

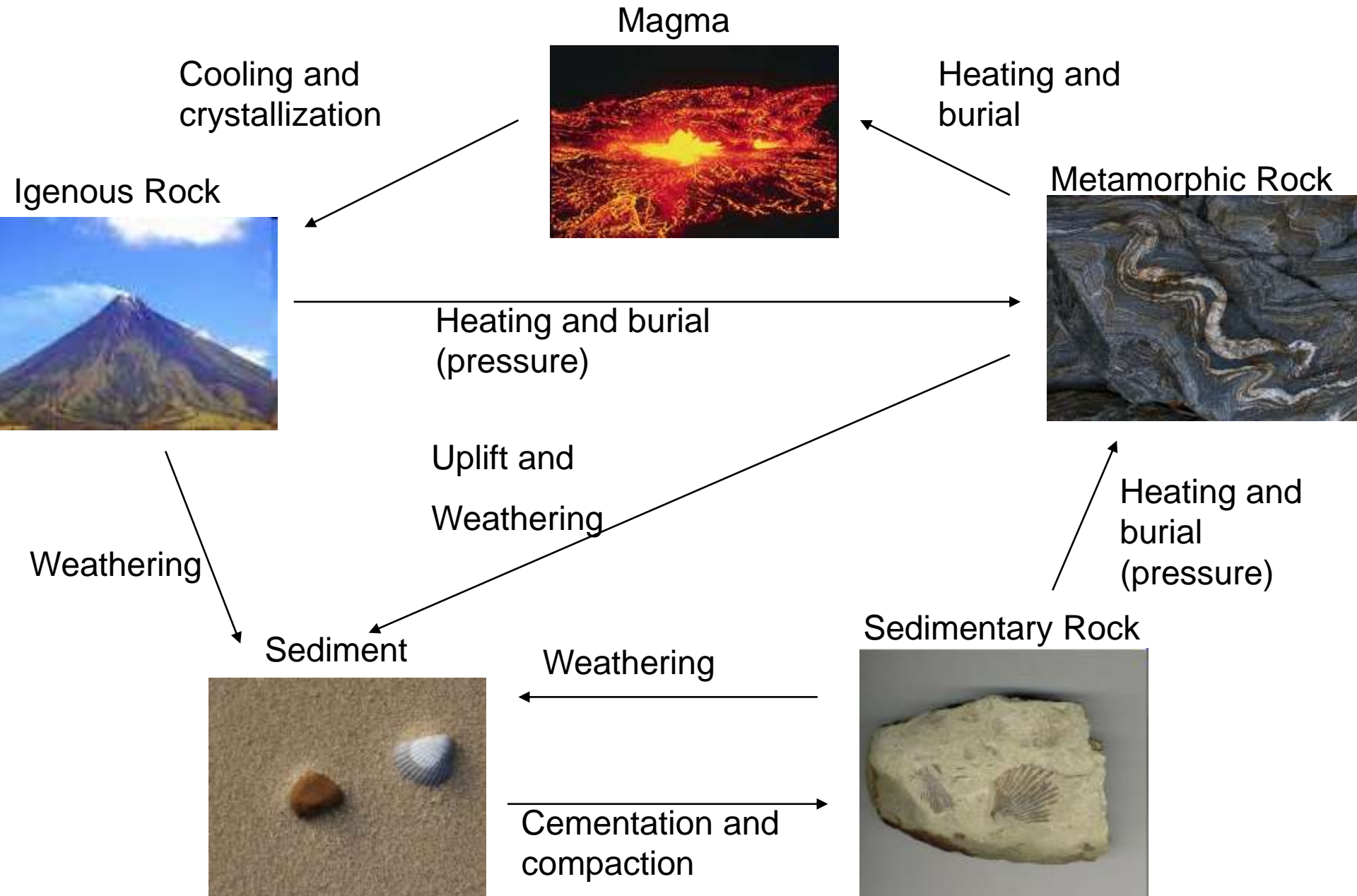


Igneous Rocks

Goals

- 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

The Rock Cycle

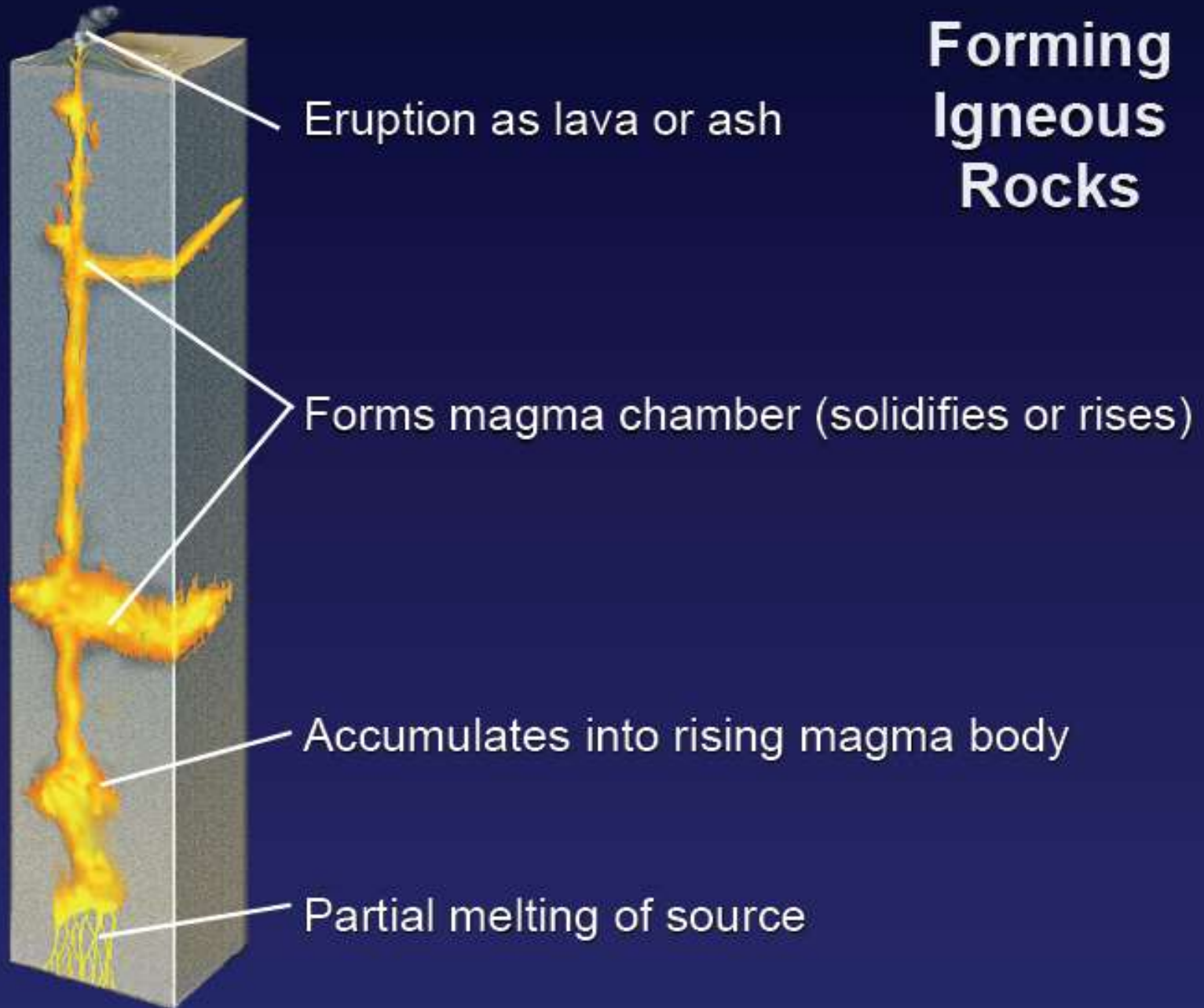


What is magma made of?

- 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)

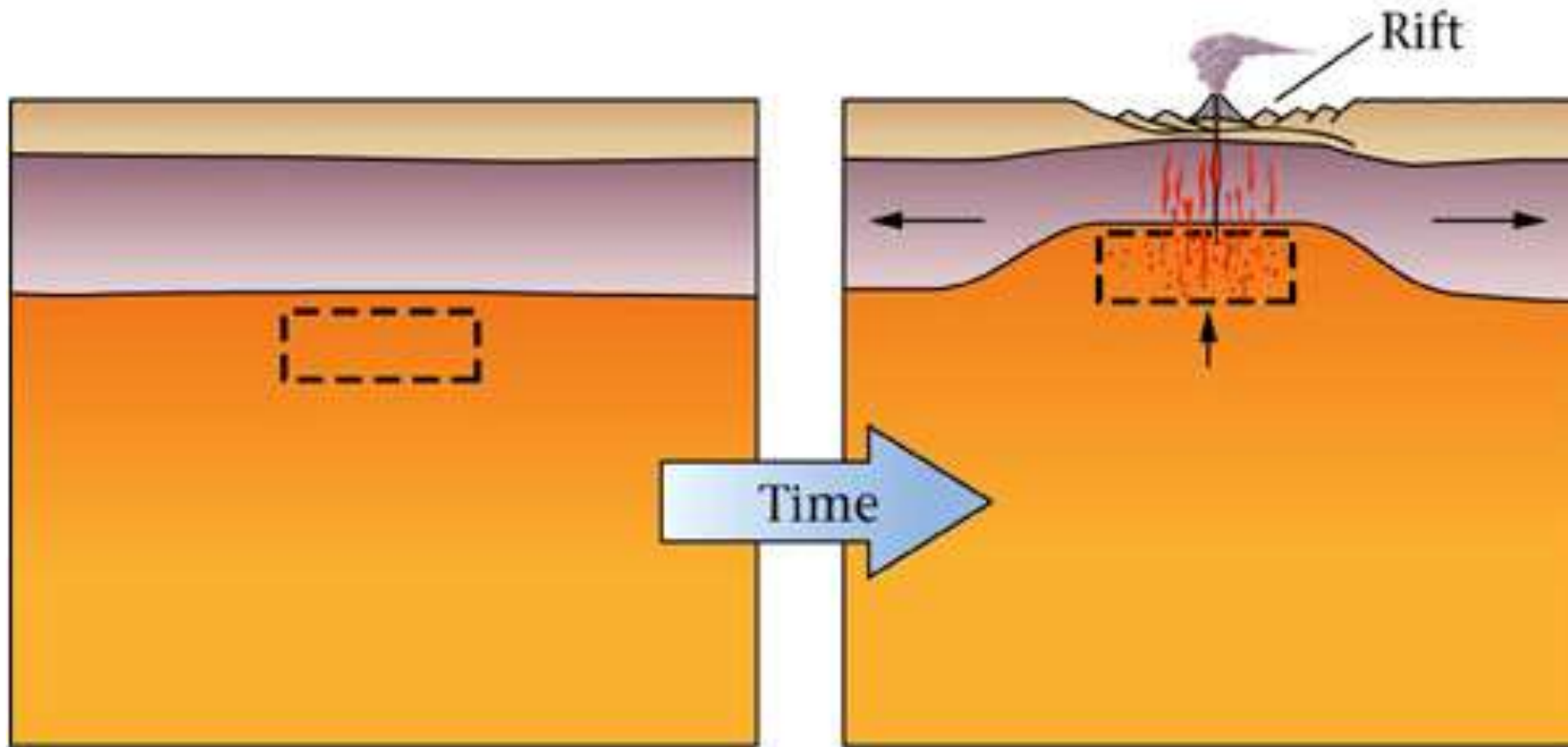


Forming Igneous Rocks



Magma Formation

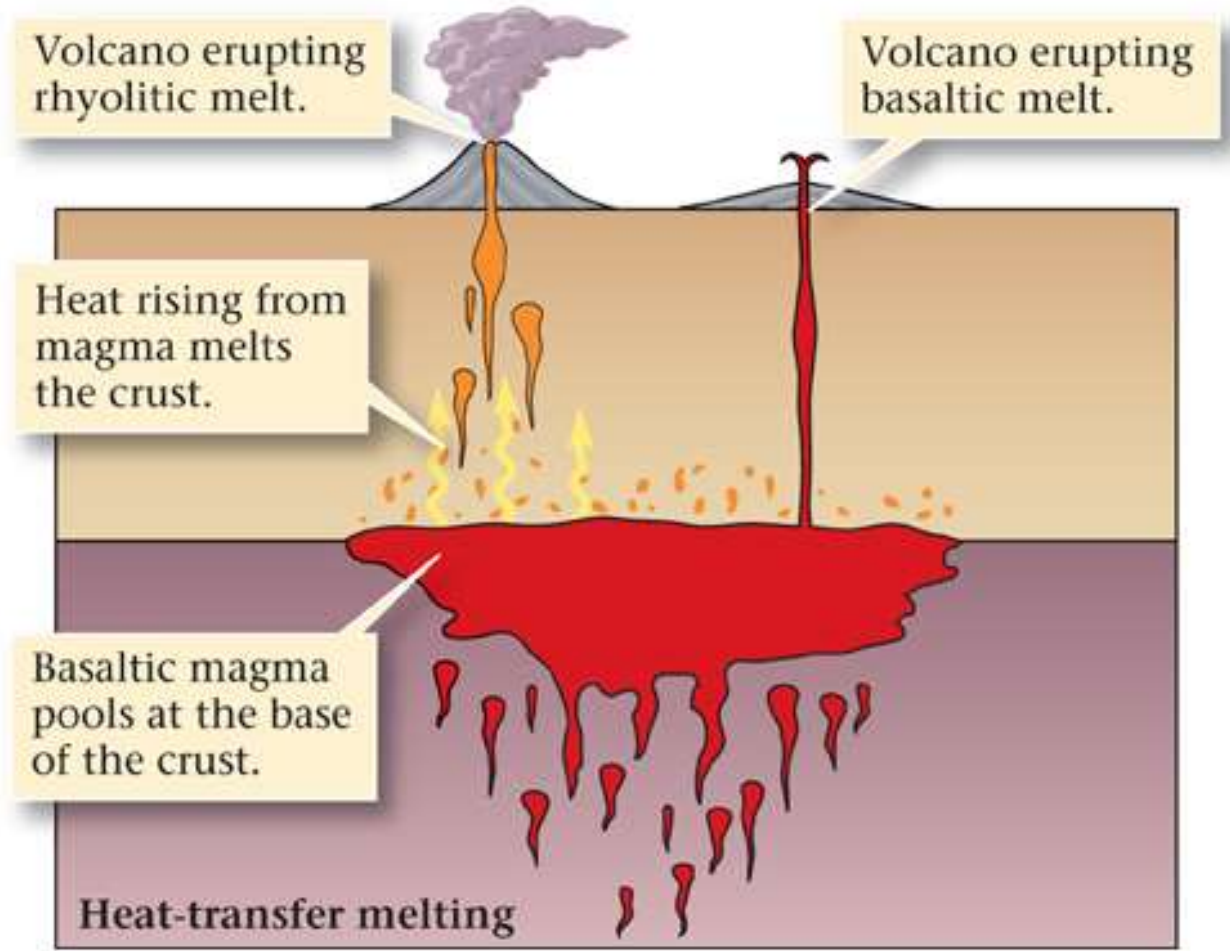
- Pressure decrease



Decompression melting beneath a rift

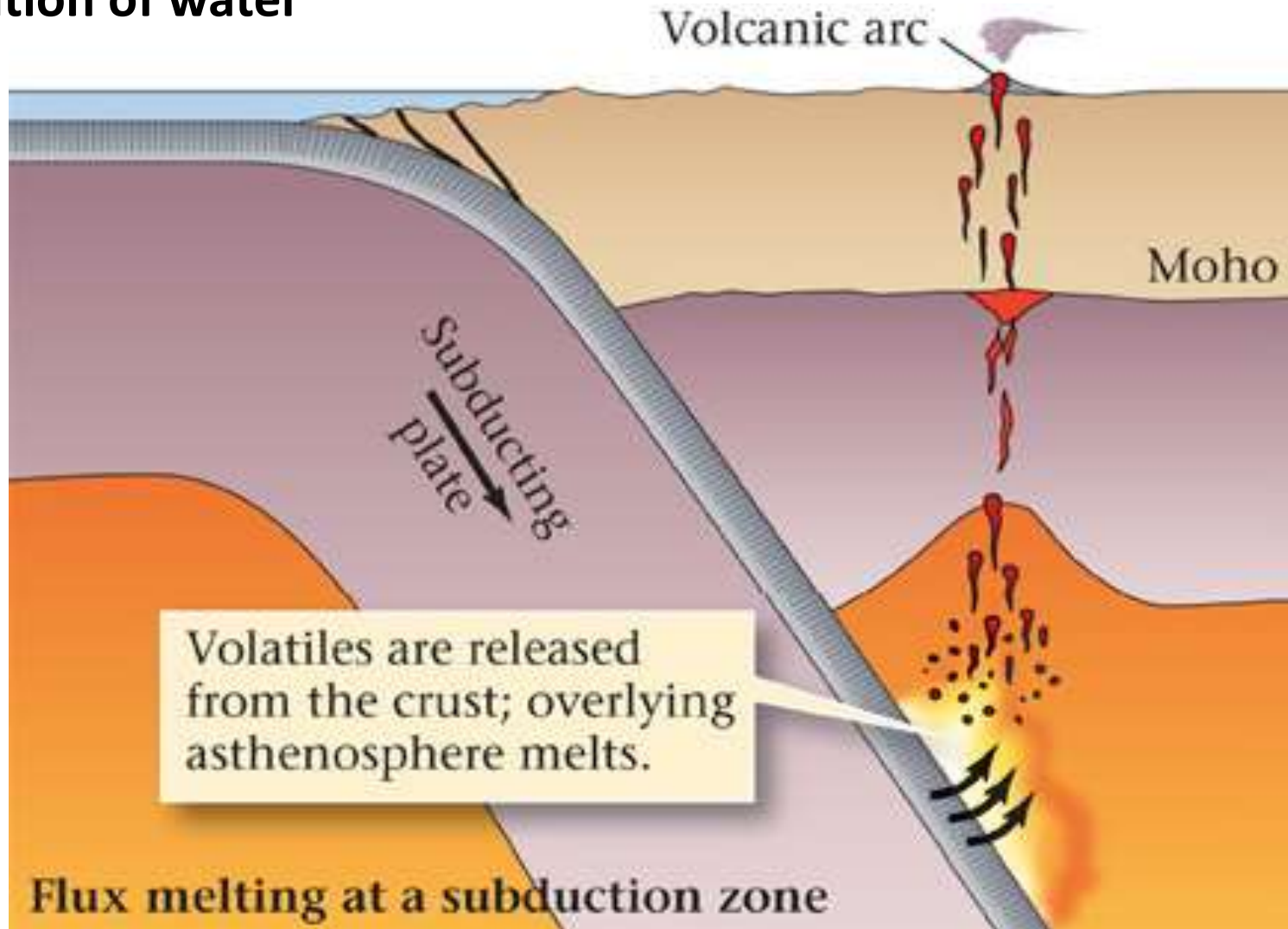
Magma Formation

- 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?

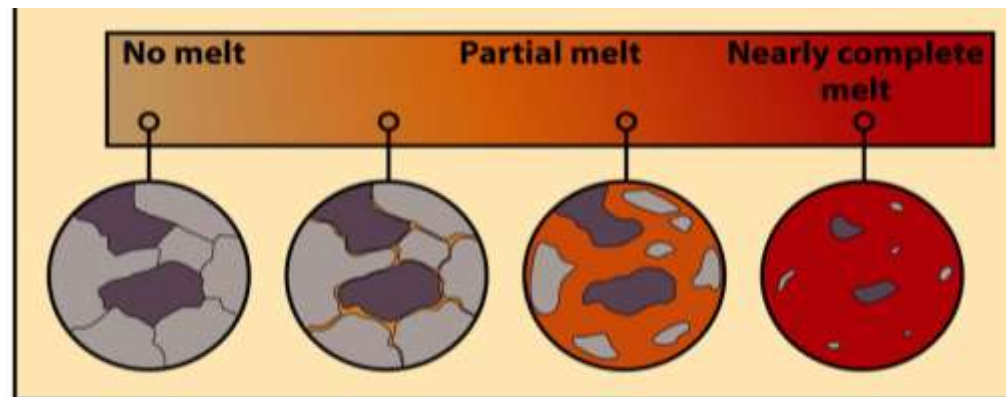
1. Depends on the **source rock**
2. That rock probably only **partially melts**
3. Magma will **evolve** over time by:
 - Fractional crystallization
 - Assimilation (when magma will melt and incorporate surrounding host rock)
 - Mixing (when 2 magmas of different composition mix)

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



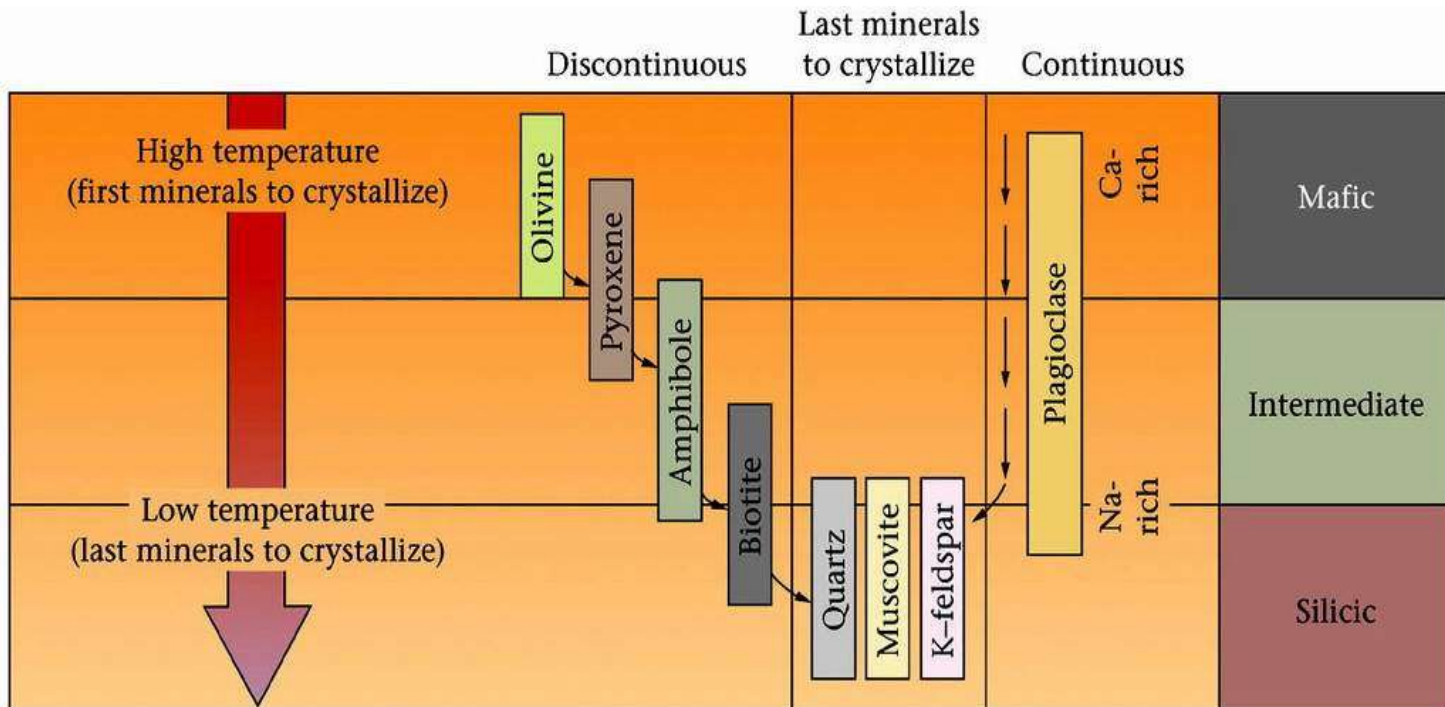
Reminder: Silicate Minerals

- 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

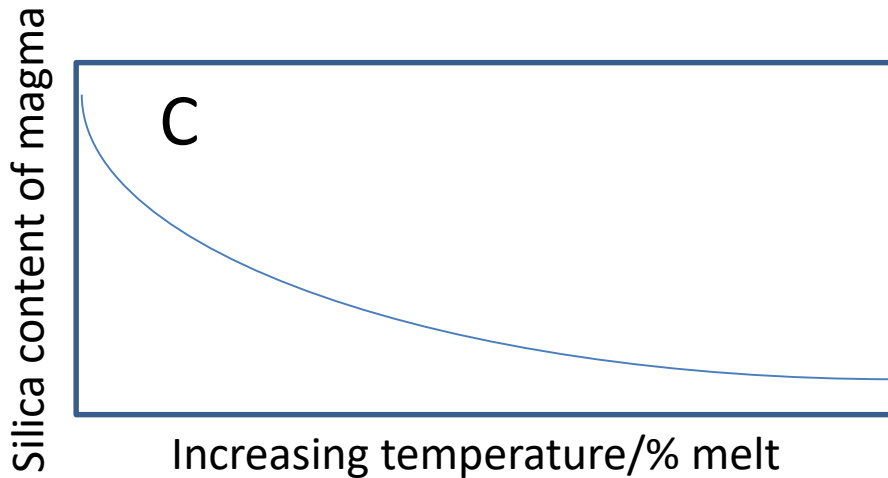
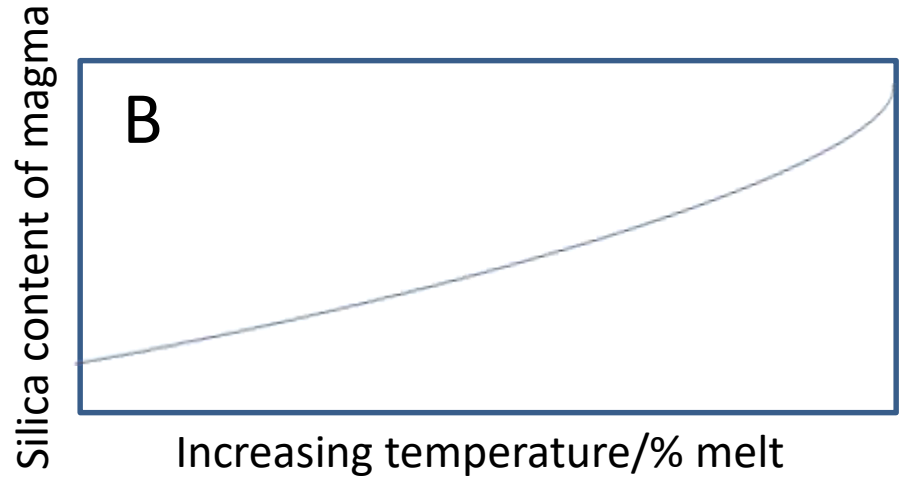
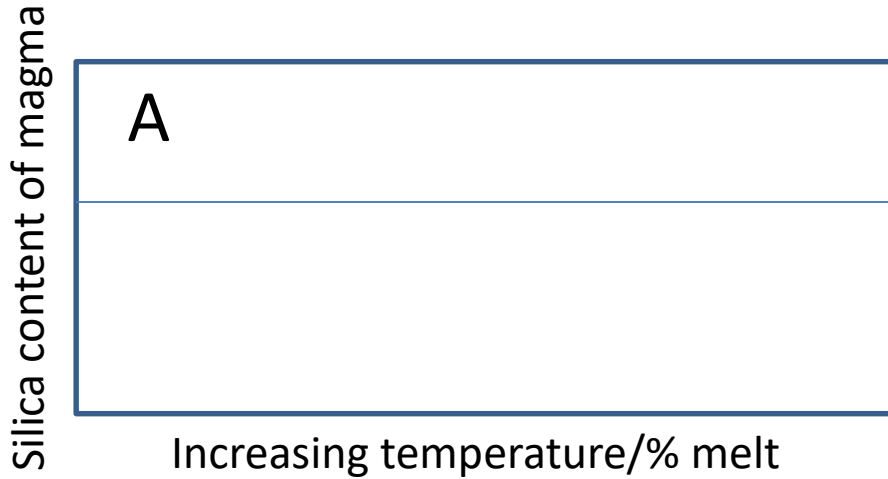
Bowen's Reaction Series

- 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



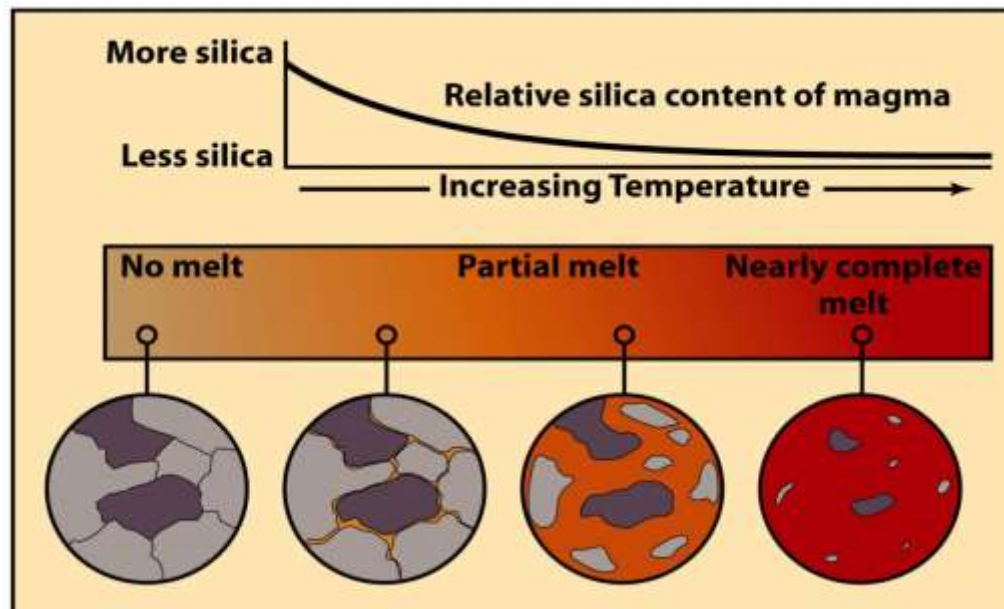
Group Question

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



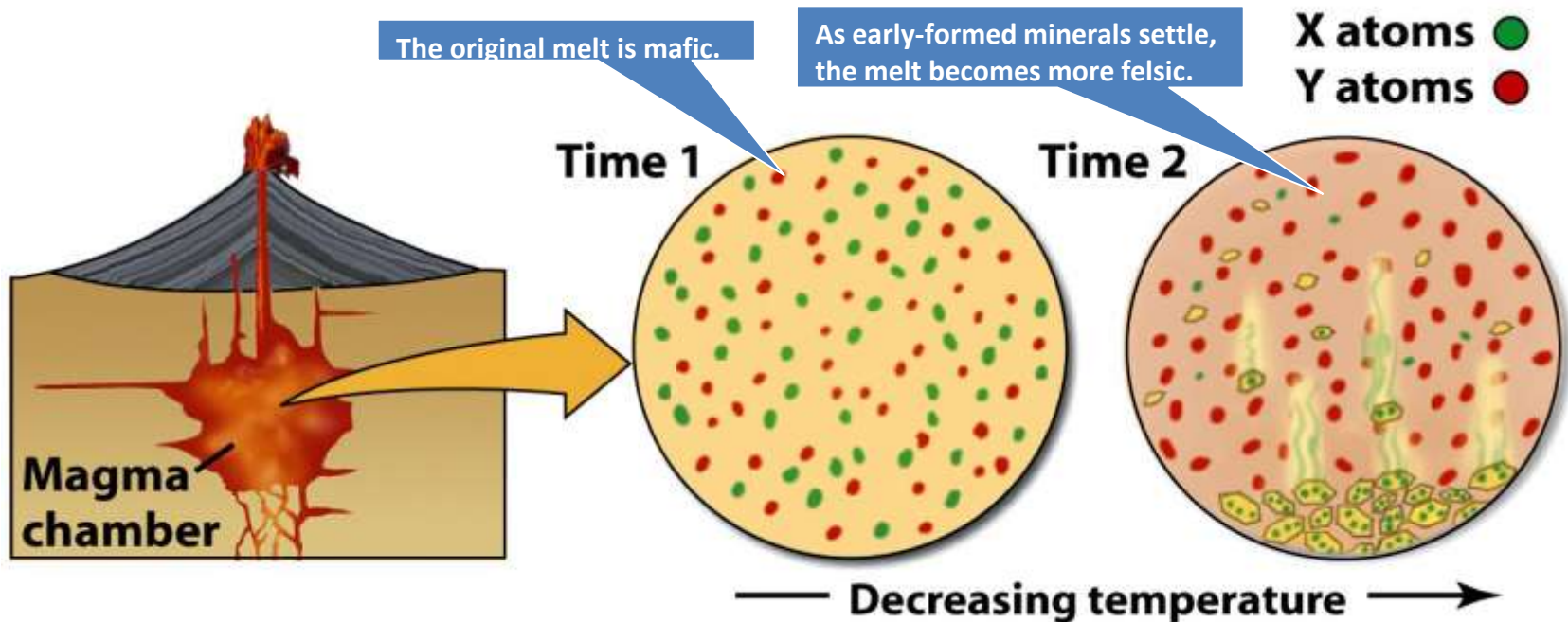
2. Partial Melting

- 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



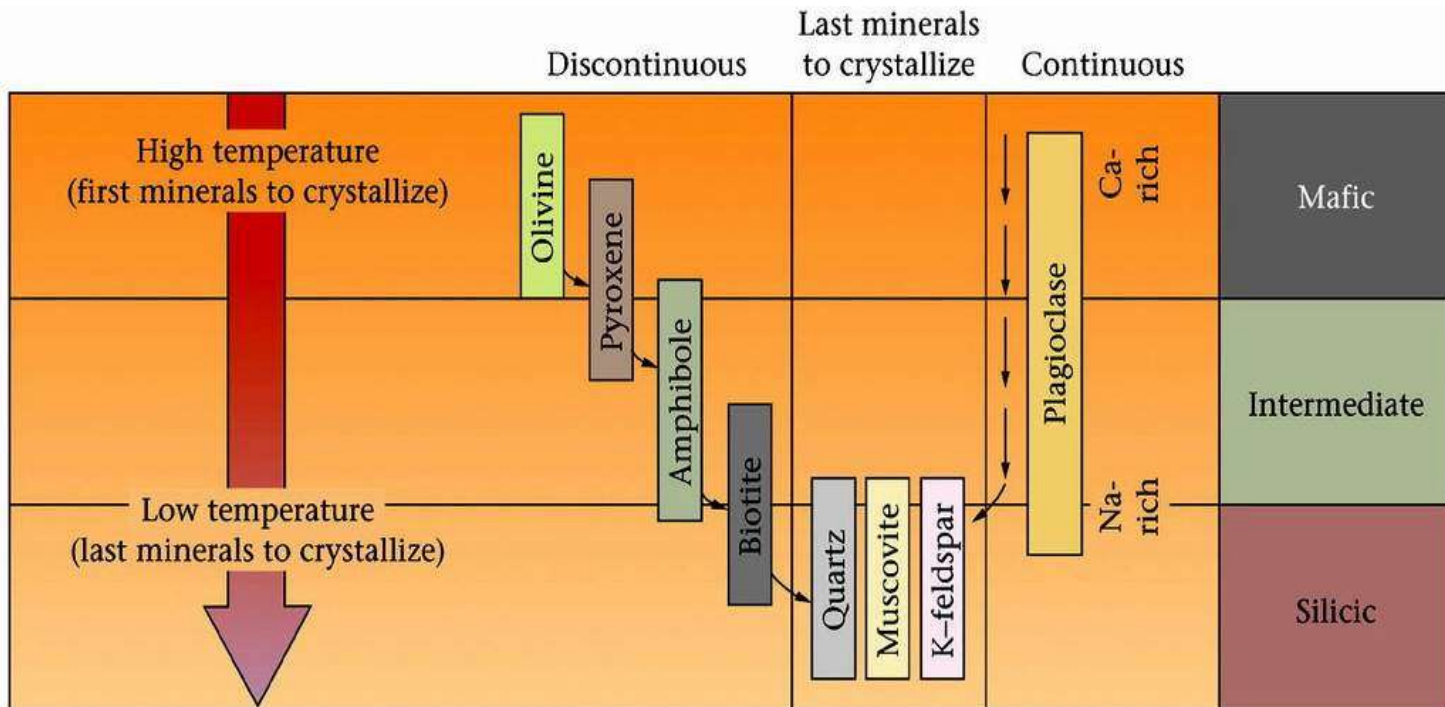
3a. Fractional Crystallization

- 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



Bowen's Reaction Series

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

2. take a mafic magma and cool it gradually

Solid:

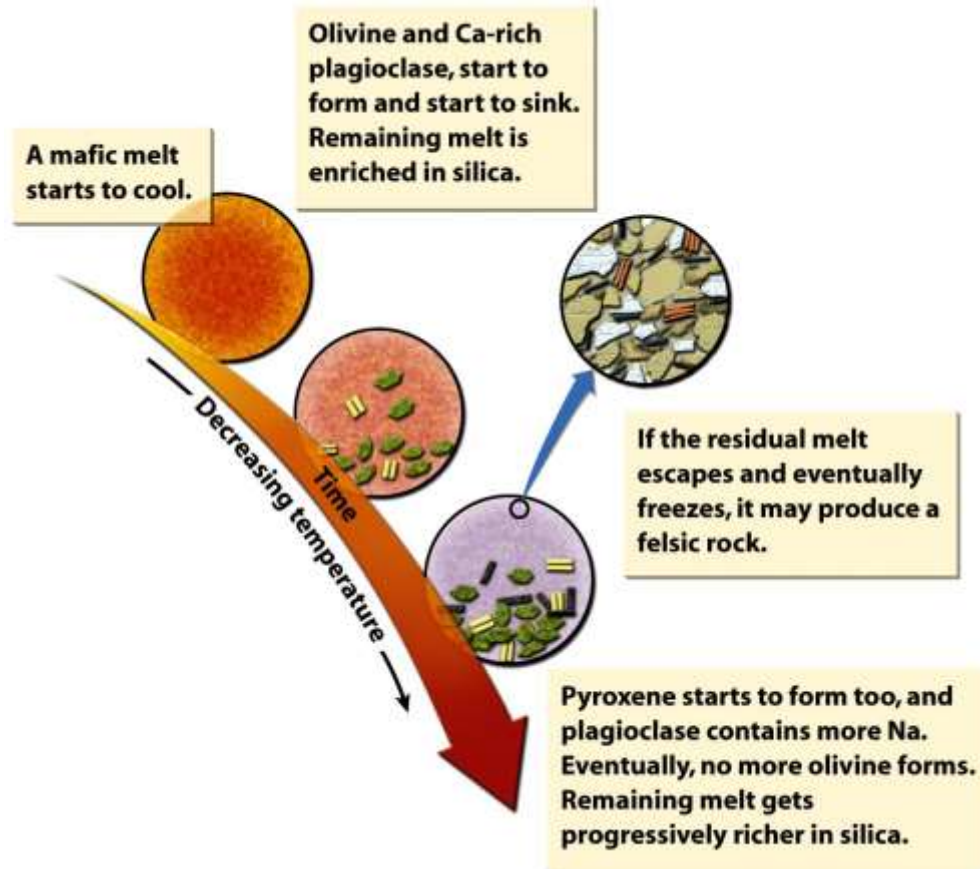
Solid:

Melt:

Melt:

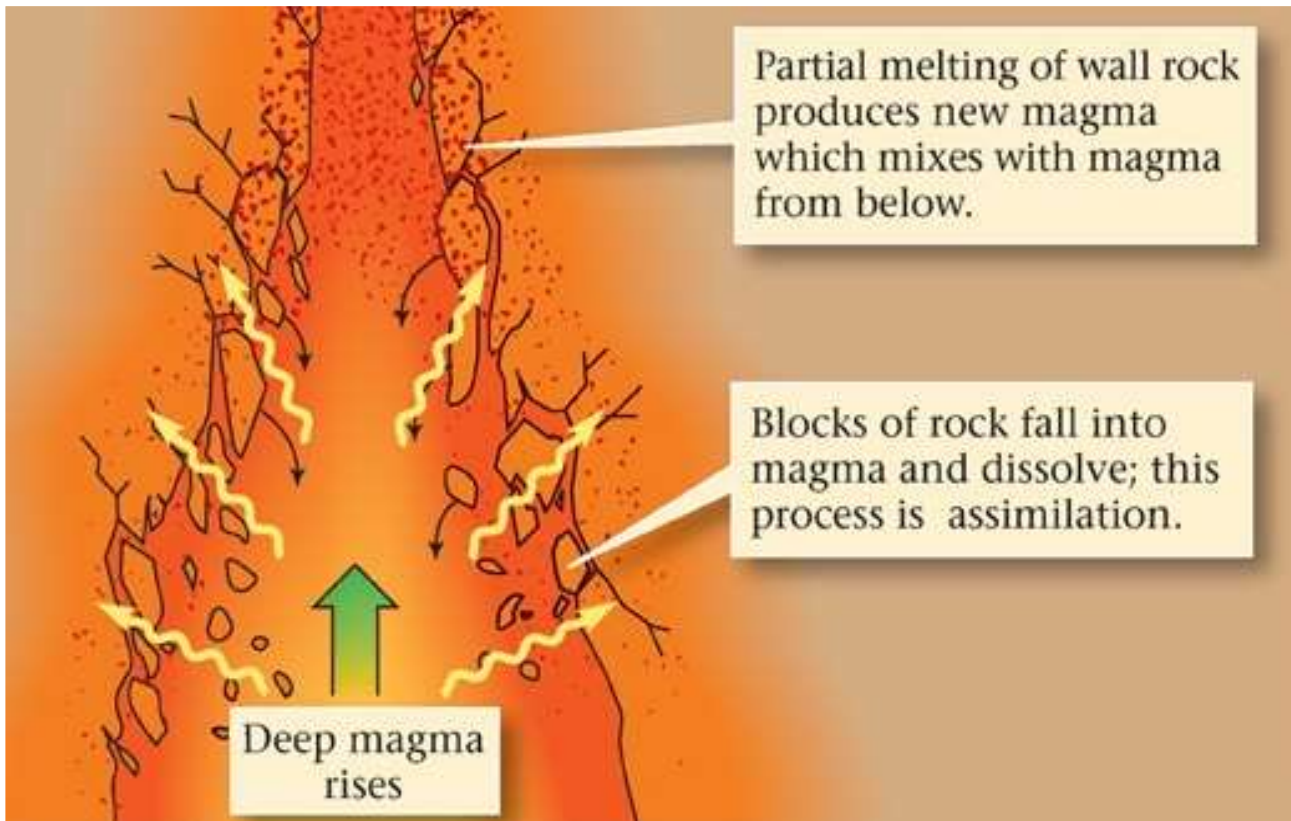
3a. Fractional Crystallization

- 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

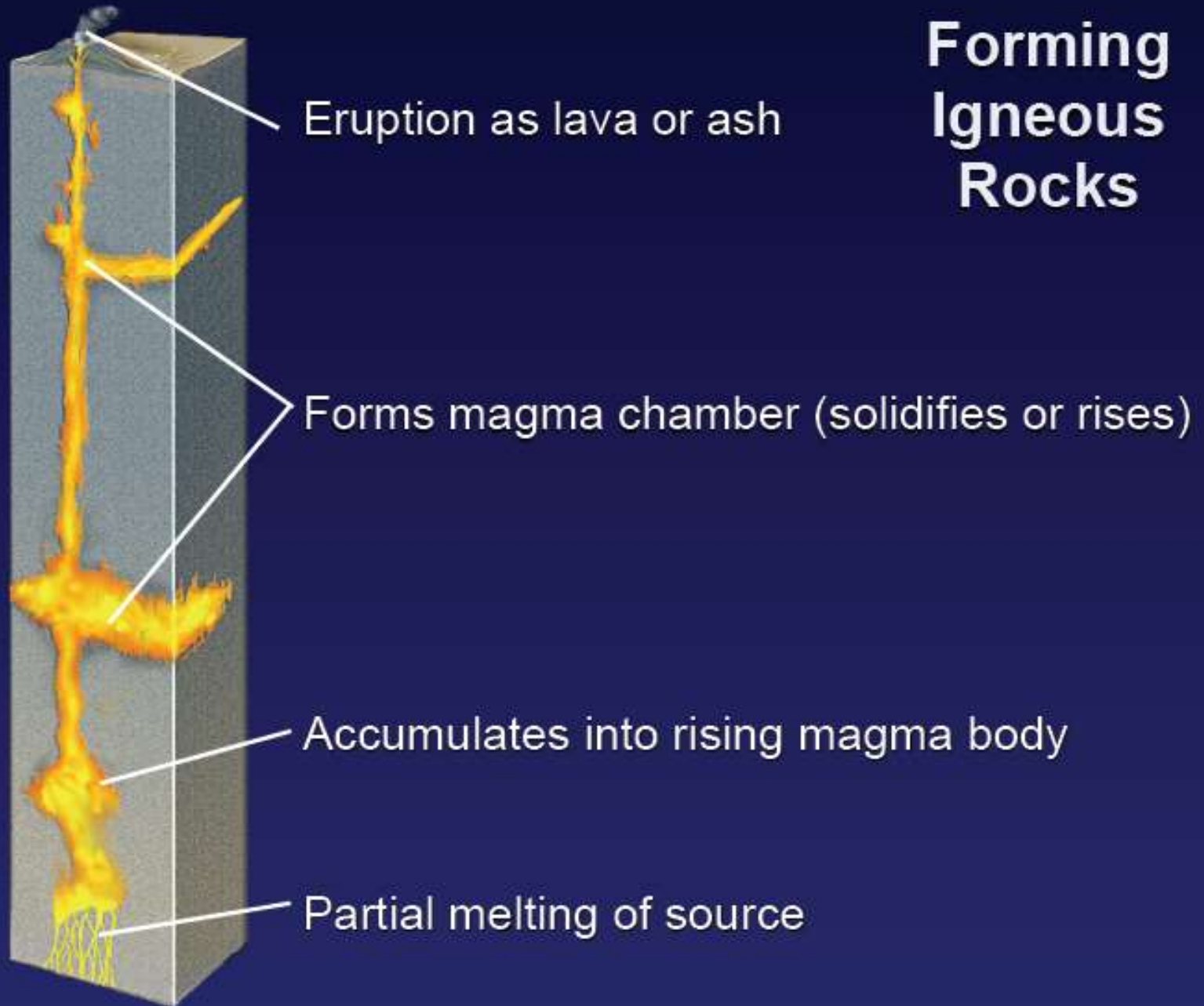


3c. Magma Mixing

- 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



Magma Migration

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

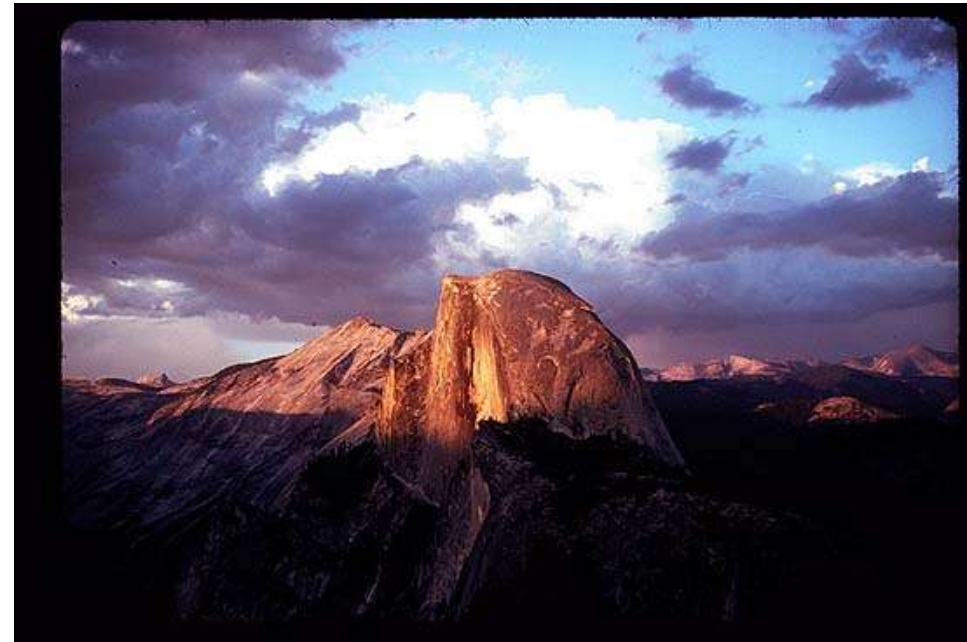


Extrusive vs Intrusive igneous rocks

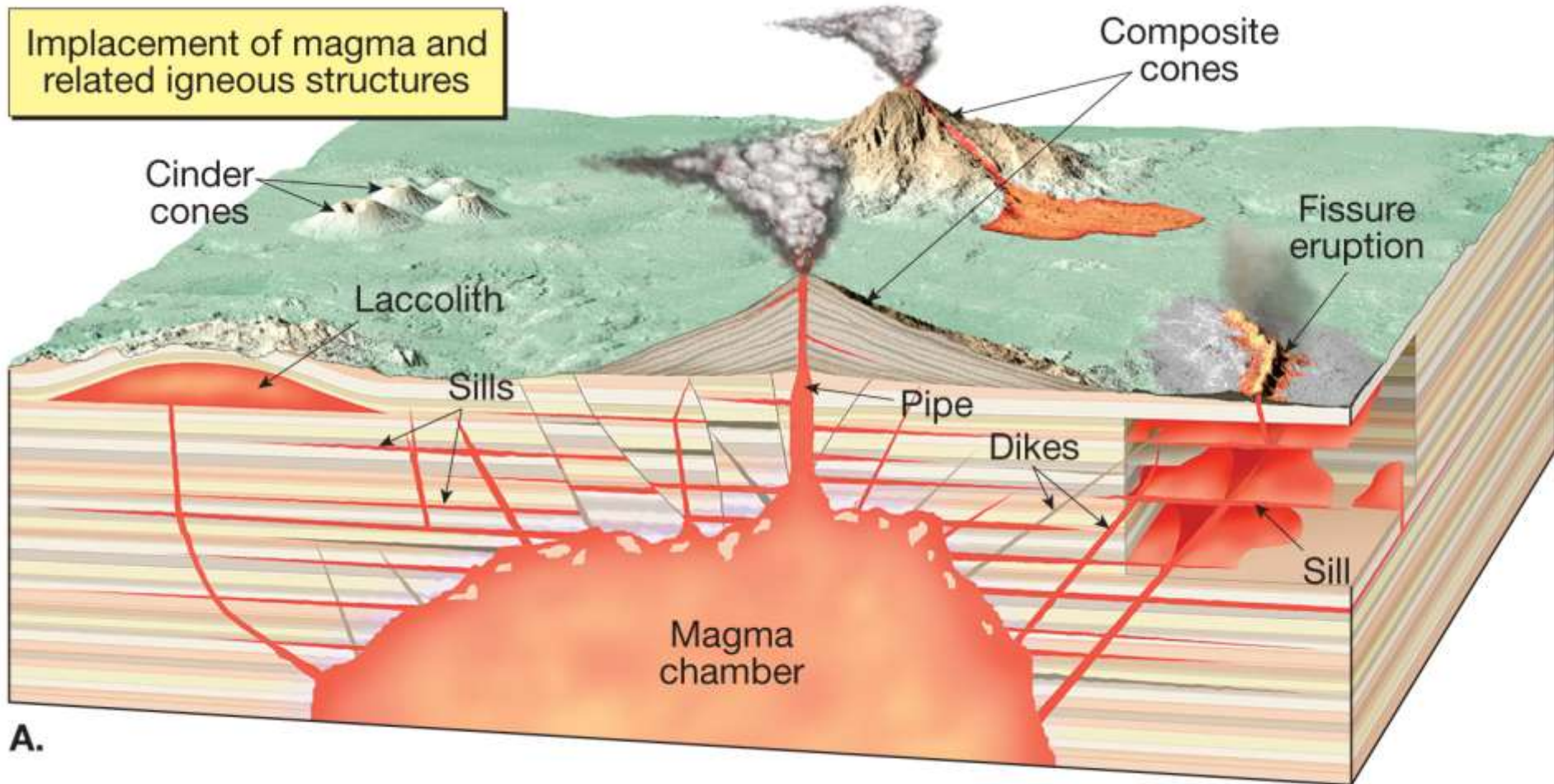


Rocks formed from lava =
extrusive or volcanic rocks

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?

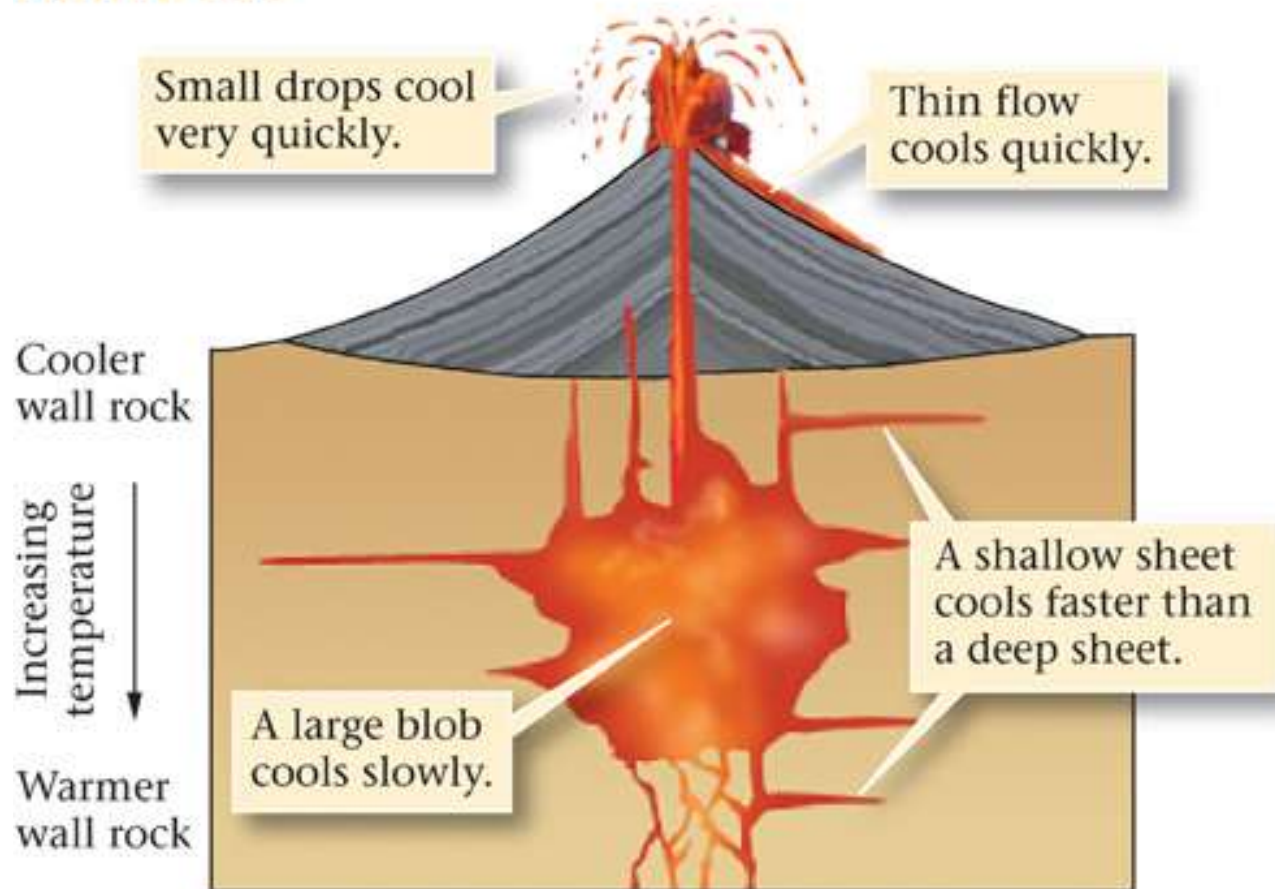


Group Question

- 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

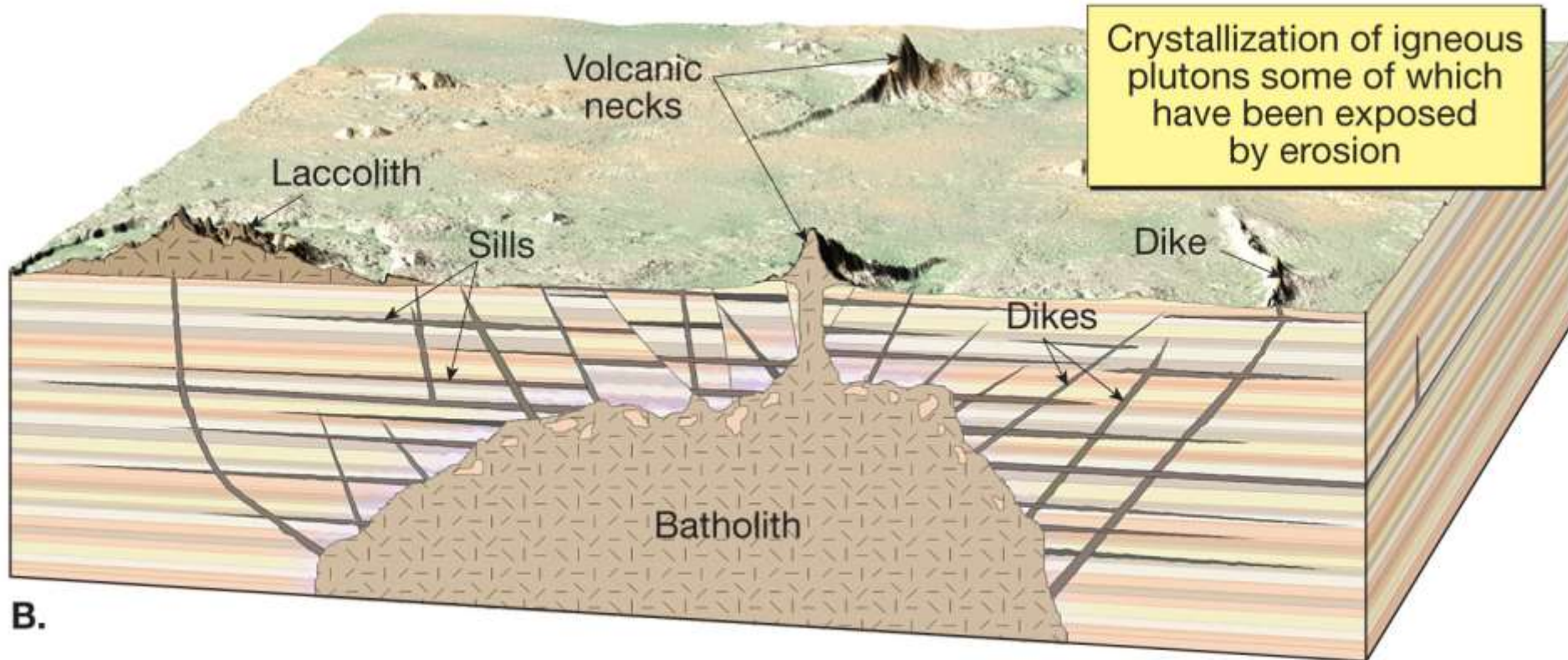
How fast magma cools depends on:

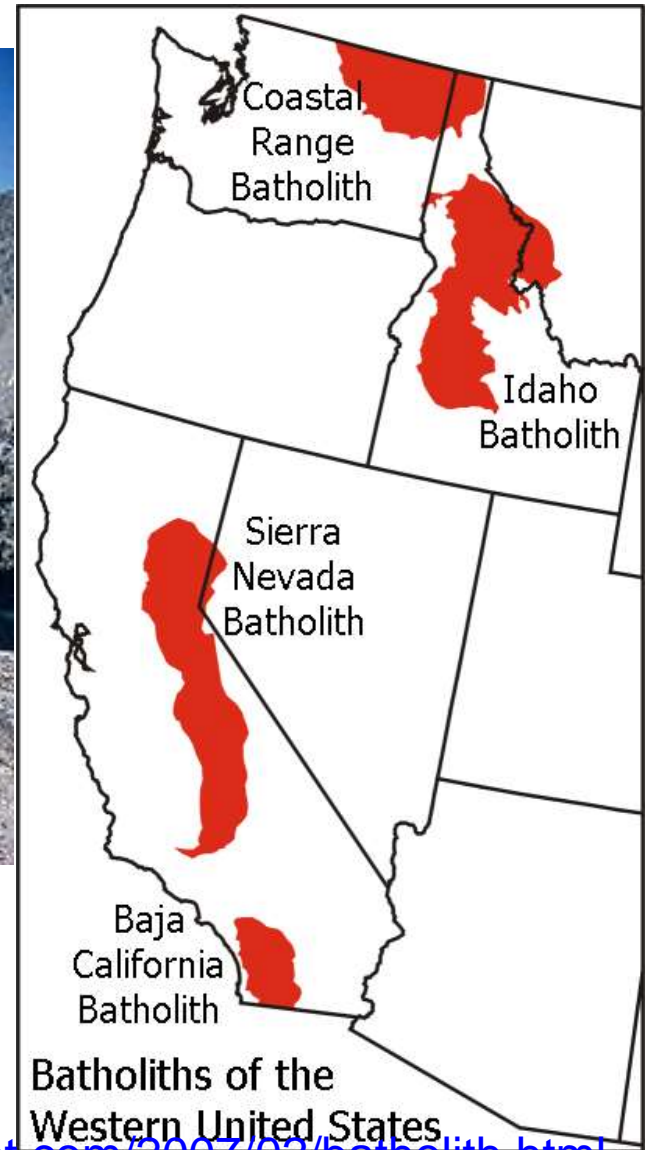
FIGURE 4.7b



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

Extrusive and intrusive igneous environments

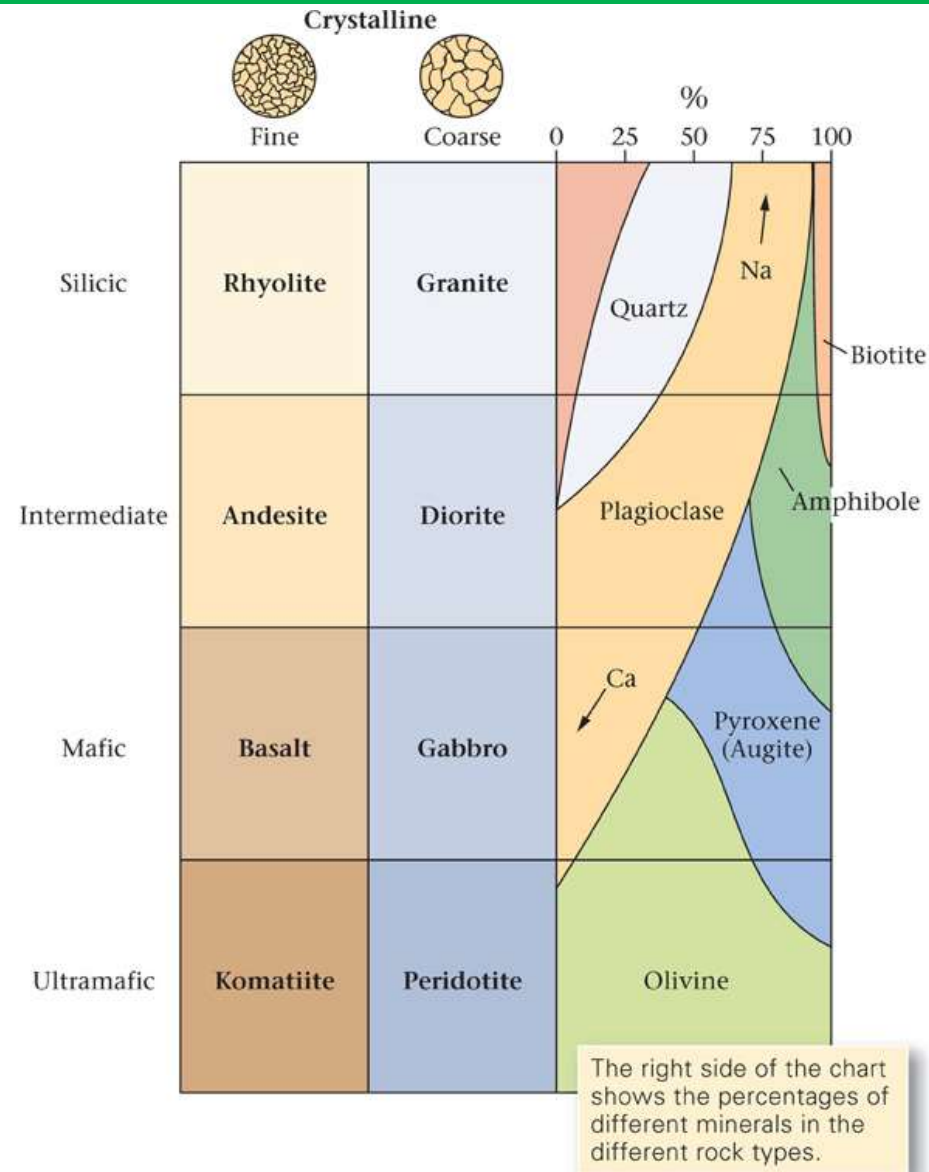




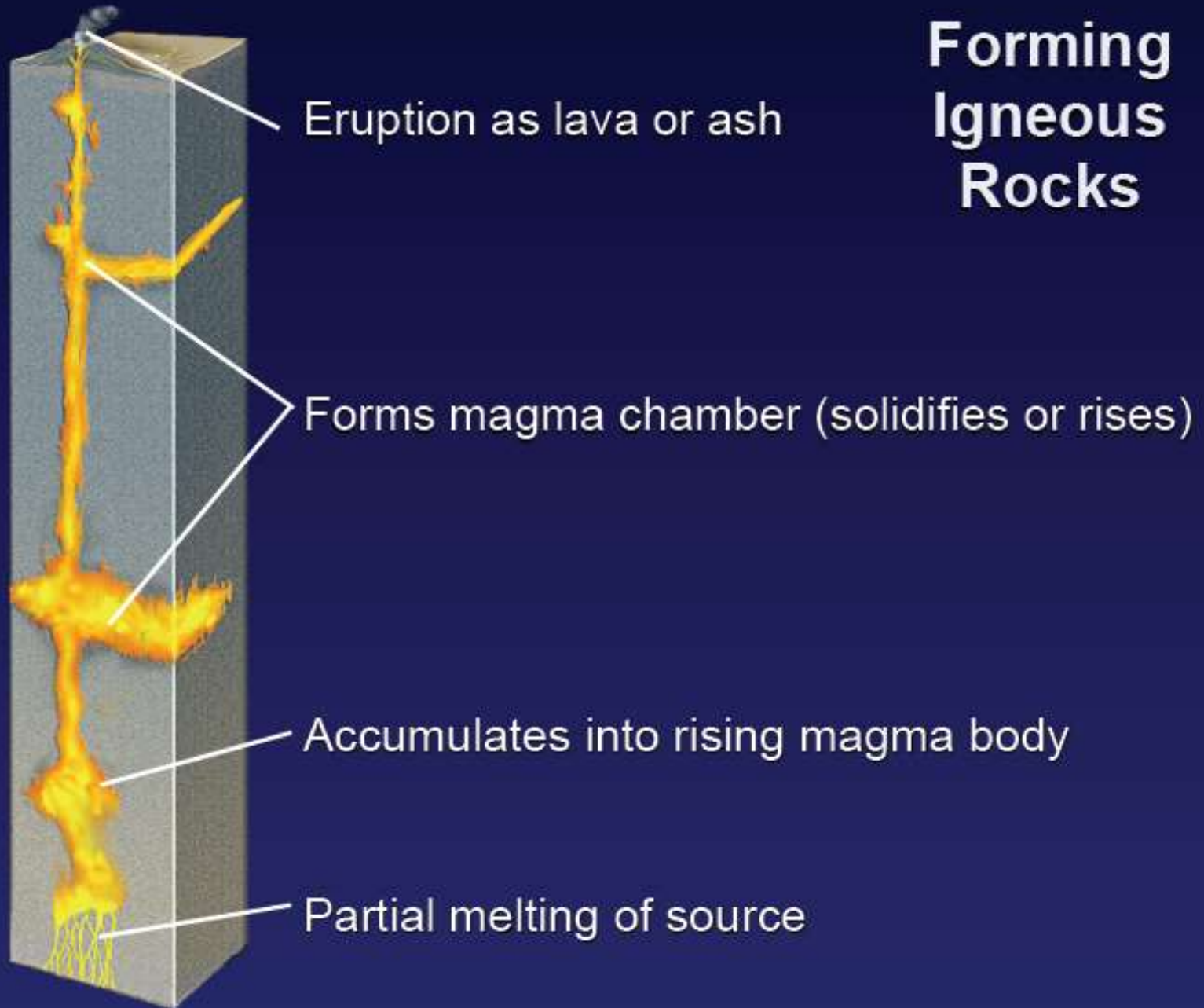
<http://bio-geotermis.blogspot.com/2007/02/batholith.html>

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



Magma Compositions

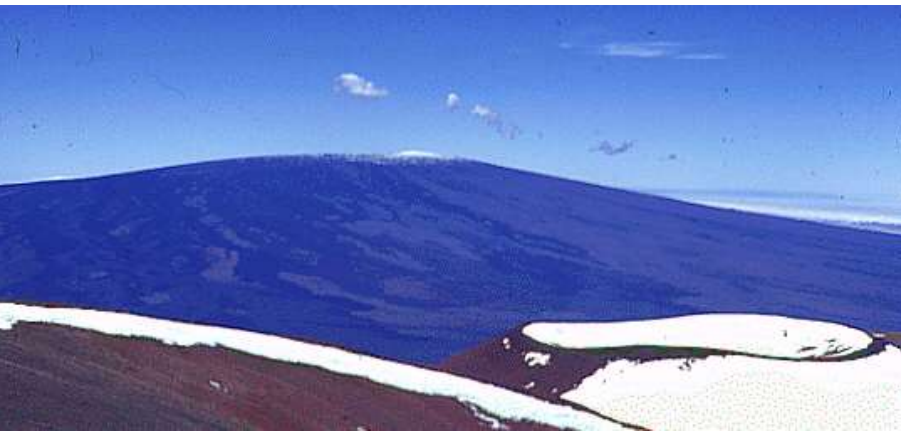
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Main types of volcano



Stratovolcano



Shield volcano

Question

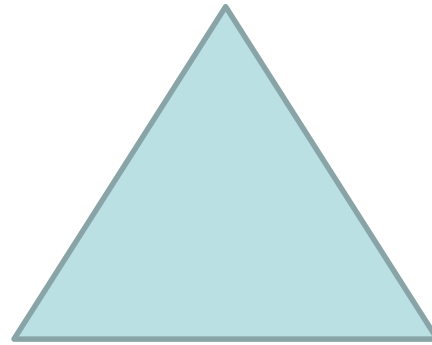
What type of magma would form each type of volcano?

shield volcano



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

stratovolcano

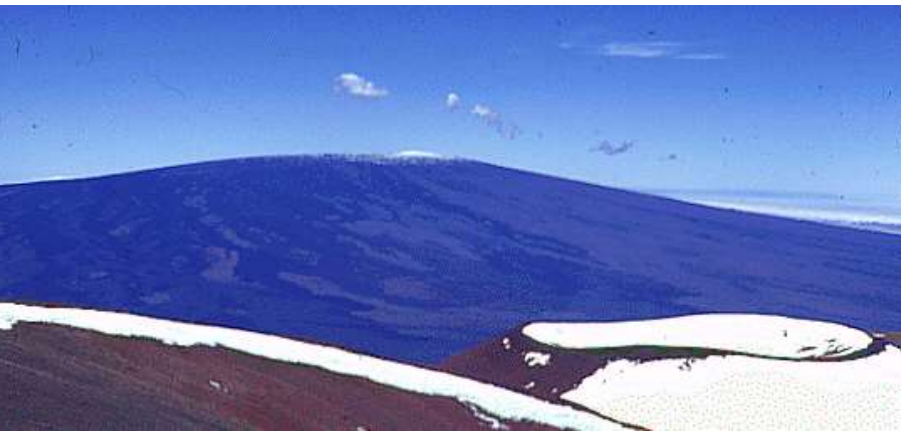


- mafic/felsic
- intermediate/mafic
- felsic/intermediate
- intermediate

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

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



example: Mt. St. Helens

http://volcan.wr.usgs.gov/Volcanoes/MSH/images/may18_images.html

Lahars



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

- Rhyolite tuff



- Pumice



- Obsidian

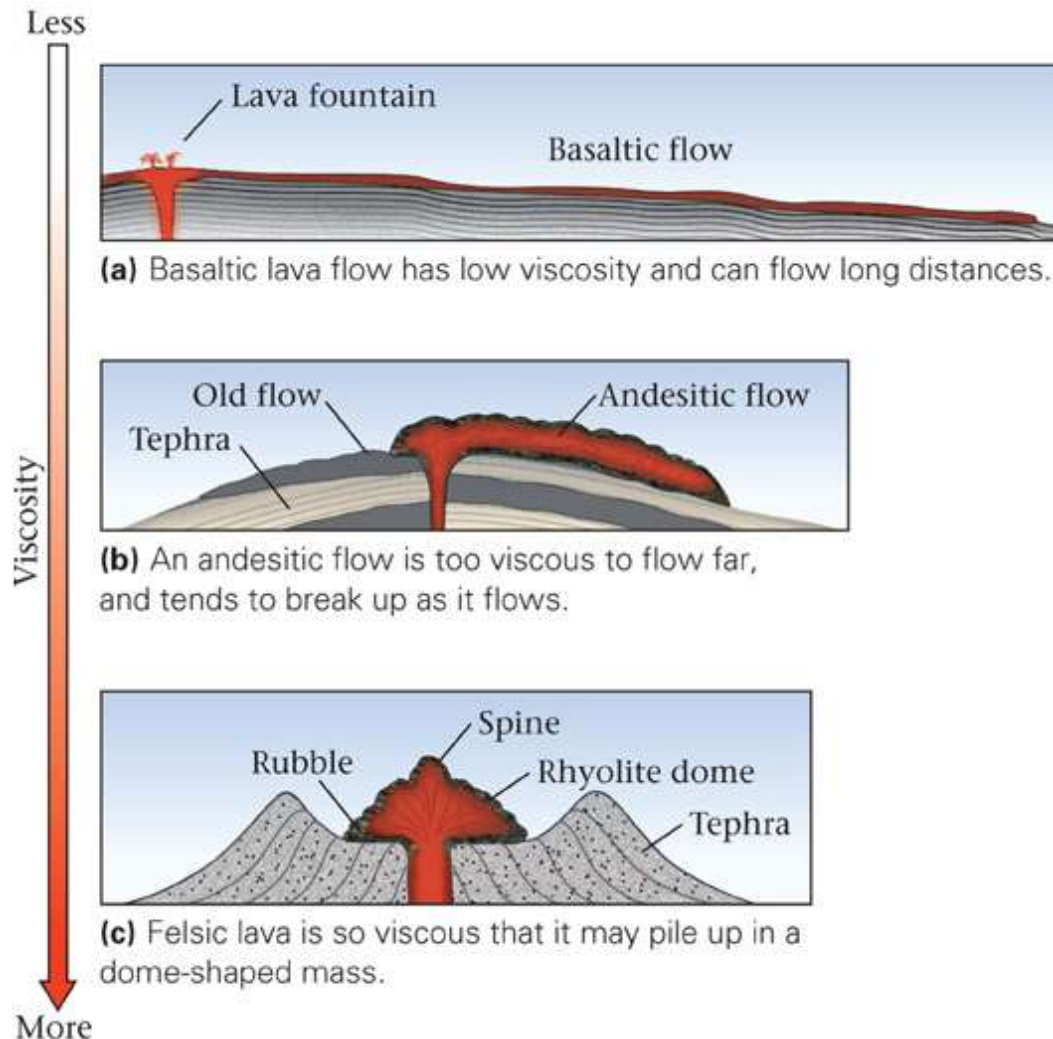


3. Volcanic Gases

- Up to 9% of magma may be gas (H₂O, CO₂, SO₂)
- 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



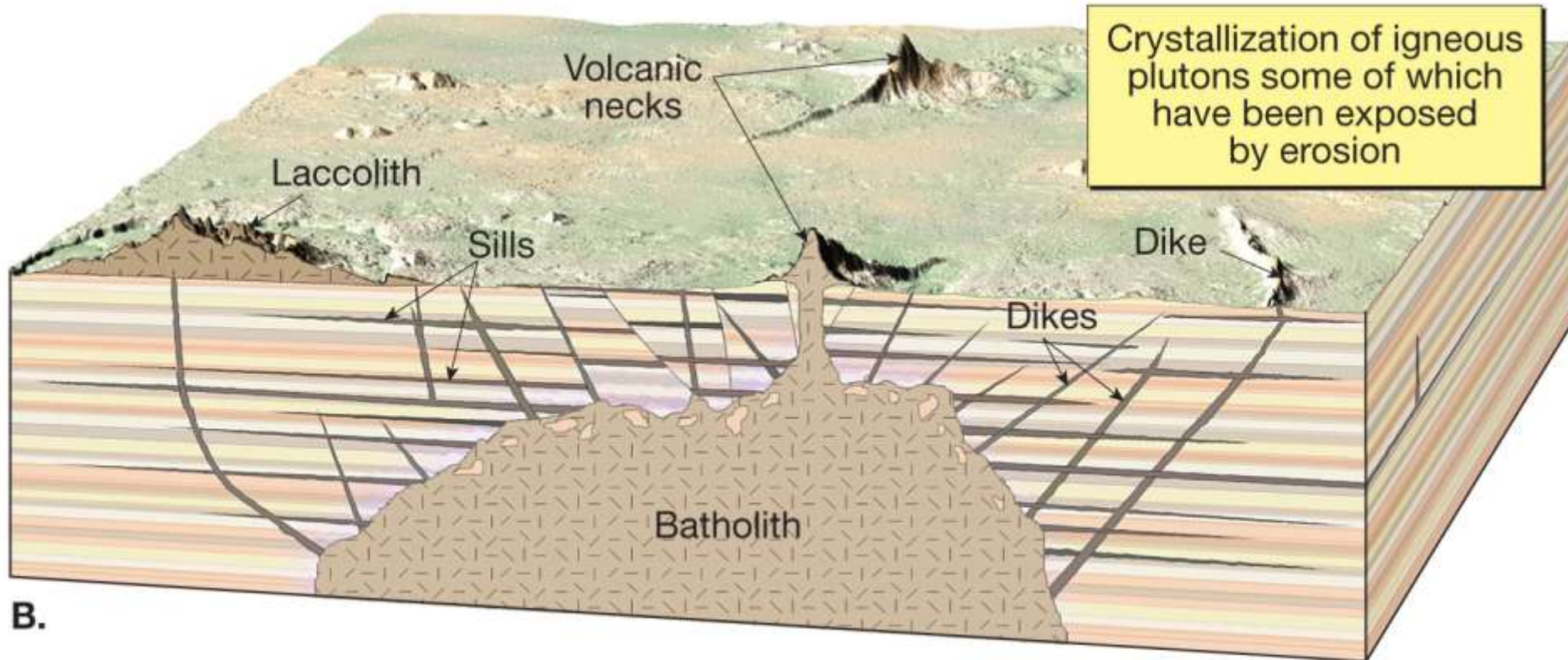
- Basalt



- Scoria



Extrusive and intrusive igneous environments



- Diorite



- Granite



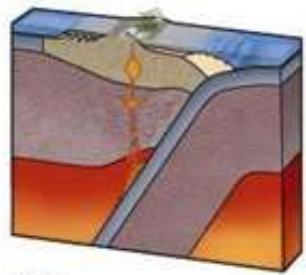
- Gabbro



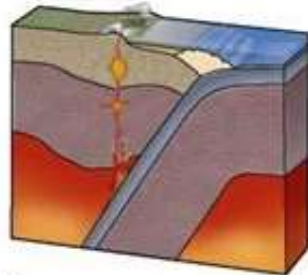
- Peridotite



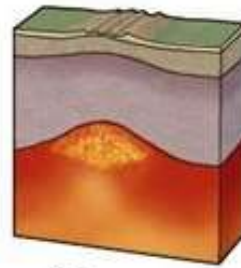
Plate tectonics and volcanism



Ⓘ = Island arc



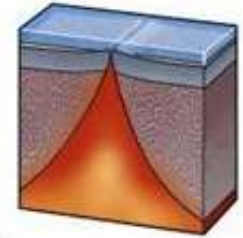
Ⓒ = Continental arc



Ⓓ = Rift



Ⓗ = Hot spot



Ⓜ = Mid-ocean ridge

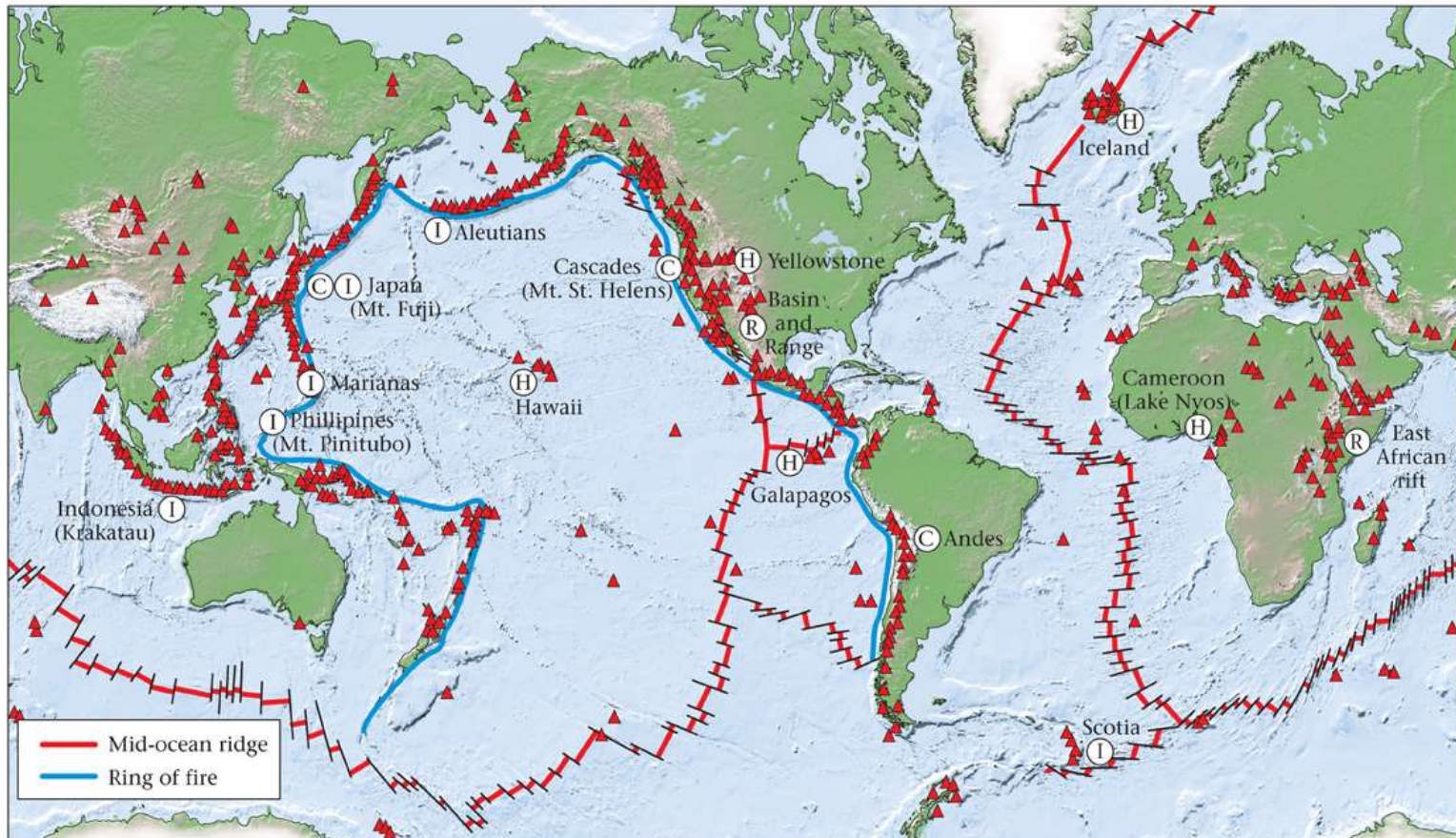
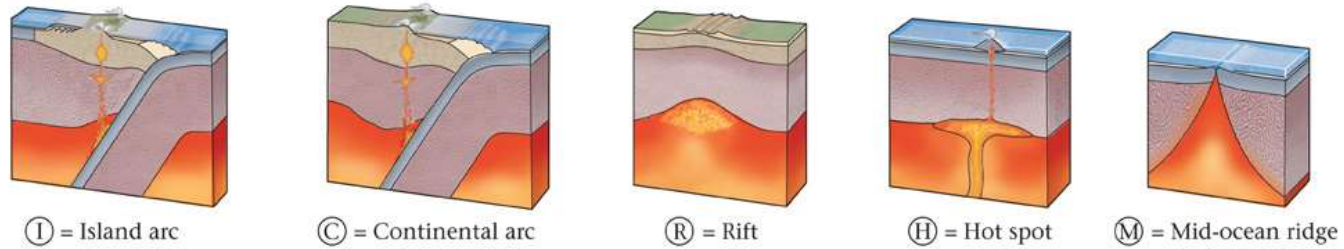
- At each type of location:
- What is melting to make up the magma and so what type of magma do you think you will get?
- What type of intrusive vs extrusive rock will you therefore see?
- What type of volcano will likely form?
- What volcanic hazards would local populations experience?

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?

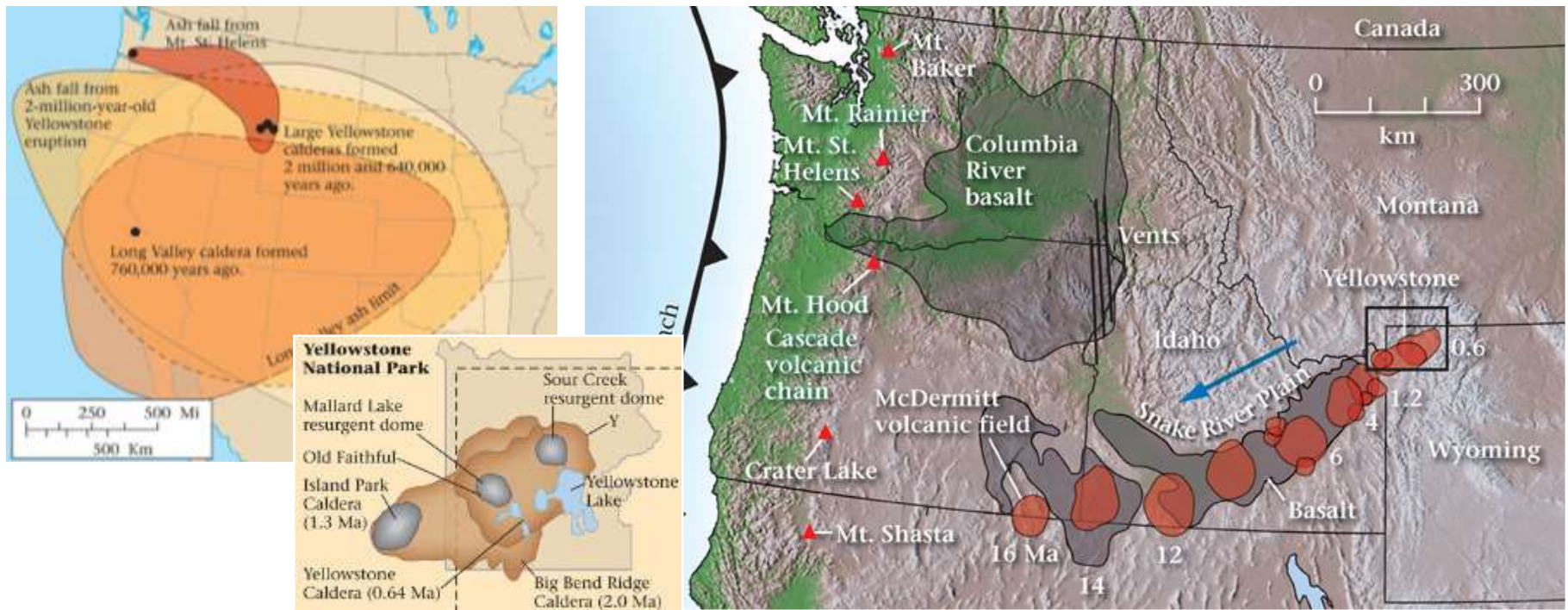
Plate tectonics and volcanism

FIGURE 5.11



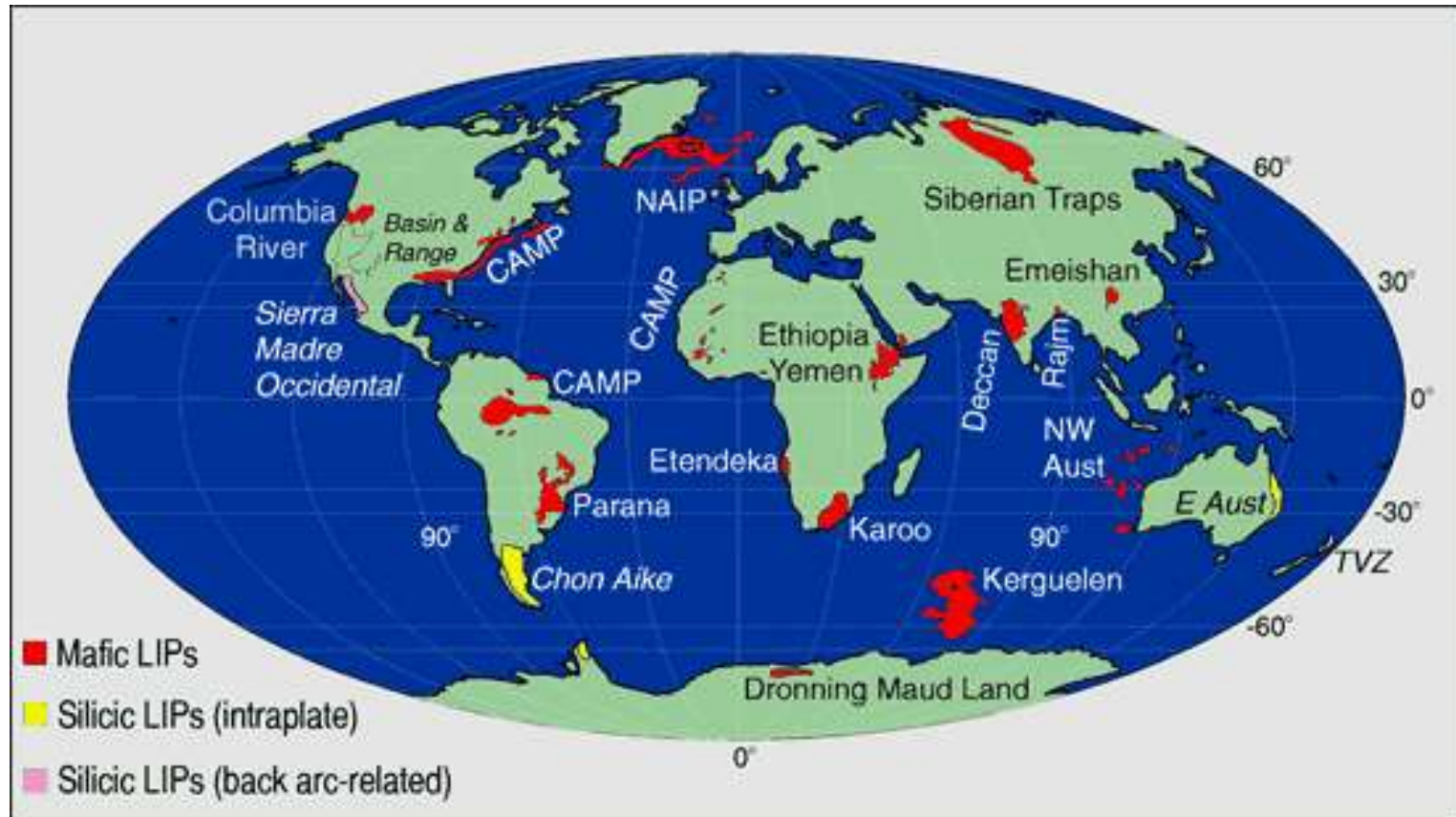
Continental Hot-Spot Volcanoes

- 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 km²) in a short geological time (few million years or less)



Looking at rocks under the microscope - igneous



Color

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

Twinning?

Characteristic shape?

Texture – size of crystals, alteration?

Plane polarized light



Cross polarized light