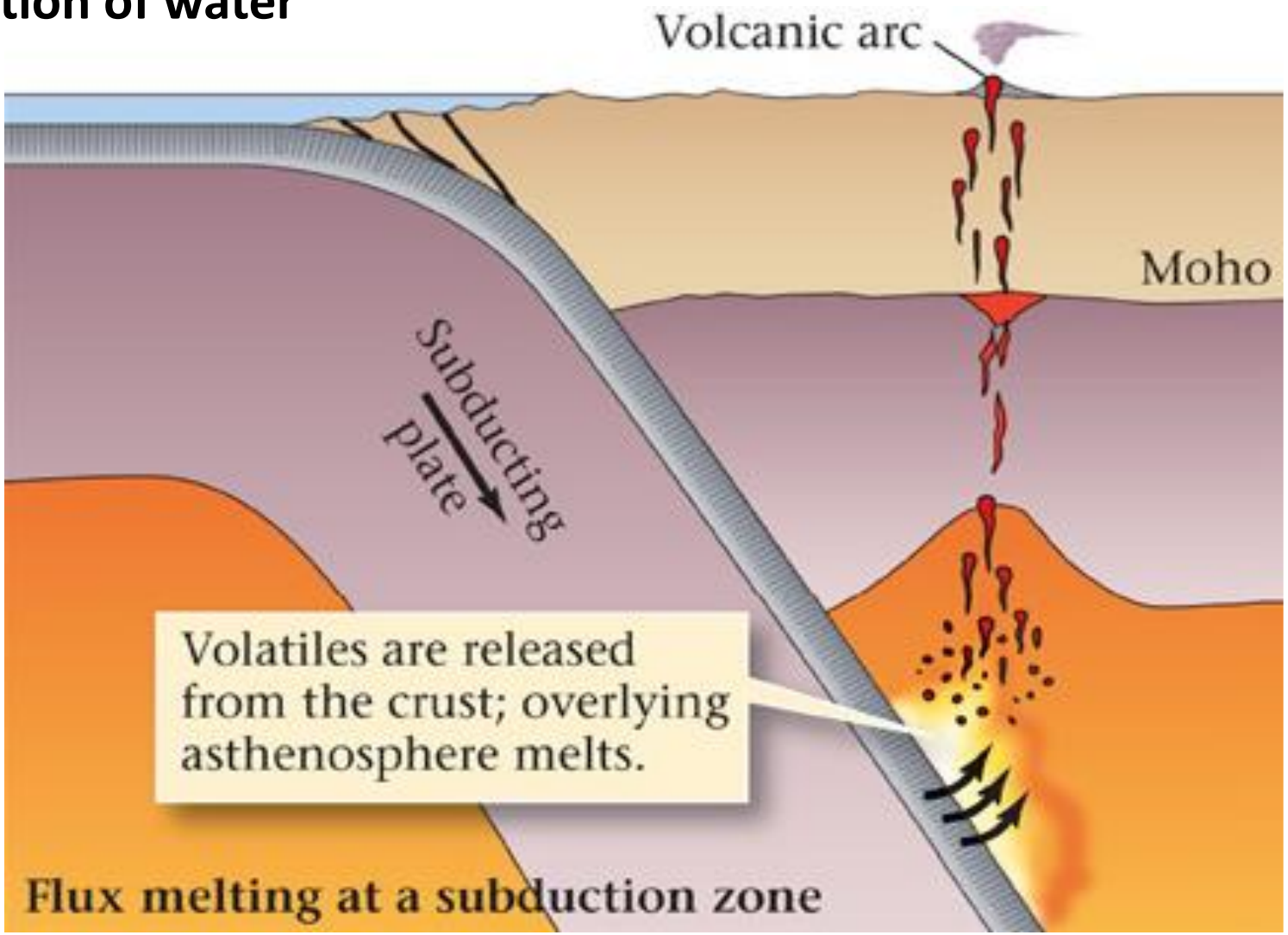
# Magma Formation

- **Temperature increase**



# Magma Formation

- **Addition of water**



# Magma Compositions

- There are four major magma types based on silica ($SiO_2$) percentage
  - Felsic (feldspar and silica) 66 to 76% $SiO_2$
  - Intermediate 52 to 66% $SiO_2$
  - Mafic (Mg and Fe-rich) 45 to 52% $SiO_2$
  - Ultramafic 38 to 45% $SiO_2$

# Magma Compositions

- Composition controls magma density, T, and viscosity
    - Silica-rich = more viscous (like syrup)
    - Silica-poor = less viscous (like water)
- These characteristics govern eruptive style

| Type | Density | Temperature | Viscosity |
|---|---|---|---|
| Felsic | Very low | Very low (600 to 850° C) | Very High: Explosive eruptions. |
| Intermediate | Low | Low | High: Explosive eruptions. |
| Mafic | High | High | Low: thin, hot runny eruptions. |
| Ultramafic | Very high | Very high (up to 1300° C) | Very low. |

# Magma Variation

Why are there different magma compositions?

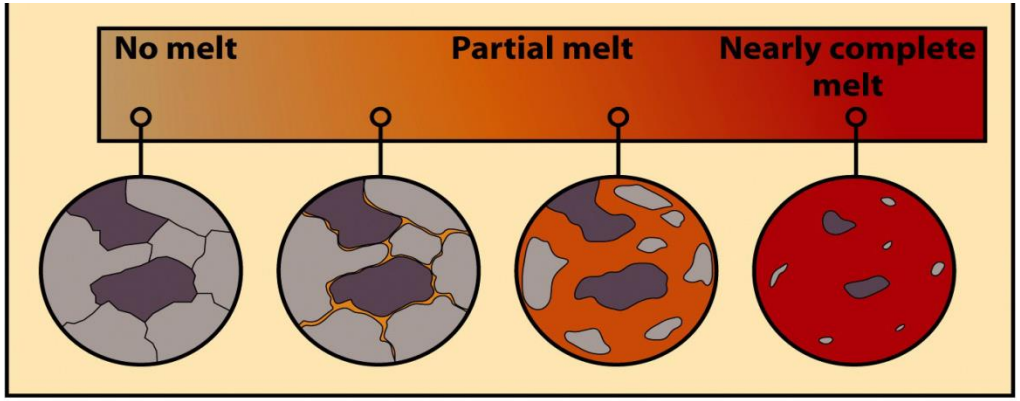
1. Depends on the **source rock**
2. That rock probably only **partially melts**
3. Magma will **evolve** over time by:
   - Fractional crystallization
   - Assimilation (when magma will melt and incorporate surrounding host rock)
   - Mixing (when 2 magmas of different composition mix)

# 1. Source rock

- Composition of a melt will depend on the source rock
- For example different magmas form depending on whether magma is derived from the mantle, ocean crust or continental crust
  - Mantle = ultramafic
  - Ocean lithosphere = mafic
  - Continental lithosphere = intermediate/felsic

# 2. Partial Melting

- Rocks rarely melt completely
- Instead, only a portion of the rock melts
  - Silica-rich minerals melt first
  - Silica-poor minerals melt last



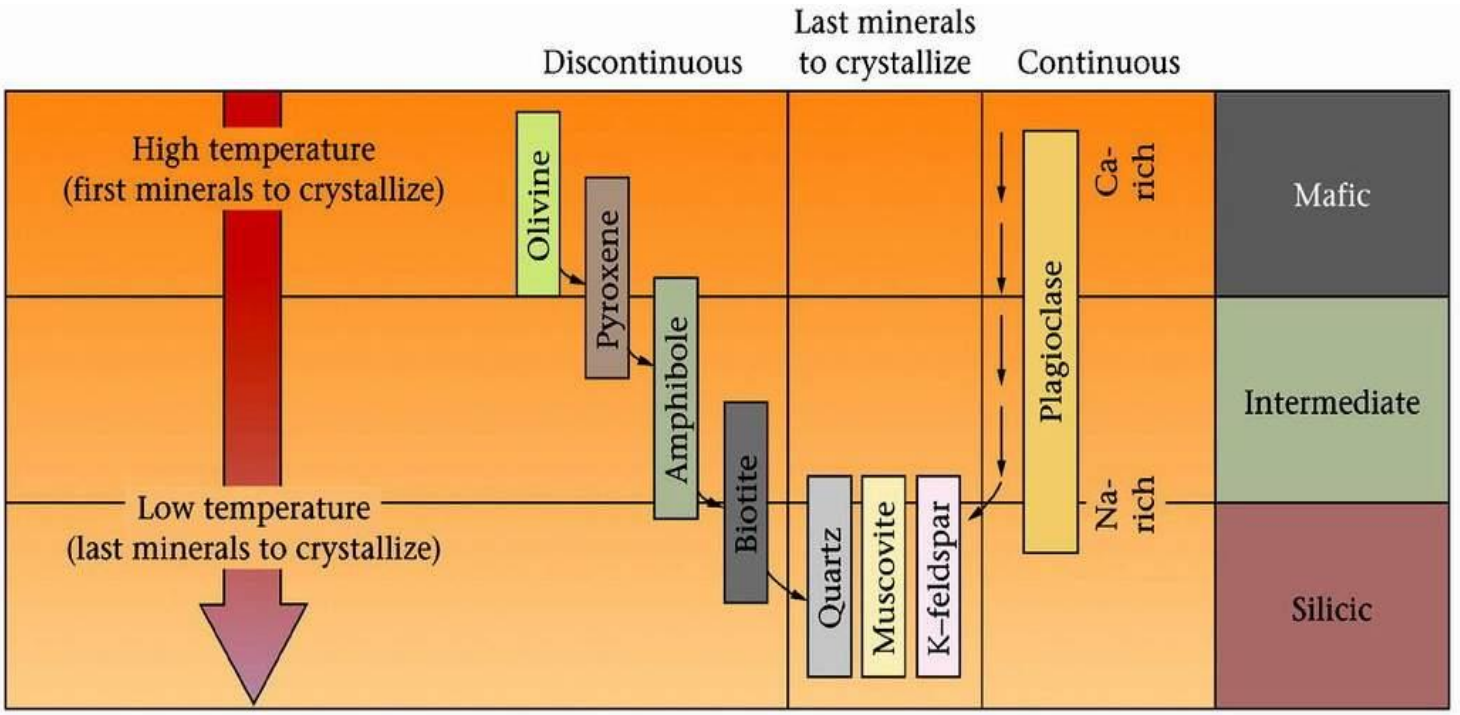
# Reminder: Silicate Minerals

- Silica tetrahedra link together by sharing oxygen molecules
- More shared oxygen = lower Si:O ratio; governs…
  - Melting temperature
  - Mineral structure and cations present
  - Susceptibility to chemical weathering

| Type of Silicate Structure | Formula | Si:O Ratio |
|---|---|---|
| Independent Tetrahedra | $SiO_4$ | 0.25 |
| Double Tetrahedra | $Si_2O_7$ | 0.29 |
| Ring Silicates | $Si_6O_{18}$ | 0.33 |
| Single Chains | $SiO_3$ | 0.33 |
| Double Chains | $Si_4O_{11}$ | 0.36 |
| Sheet Silicates | $Si_2O_5$ | 0.40 |
| Framework Silicates | $SiO_2$ | 0.50 |

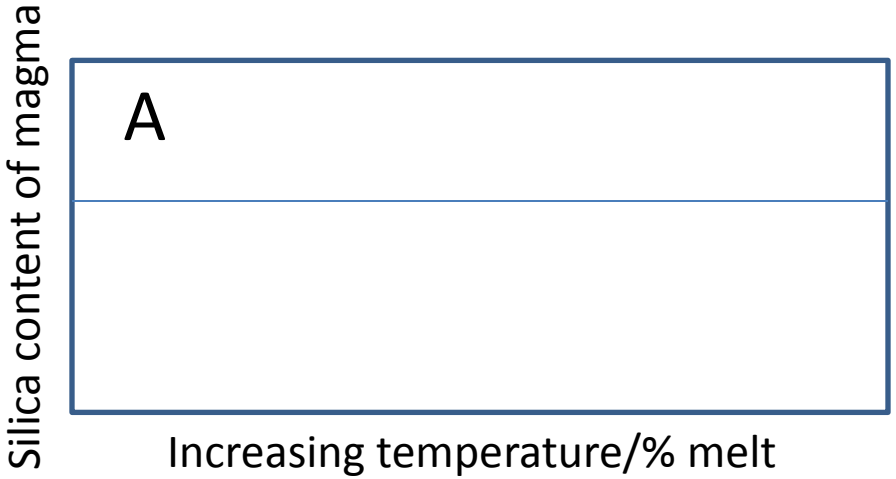
# Bowen's Reaction Series

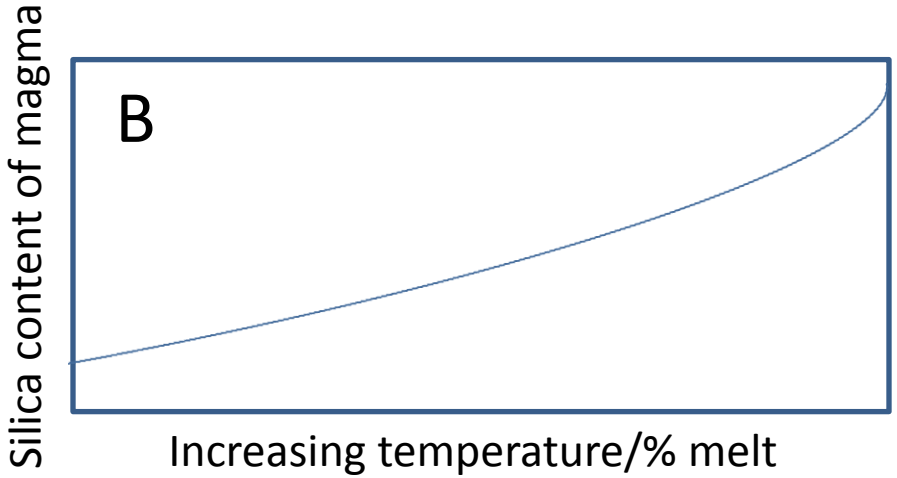
- Minerals solidify (and melt) in a specific series
  - Continuous – Plagioclase changed from Ca-rich to Na-rich
  - Discontinuous – Minerals that solidify in a narrow T range

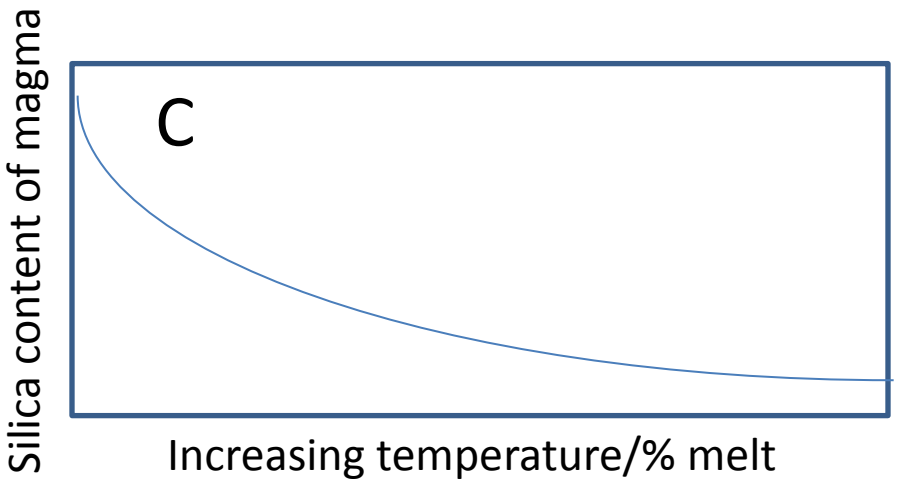


# Group Question

- Which of these would represent a graph of the silica content of a magma from rock that melts as temperature increases?

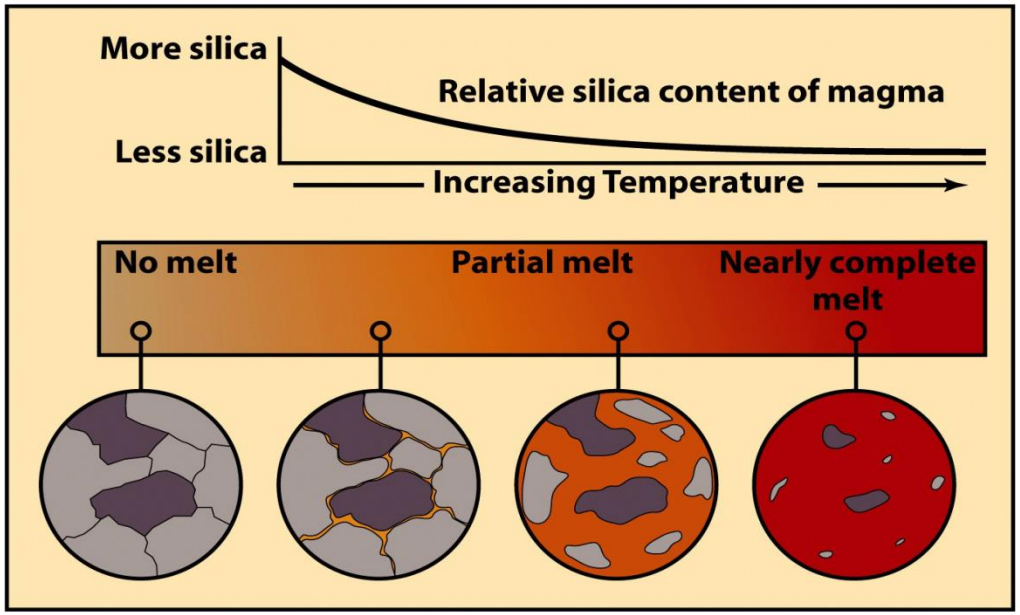


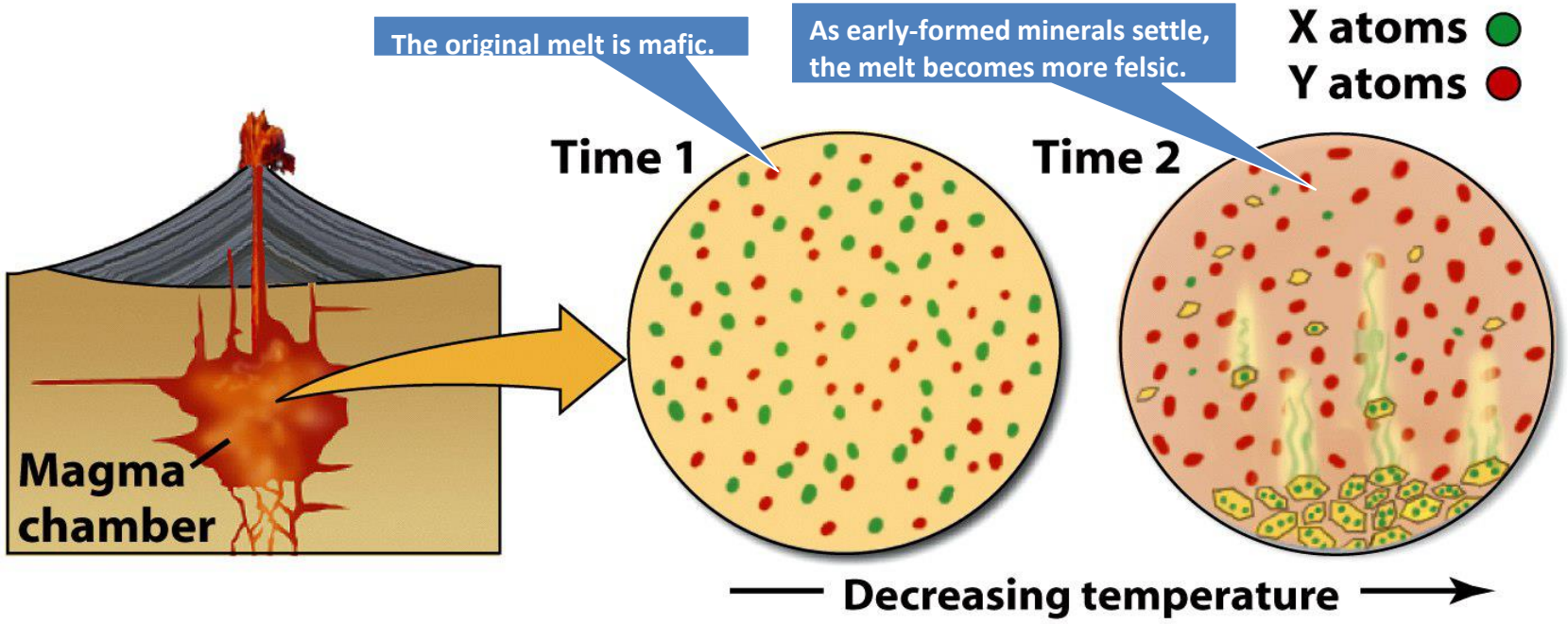
# 2. Partial Melting

- Rocks rarely melt completely
- Instead, only a portion of the rock melts
  - Silica-rich minerals melt first
  - Silica-poor minerals melt last
- Partial melting, then, yields a more silica-rich magma than the source rock



# 3a. Fractional Crystallization

- As magma cools, early crystals settle by gravity
- Not all minerals crystallize at the same temperature
- Melt composition changes as a result
  - Fe, Mg, and Ca are removed in early settled solids
  - Si, Al, Na, and K remain in melt and increase in abundance



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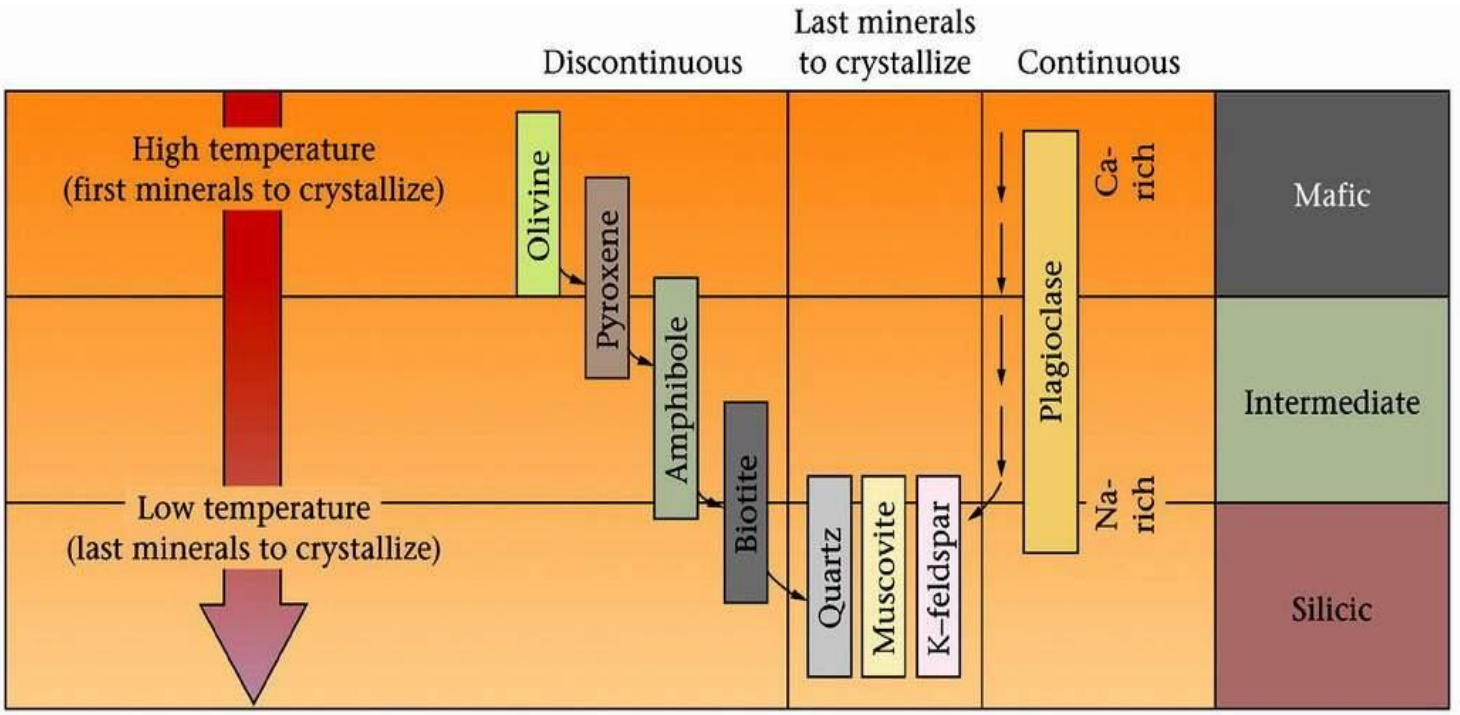


# Partial Melting vs Fractional Crystallization

How would the compositions of the melt and the solid rock change through time as you:

1. take a mafic rock and gradually melt it

Solid:

Melt:

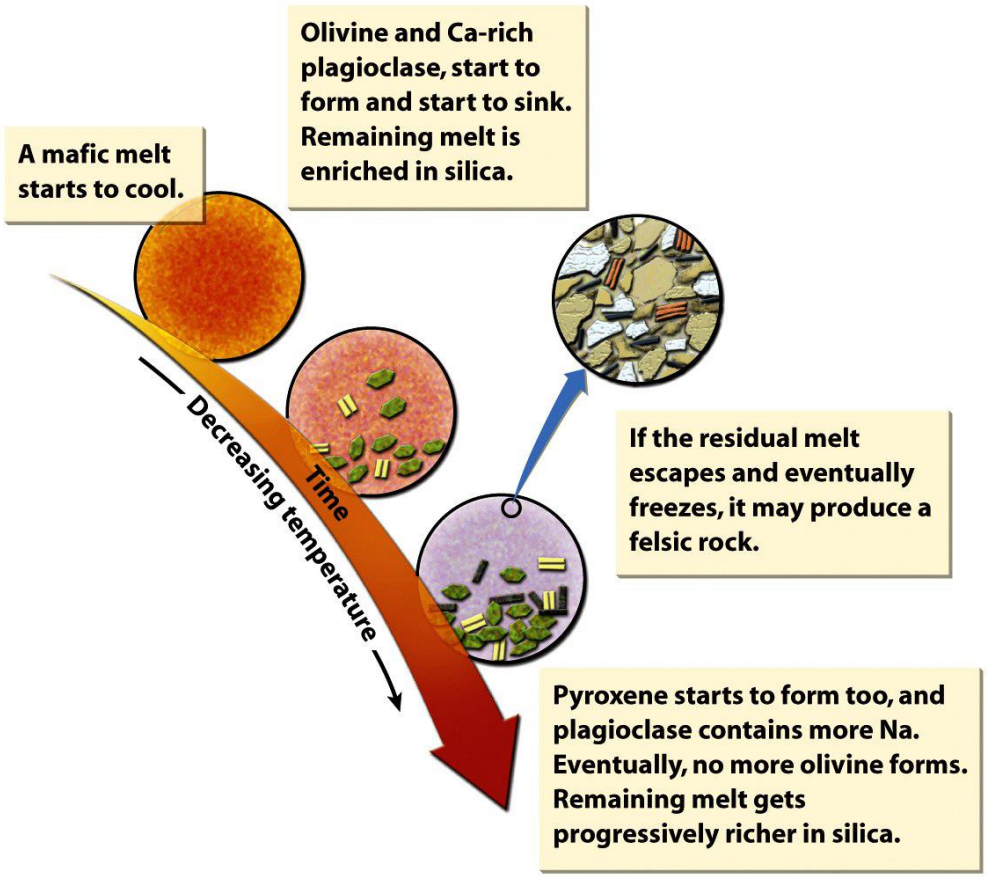
2. take a mafic magma and cool it gradually

Solid:

Melt:

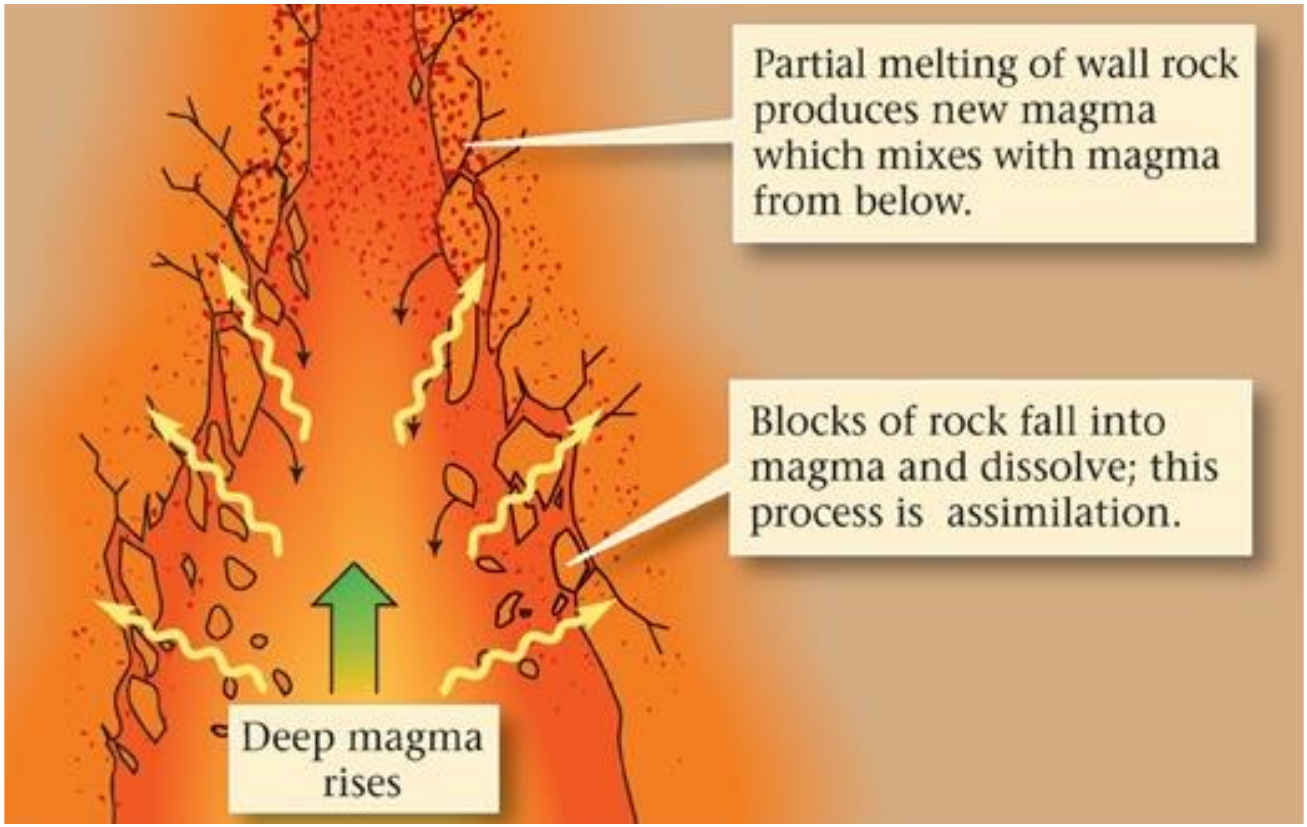
# 3a. Fractional Crystallization

- Felsic magma can evolve from mafic magma.
  - Progressive removal of mafics depletes Fe, Mg, and Ca.
  - Remaining melt becomes enriched in Na, K, Al, and Si.



# 3b. Assimilation

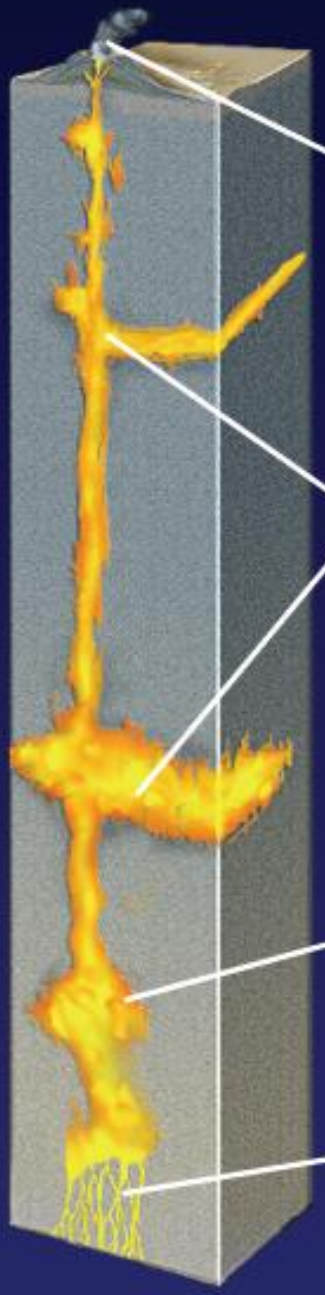
- Magma melts the country rock it passes through
- Blocks of country rock/host rock (xenoliths) fall into magma
- Assimilation of these rocks alters magma composition



# 3c. Magma Mixing

- Different magmas may mix in a magma chamber
- The result combines the characteristics of the two magmas
- Often magma mixing is incomplete, resulting in blobs of one rock type suspended within the other

# Forming Igneous Rocks



Eruption as lava or ash

Forms magma chamber (solidifies or rises)

Accumulates into rising magma body

Partial melting of source

# Magma Migration

- Magma moves by…
  - Injection into cracks
  - Melting overlying rocks
  - Squeezed by overlying weight


Not to scale

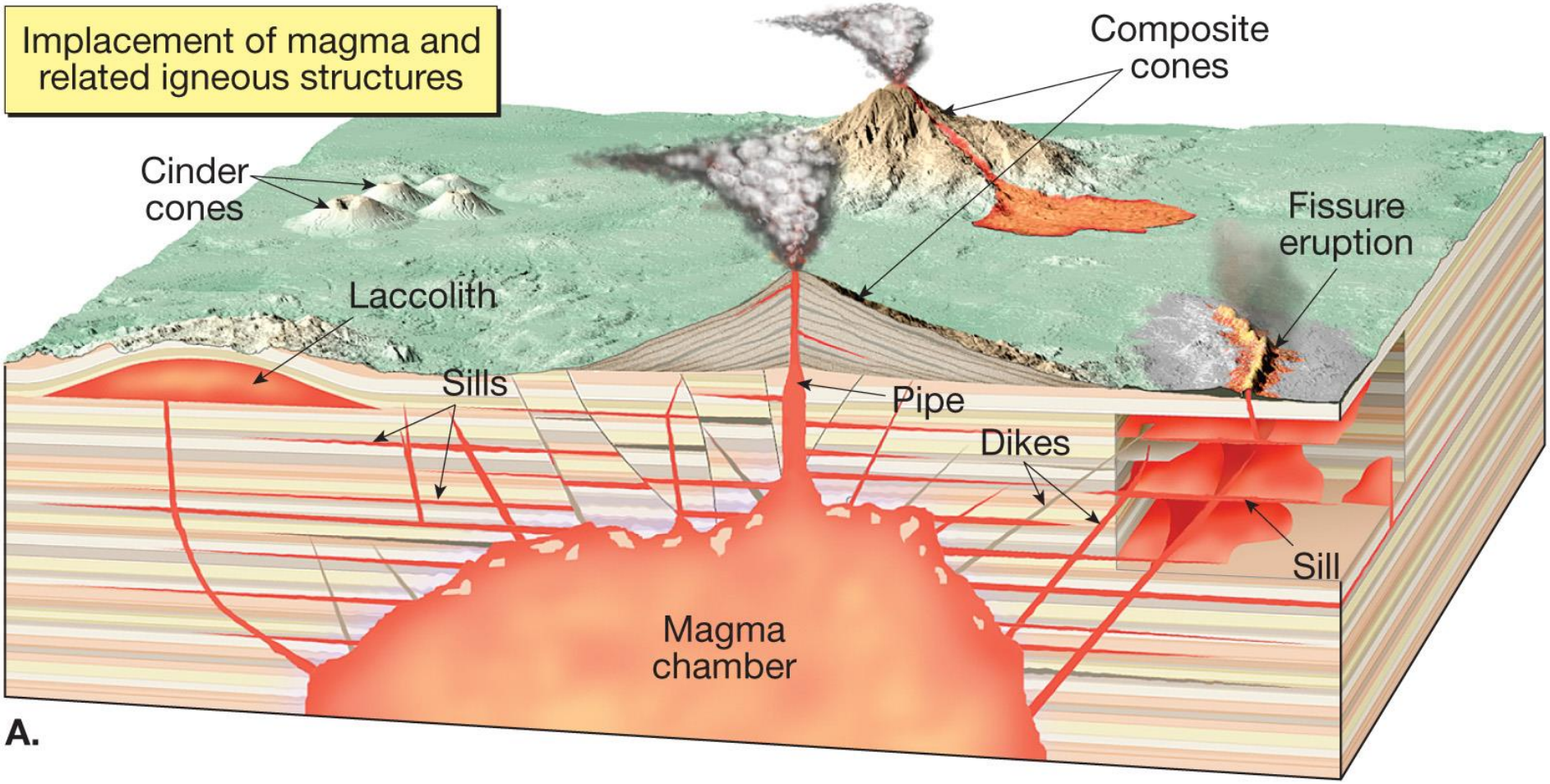

Not to scale

# Extrusive vs Intrusive igneous rocks

Rocks formed from lava = extrusive or volcanic rocks

Rocks formed from magma at depth = intrusive or plutonic rocks

# Extrusive and intrusive igneous environments



# From magma to igneous rocks

- Cooling of magma (or lava) results in the systematic arrangement of ions into orderly patterns = crystallization

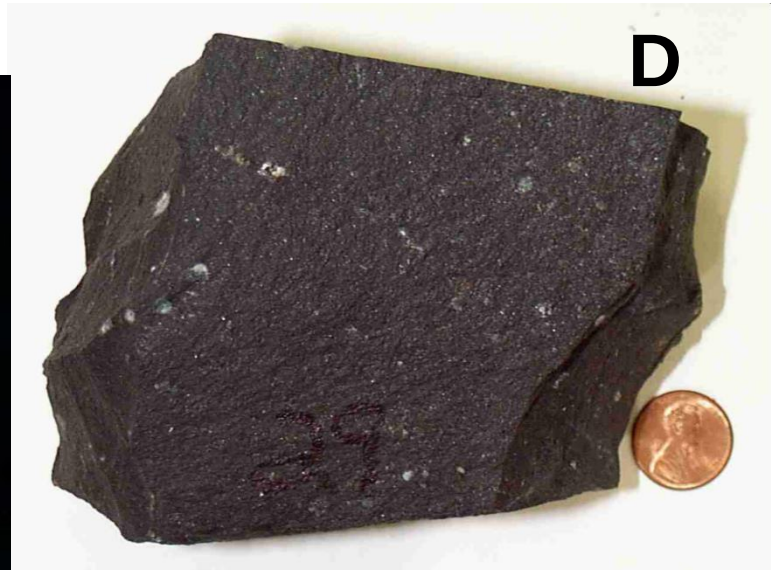
**How do we work out from the rock how quickly it cooled?**

**What factors do you think might affect the rate of cooling?**

# Intrusive vs Extrusive igneous rocks

- Which of these is an extrusive rock?



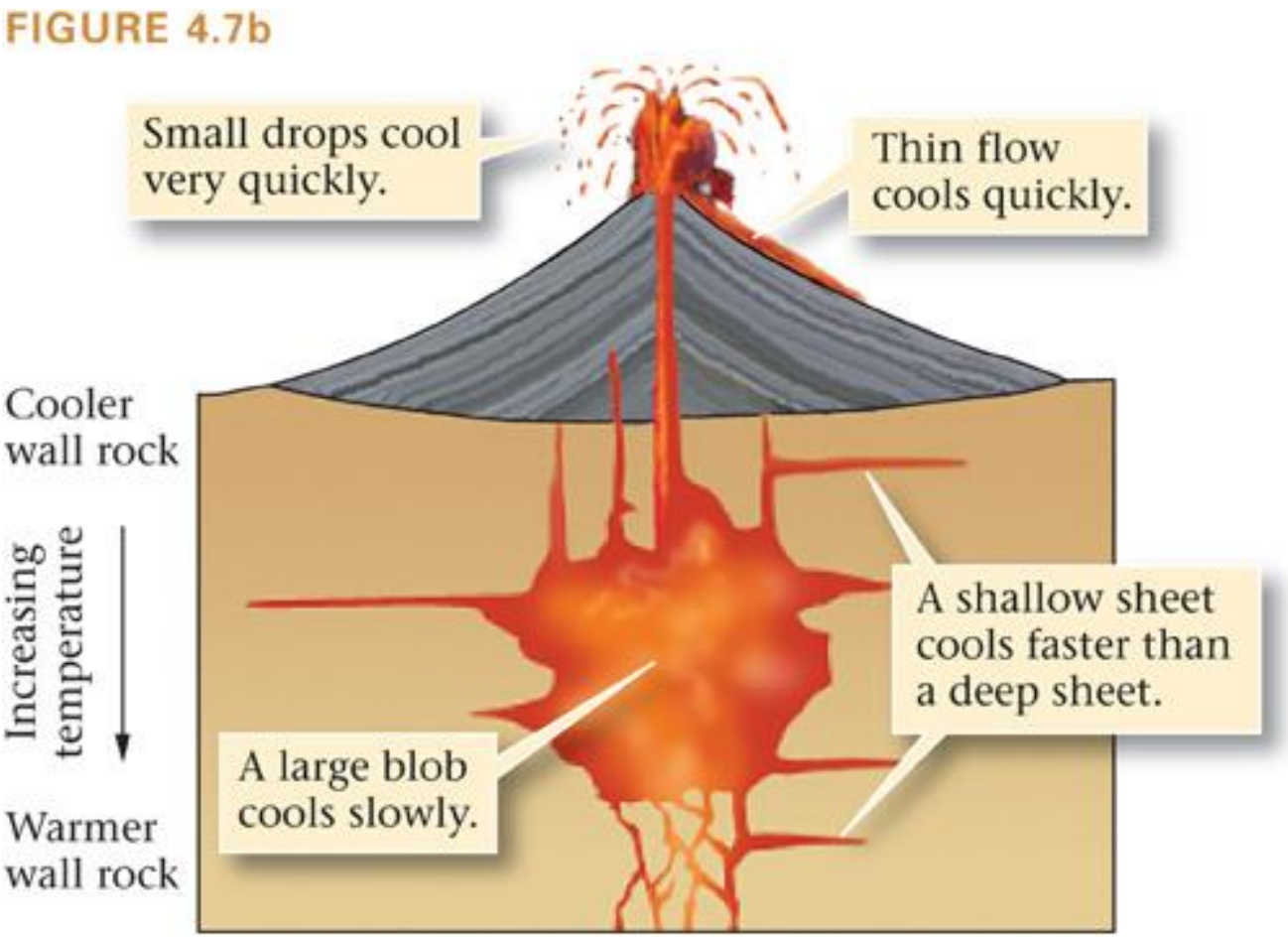



# Group Question

- Which of these would cause magma to cool down more slowly?

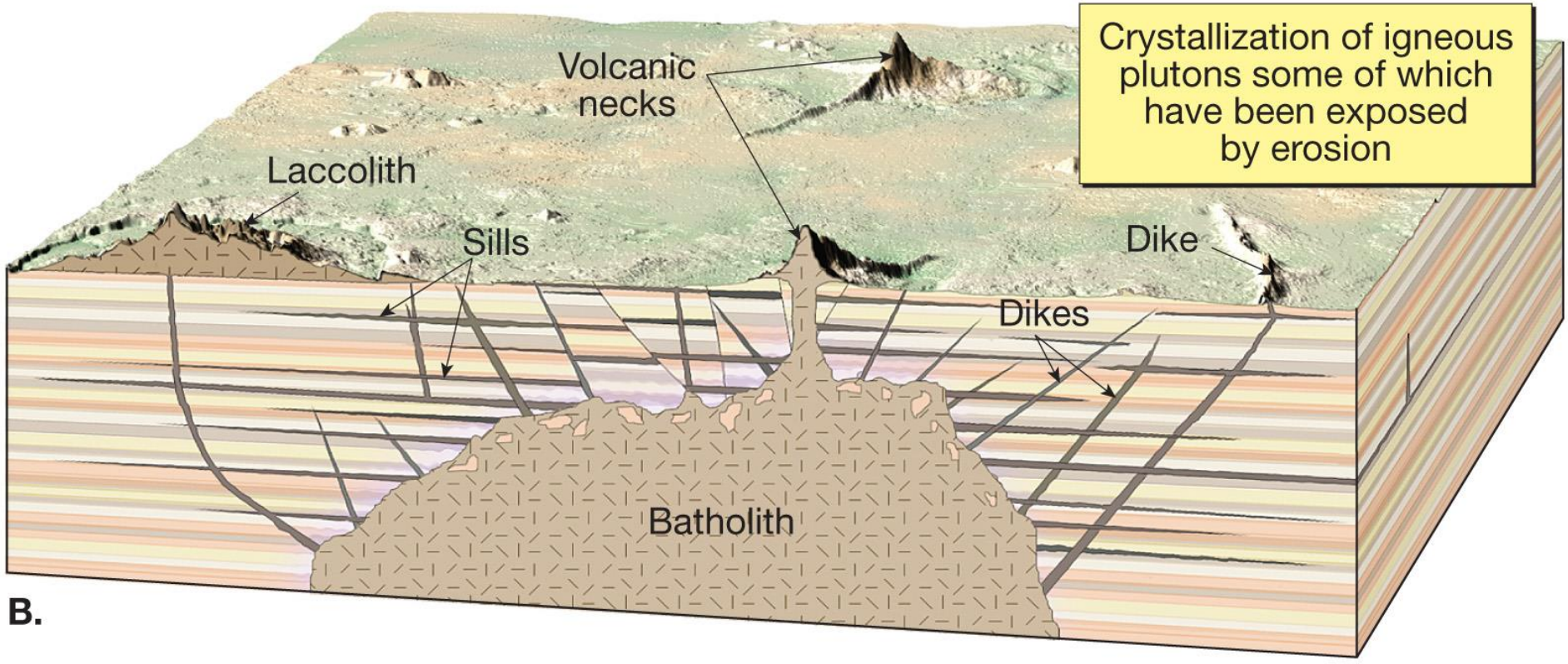
a) Shallower depth
b) Larger volume
c) Presence of water and ice
d) Longer, thinner shape

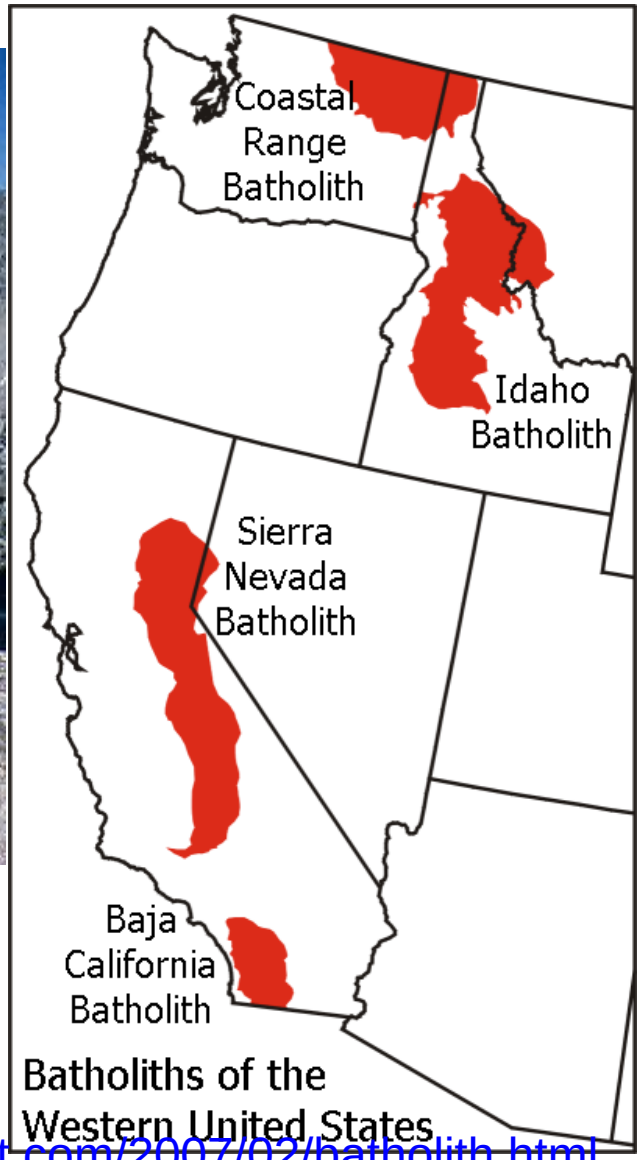
# How fast magma cools depends on:




- Depth
- Shape
- Size
- Presence of ground water/ice

# Extrusive and intrusive igneous environments

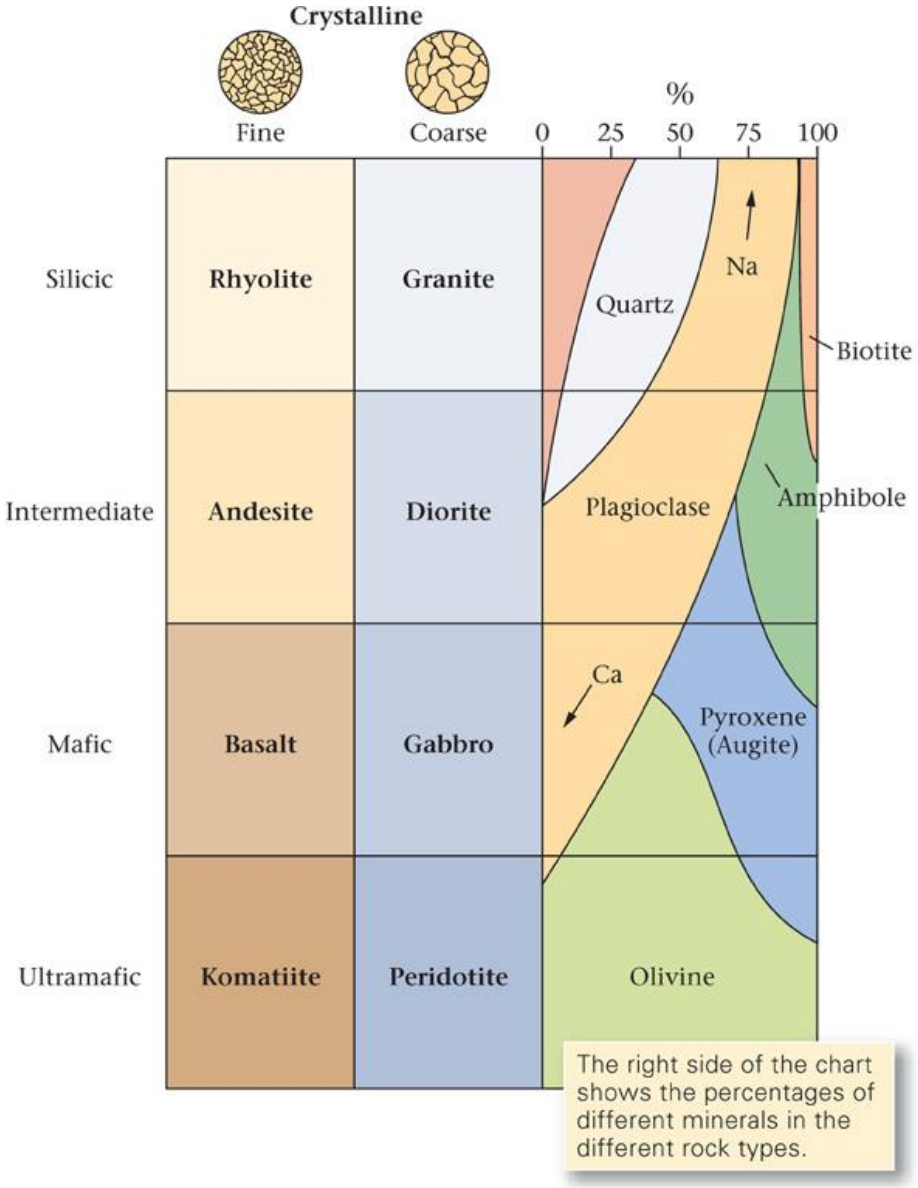




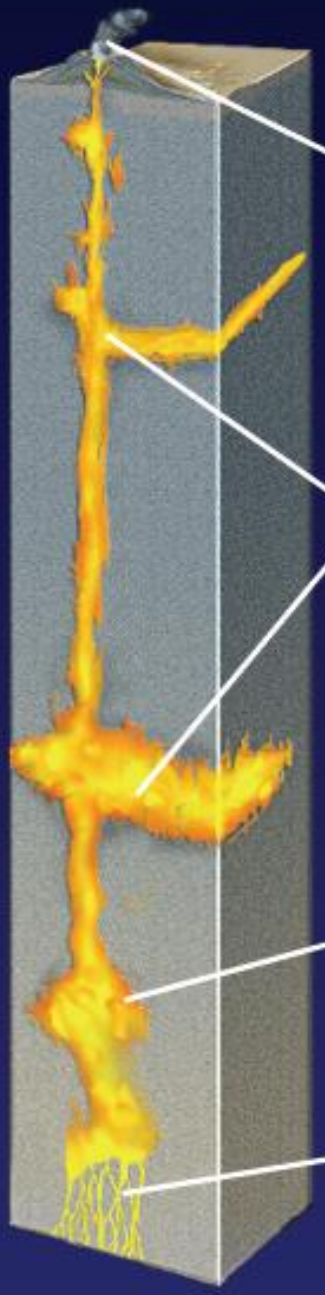

http://bio-geo-terms.blogspot.com/2007/02/batholith.html

# Crystalline Igneous Rock Classification

- Classification is based upon composition and texture
  - Composition – Felsic, intermediate, mafic, and ultramafic
  - Texture – Fine (aphanitic); coarse (phaneritic)



# Forming Igneous Rocks



Eruption as lava or ash

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# Magma Compositions

- Composition controls magma density, T, and viscosity
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| Ultramafic | Very high | Very high (up to 1300° C) | Very low. |

# Main types of volcano

Stratovolcano

Shield volcano

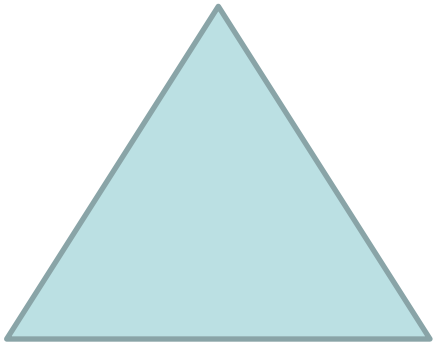
http://www.youtube.com/watch?v=xExdEXOaA9A&feature=fvwrel

# Question

What type of magma would form each type of volcano?

shield volcano

stratovolcano



A) Intermediate
B) Felsic
C) Mafic
D) Mafic/Felsic

mafic/felsic
intermediate/mafic
felsic/intermediate
intermediate

# Main types of volcano

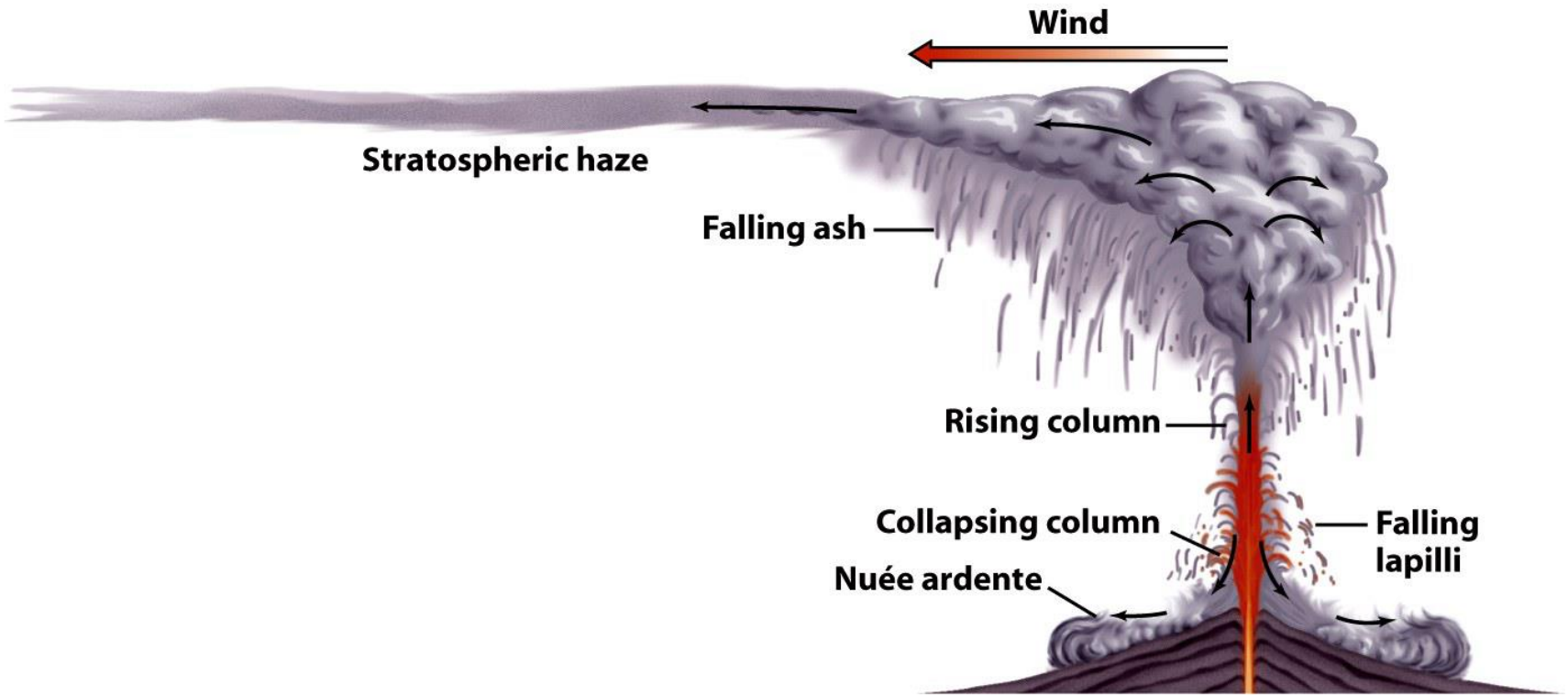
Stratovolcano – large (1-10 km across), layers of lava and pyroclastics, explosive, intermediate magma but sometimes felsic and mafic e.g. Mt St Helens, Mt Fuji

Shield volcano – large (10s of km across), layers of lava flows, mafic magma, non-explosive e.g. Kilauea, Hawaii

http://www.youtube.com/watch?v=xExdEXOaA9A&feature=fvwrel

# Volcanic Materials

- The products of volcanic eruption take three forms:
  1. **Lava flows** – Molten rock that moves over the ground.
  2. **Pyroclastic debris** – fragments blown out of a volcano.
  3. **Volcanic gases** – Volatiles that exit a volcano.



# 2. Pyroclastic (volcaniclastic) deposits

- Accumulations of fragmented igneous material
  - Pyroclastic debris
  - Pre-existing rock fragments
  - Landslide debris
  - Mudflows

# Tephra and Volcanic Ash


**Eruption column = mixture of gas and pyroclasts that rises rapidly above the volcano**

# Lahars


http://www.youtube.com/watch?v=kznwnpNTB6k

- Rhyolite tuff

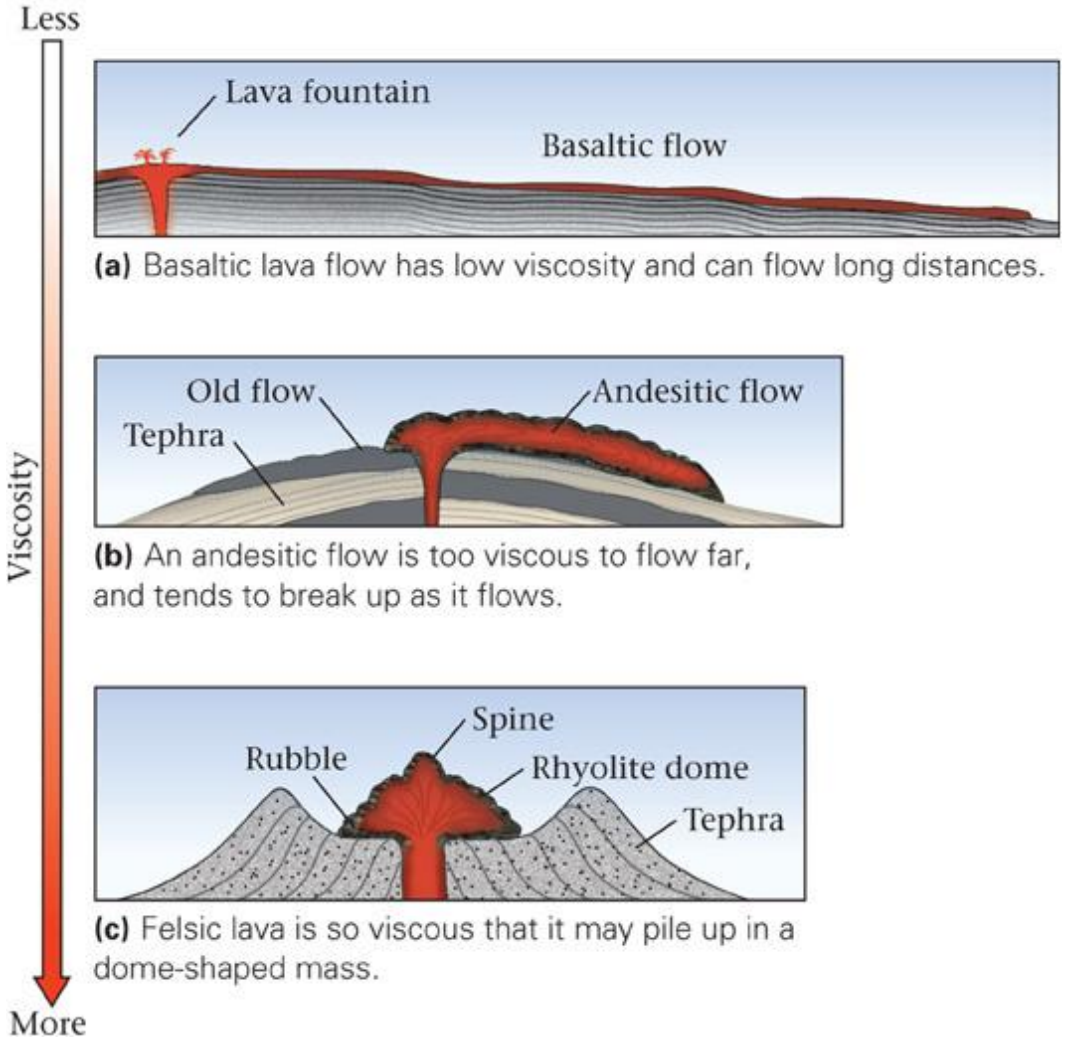

- Pumice

- Obsidian

# 3. Volcanic Gases

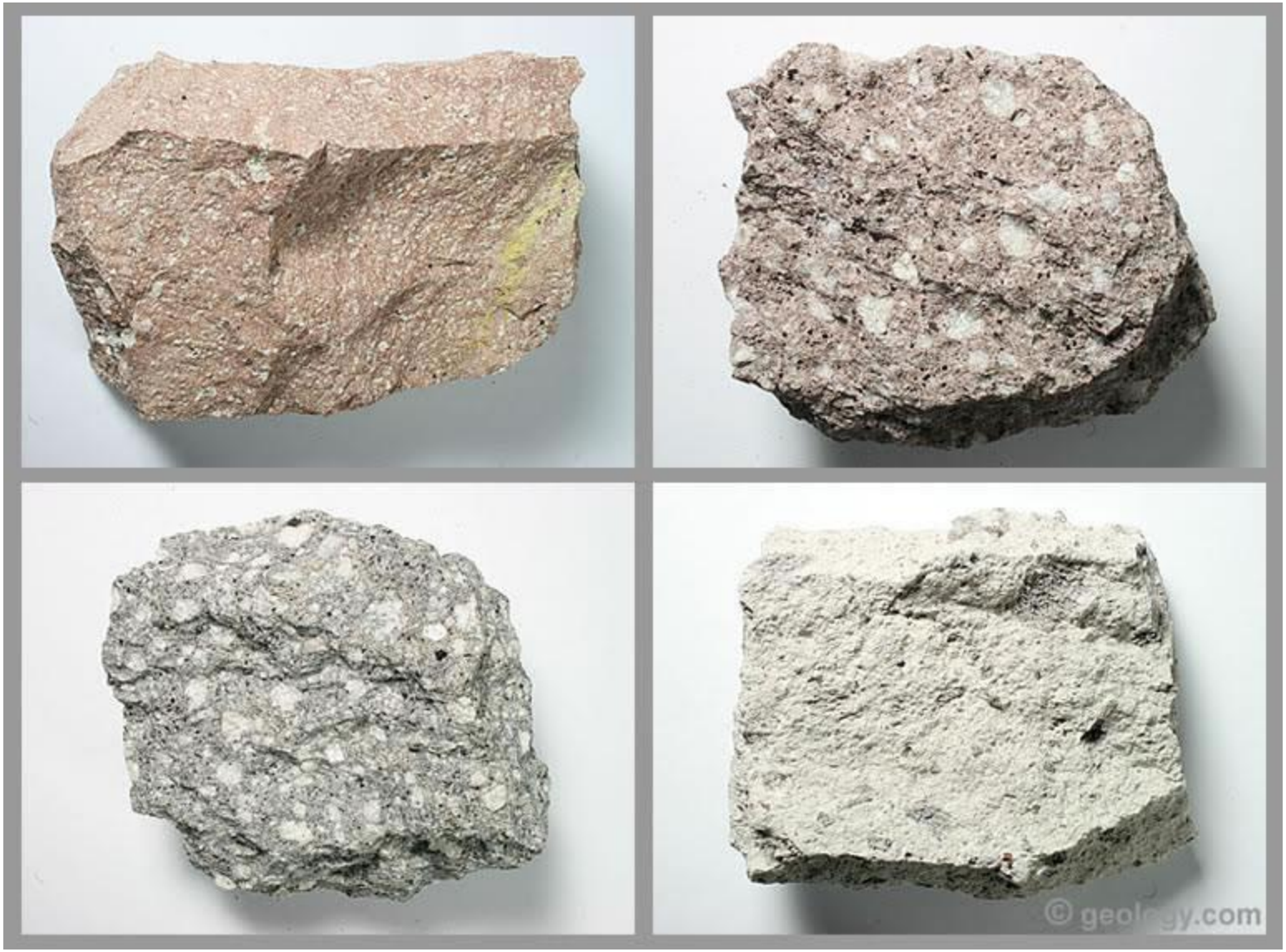
- Up to 9% of magma may be gas ($H_2O$, $CO_2$, $SO_2$)
- Gases are expelled as magma rises (P drops)
- Rate of gas escape controls eruption violence
- Gas bubbles in rock are called vesicles

# 1. Lava Flows




How dangerous do you think lava flows are to human populations?

- Rhyolite



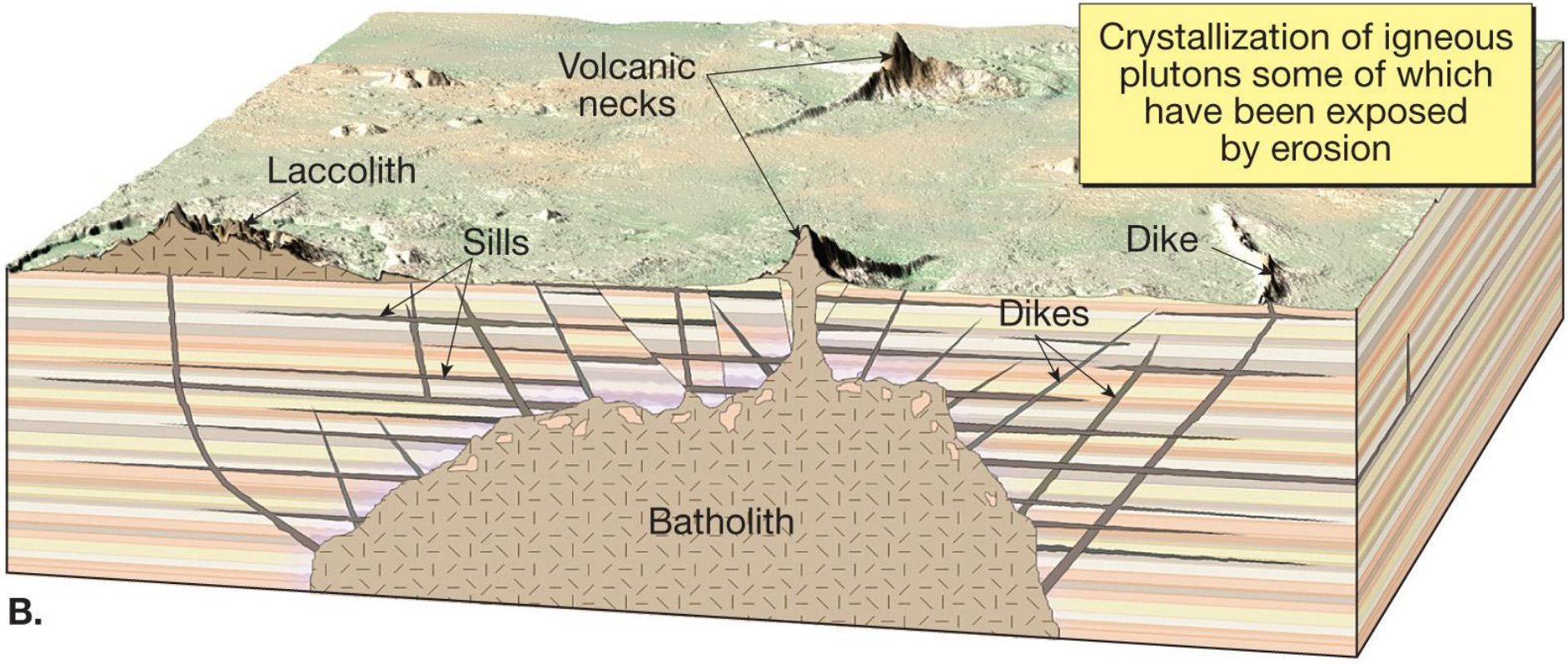
- Andesite

- Scoria

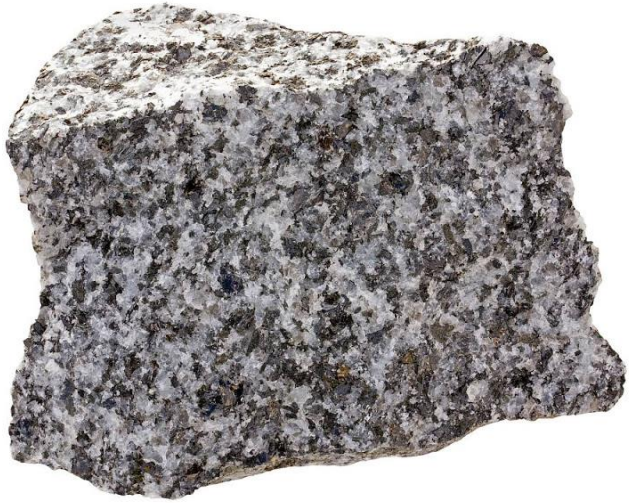
- Basalt

- Scoria

# Extrusive and intrusive igneous environments



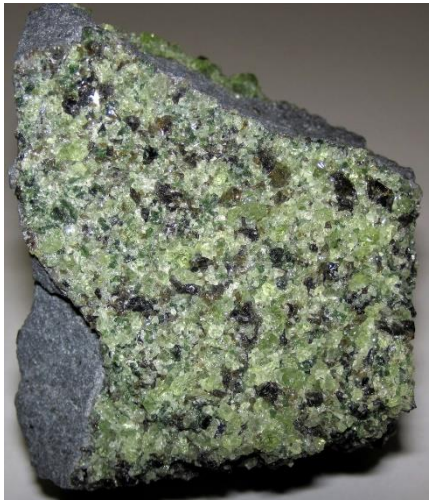
- Diorite



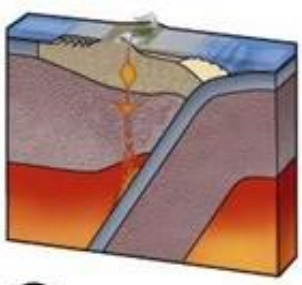
- Granite


- Gabbro

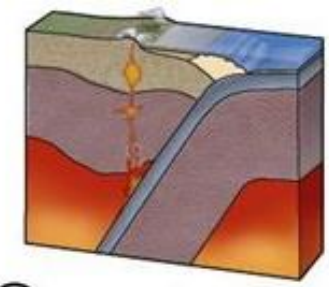
- Peridotite



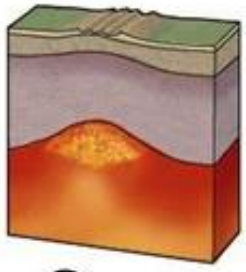
# Plate tectonics and volcanism



Ⓘ = Island arc



Ⓒ = Continental arc



Ⓡ = Rift

Ⓗ = Hot spot

Ⓜ = Mid-ocean ridge

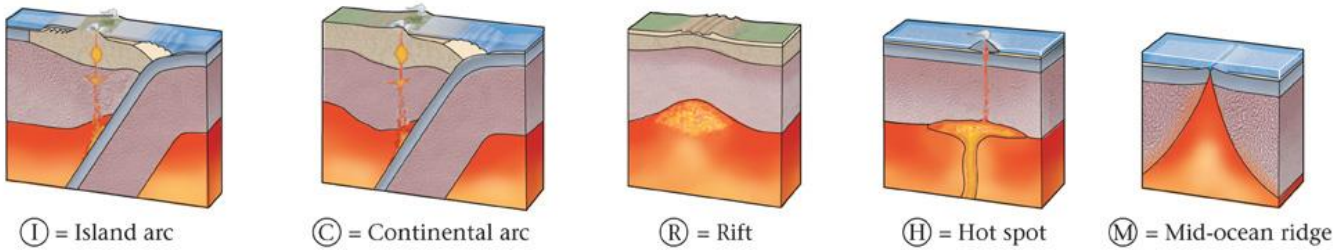
- At each type of location:
- What is melting to make up the magma and so what type of magma do you think you will get?
- What type of intrusive vs extrusive rock will you therefore see?
- What type of volcano will likely form?
- What volcanic hazards would local populations experience?

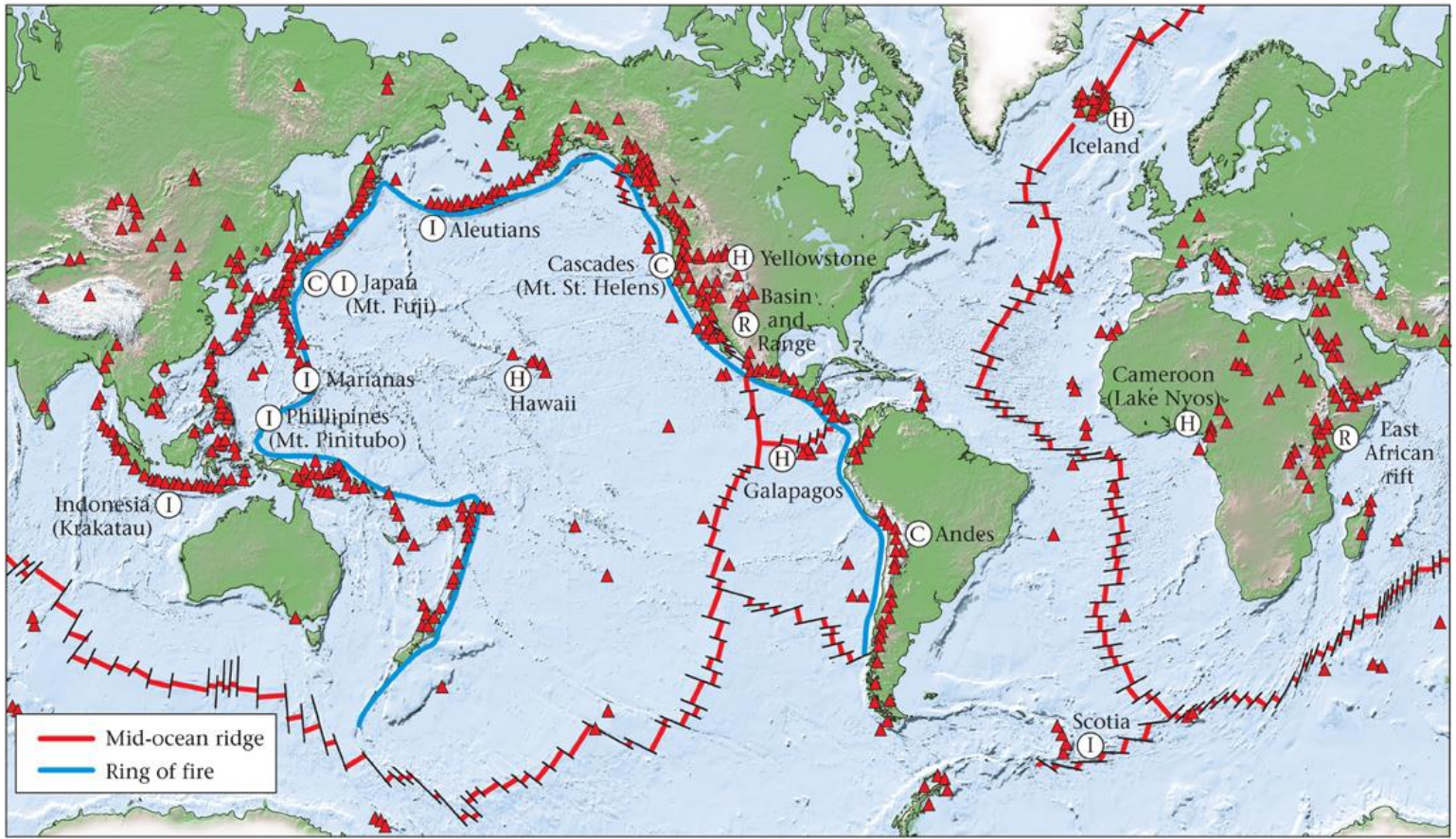
# Westeros map activity

- Where is magma formation and volcanism occurring on your map?
- Which of the 3 mechanisms of magma formation is likely responsible in each case?
- What type of igneous rocks would you get in each location?

# Plate tectonics and volcanism

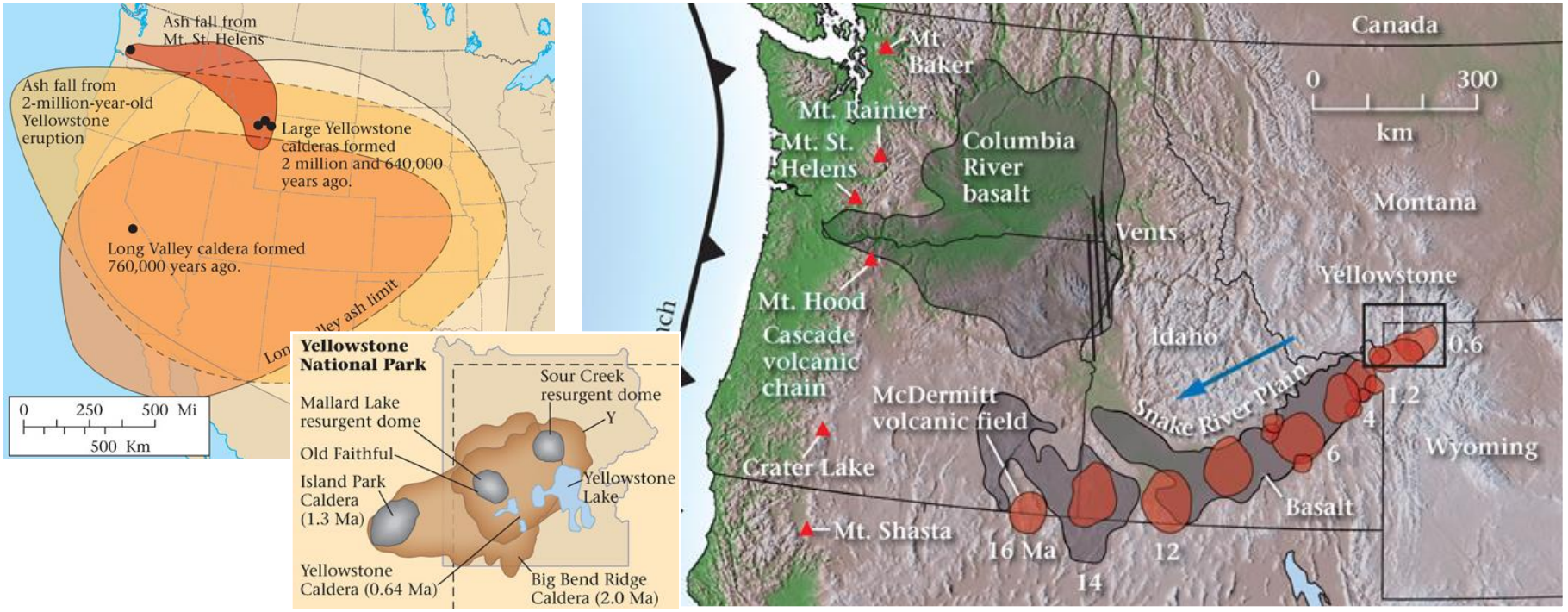
FIGURE 5.11



# Continental Hot-Spot Volcanoes

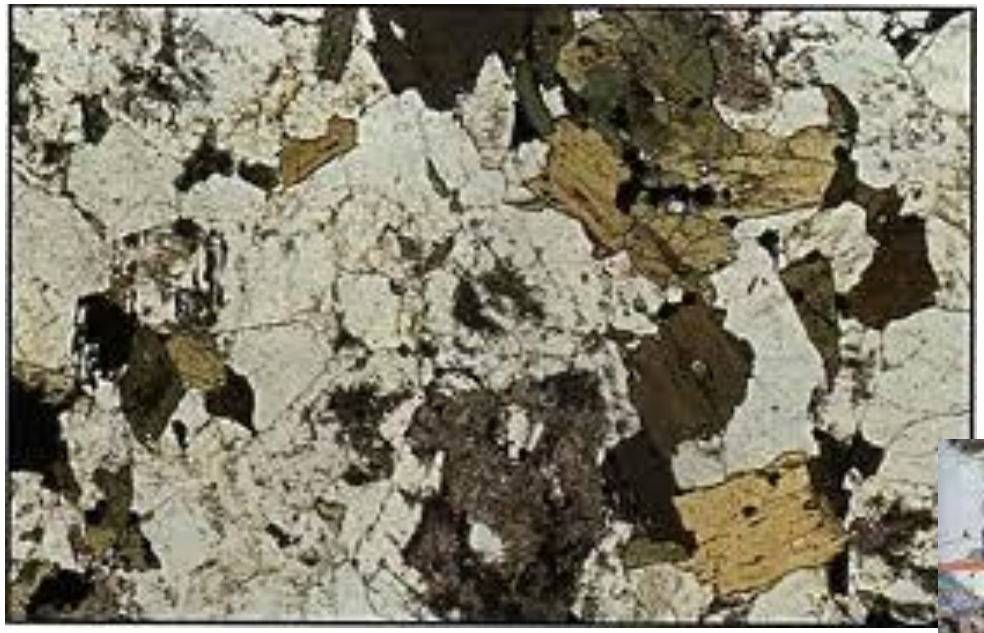
- Yellowstone – Eruption ~ 640 Ka created a 100 km caldera.
  - 1,000 times more powerful than Mt. St. Helens
  - Magma beneath the caldera continues to fuel geysers



# Large Igneous Provinces

Very large accumulations of igneous rocks (greater than 100,000 $km^2$) in a short geological time (few million years or less)

# Looking at rocks under the microscope - igneous



Plane polarized light

Color
- In PPL (opaque?, pleochroic?)
- In XPL (birefringence? Isotropic

Twinning?

Characteristic shape?

Texture – size of crystals, alteration?

Cross polarized light