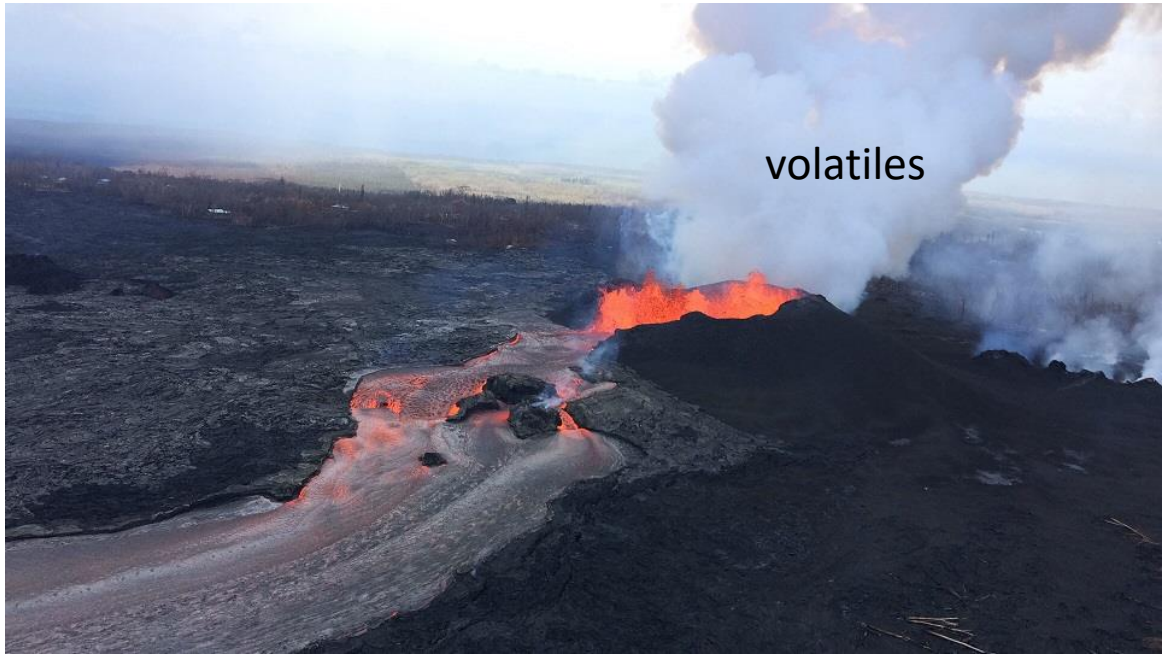
Igneous Rocks

- Made of silicate minerals that crystallize from cooling magma
  - How magma forms
  - how magma changes
  - What structures it forms when magma is cooling underground
  - Main types of igneous rocks by texture and composition.

What is magma?

- Melt – liquid portion of mobile ions + silicon tetrahedrons
- Solids – Silicate minerals already crystallized
- Volatiles – Dissolved gases: water vapor (H_2O), carbon dioxide (CO_2), and sulfur dioxide (SO_2)

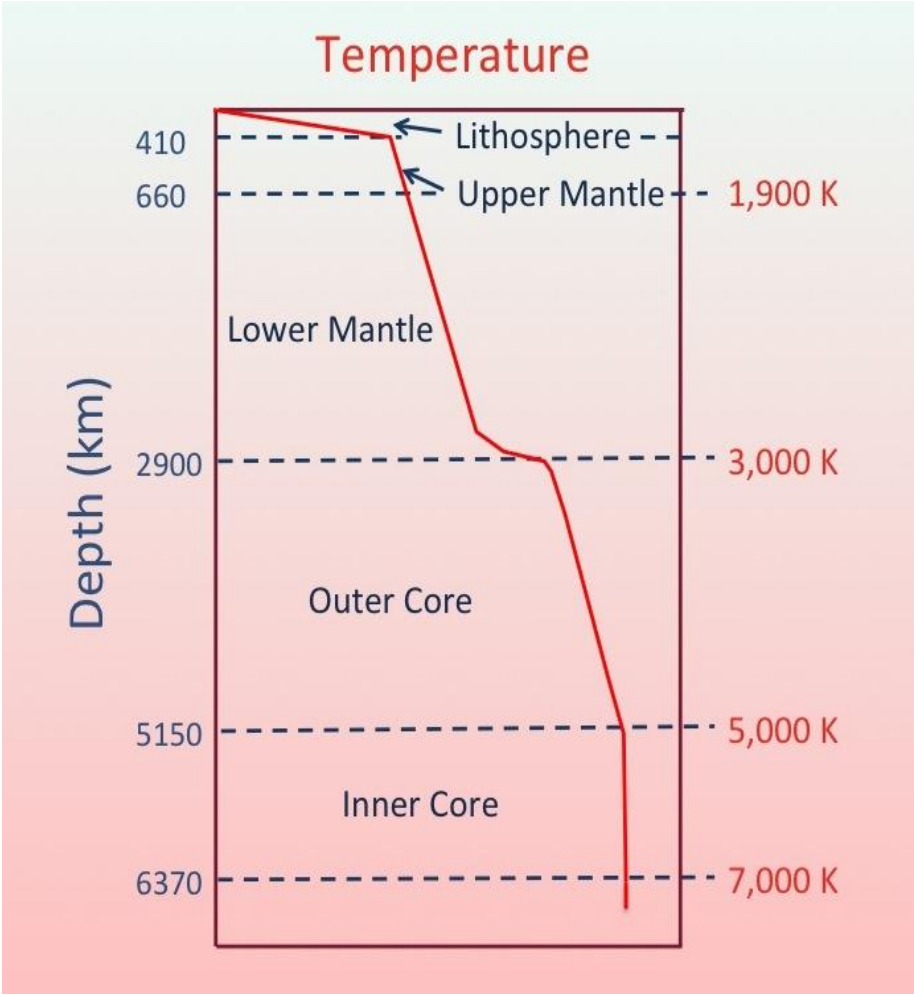


What we see when magma arrives on the surface of Earth

The formation of magma

- The interior of Earth is SOLID (but for the outer core)
  - Temperature and Pressure increase steadily→ Earth's interior is HOT but SOLID

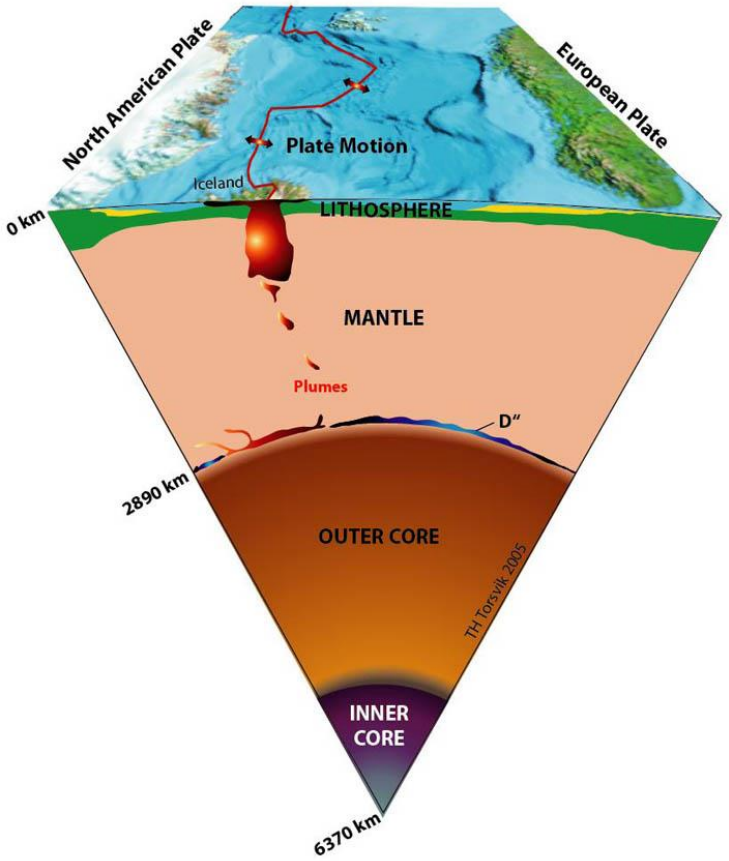
- Magma forms only under 3 circumstances that cause partial melting of the rocks in the subsurface of Earth

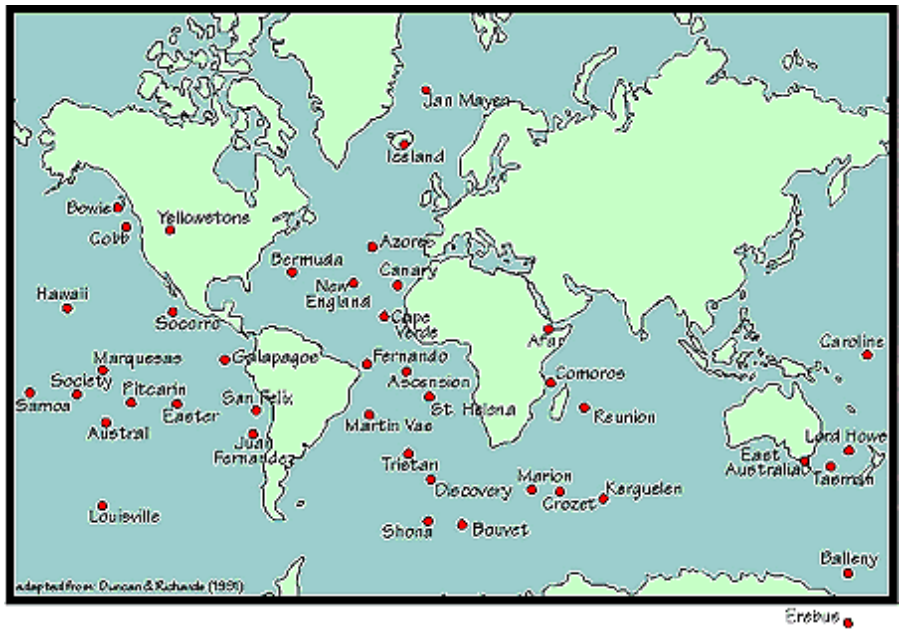


The geothermal gradient shows how the heat and pressure work inside Earth

1 – partial melting produced by heat anomalies (mantle plumes) under the Lithosphere

Magma forms because of a heat anomaly generating a Mantle plume: the heat forms a Hot Spot

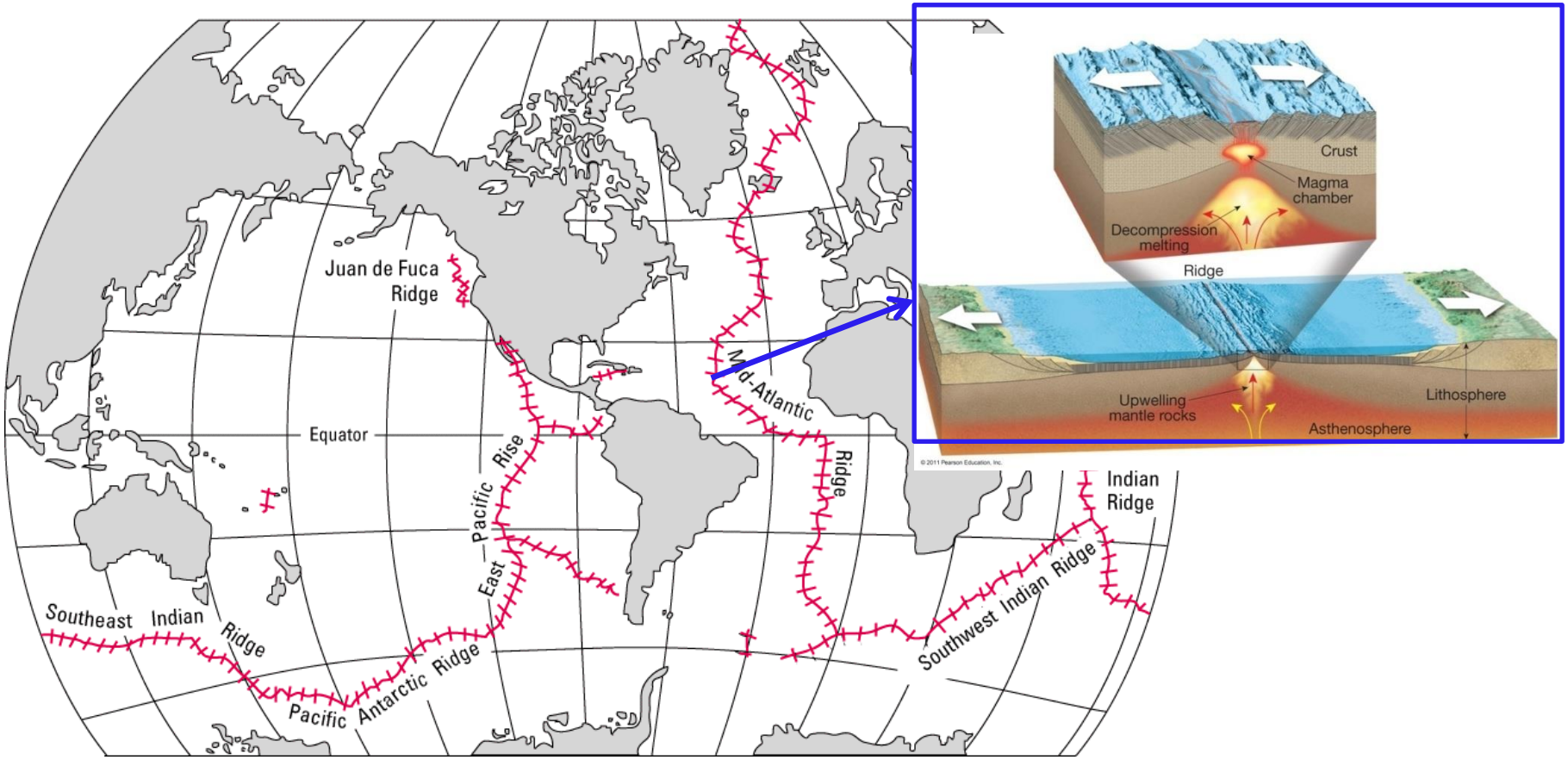




There are many hot spots!

2- partial melting produced by decreasing pressure at divergent plate boundaries

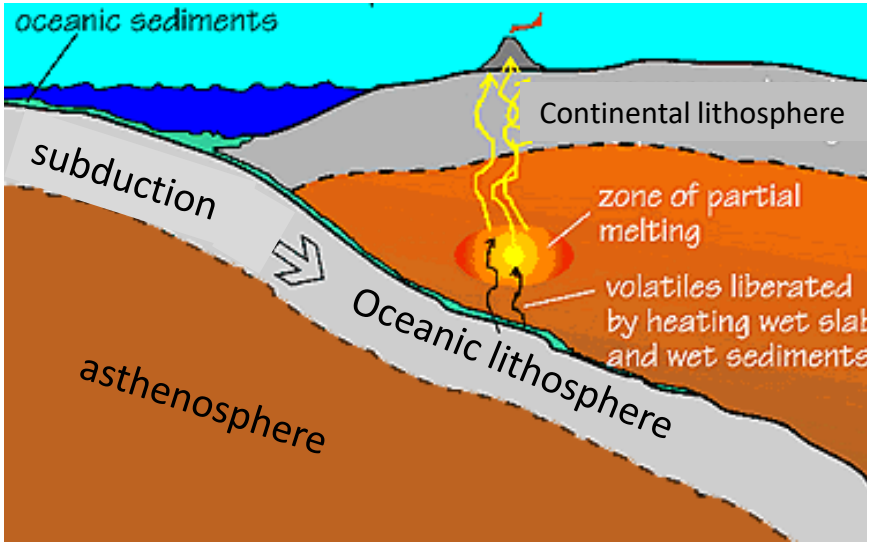
where lithosphere plates move away from each other the pressure drops →decompression partially melts the rocks underneath.

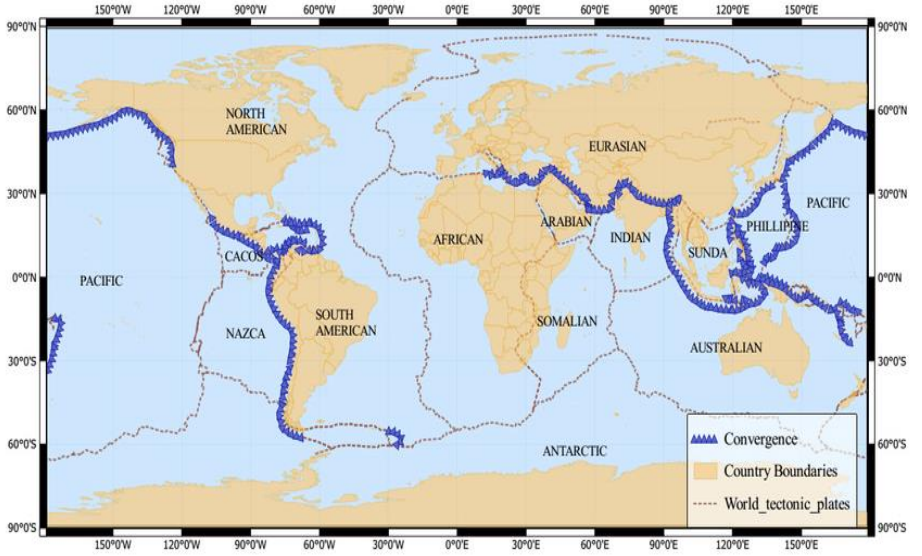


3 – Partial melting by adding volatiles – during subduction at convergent plate boundaries

When plates collide, the “diving” denser oceanic lithosphere carries volatiles (mostly water) into the mantle domain

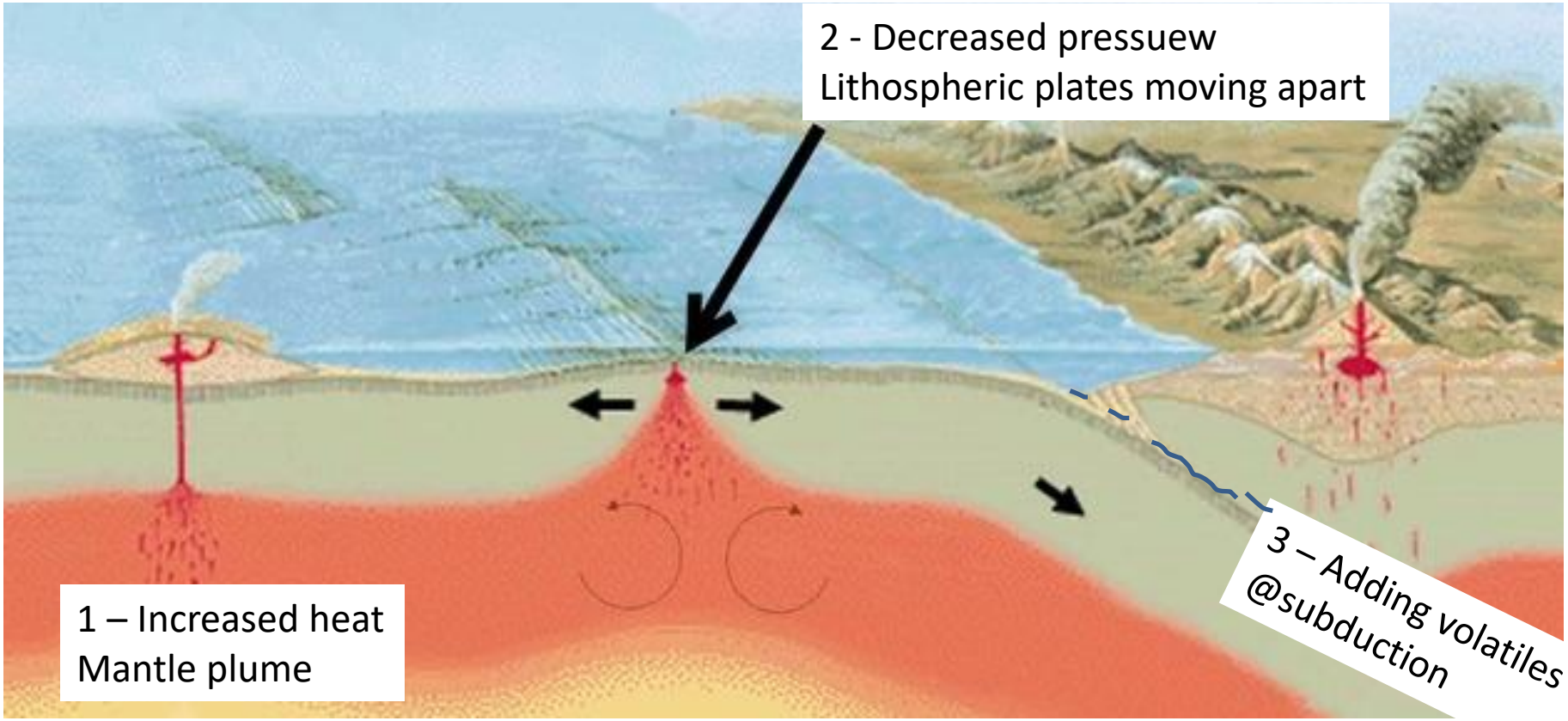
- Volatiles added to the mantle by subduction can cause rocks to partially melt forming magma





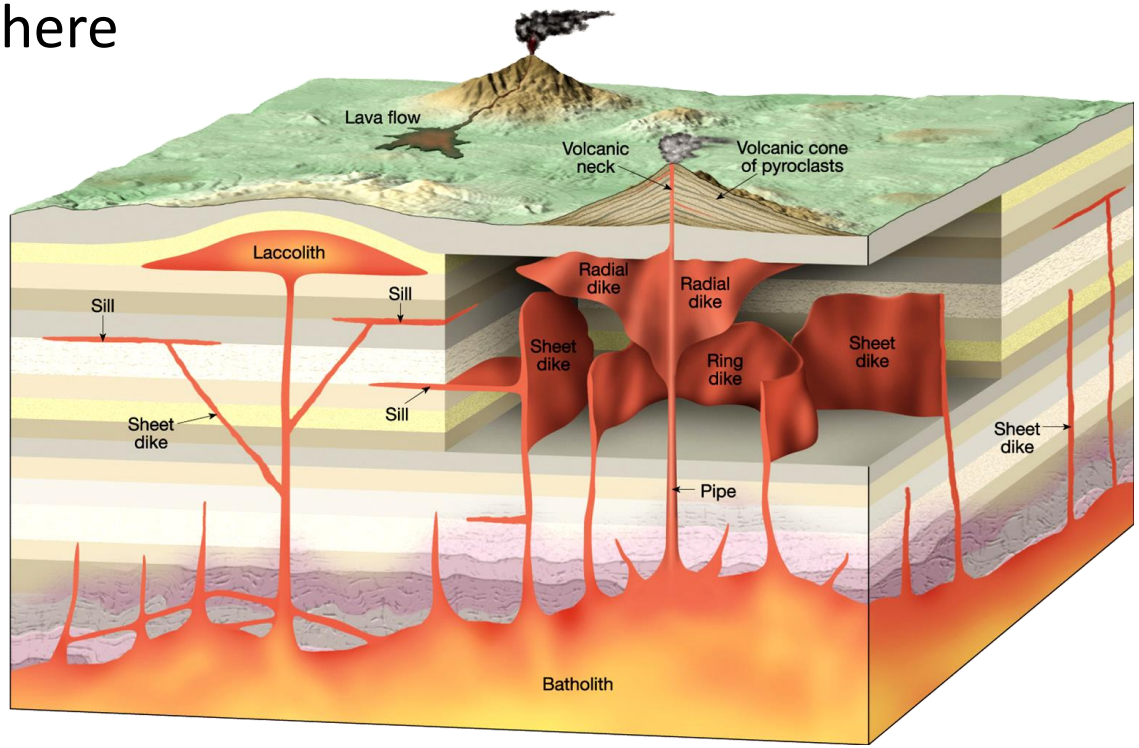
In summary

- The interior of Earth is all solid (but the outer core)
- magma forms under exceptional circumstance by partial melting of lower lithosphere and mantle rocks only under 3 conditions:



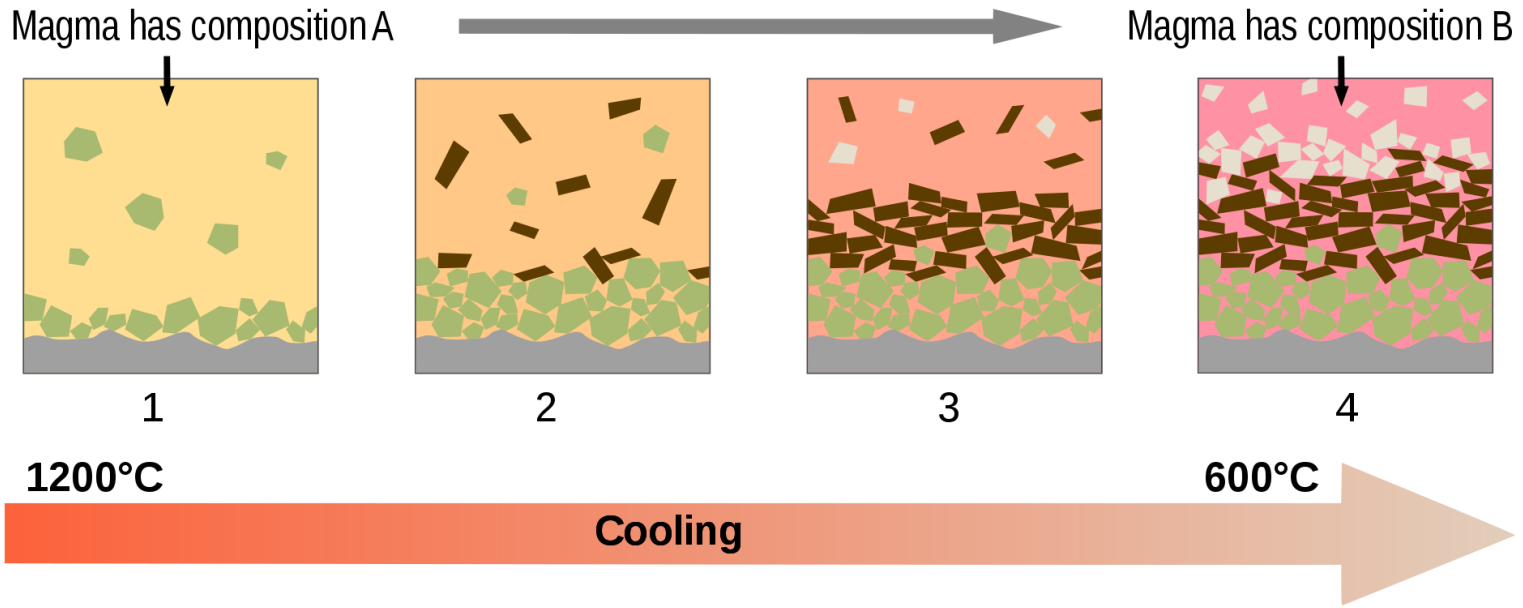
What magma does

- Magma rises/moves upward: it is hot and buoyant → as soon as it forms, it tends to rise to the surface of Earth by breaking through the rocks of the lithosphere (a.k.a. country rocks)
- Only a small % of magma makes it to the surface, most Magma it cools down below the surface of Earth, within the lithosphere



From magma to igneous rocks

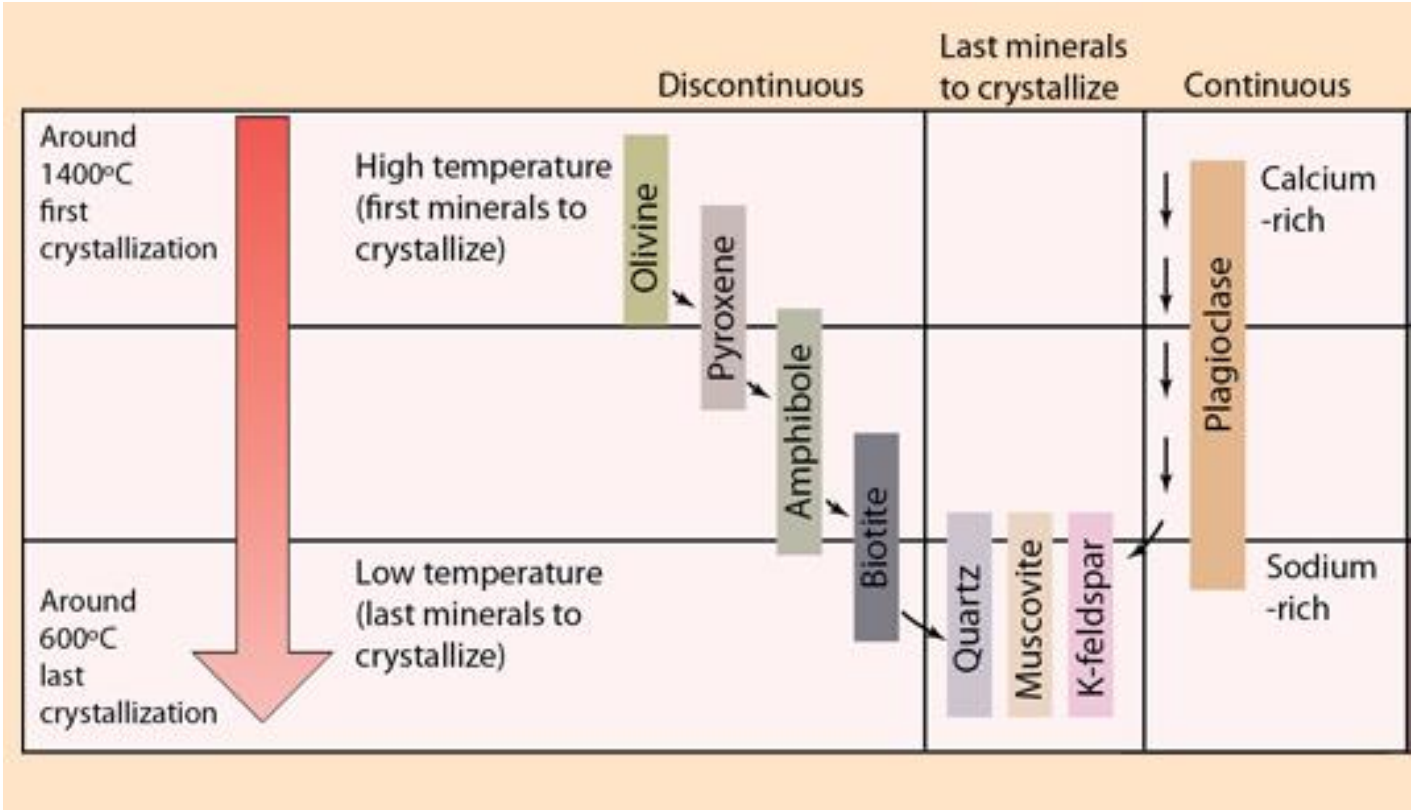
- As Magma rises, it starts to cool down → its components arrange themselves into the orderly crystalline structures of the silicate minerals
- The silicates crystallize in a sequence controlled by decreasing temperature. This way of cooling down is called fractional crystallization



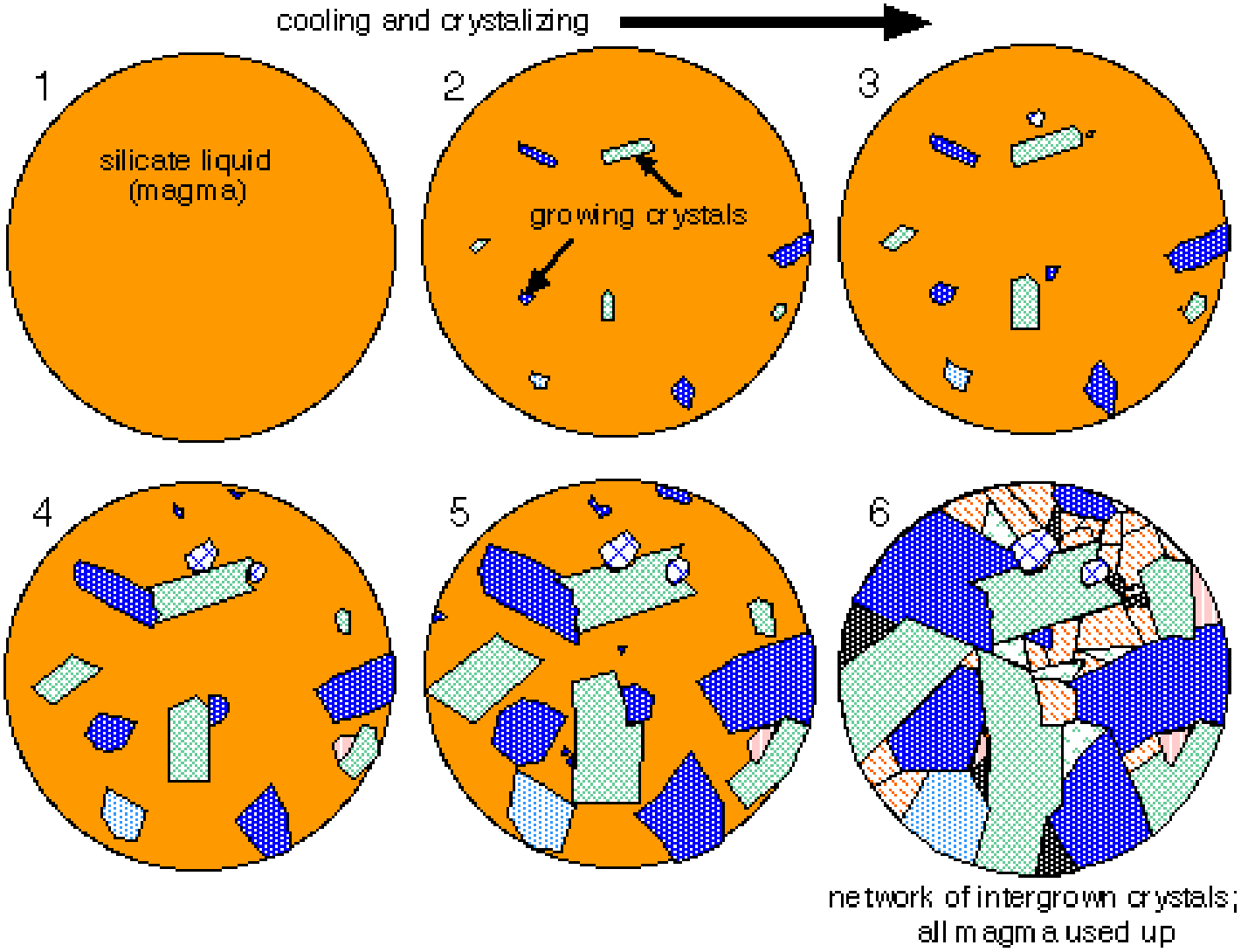
Magma crystallization rules (Bowen's series)

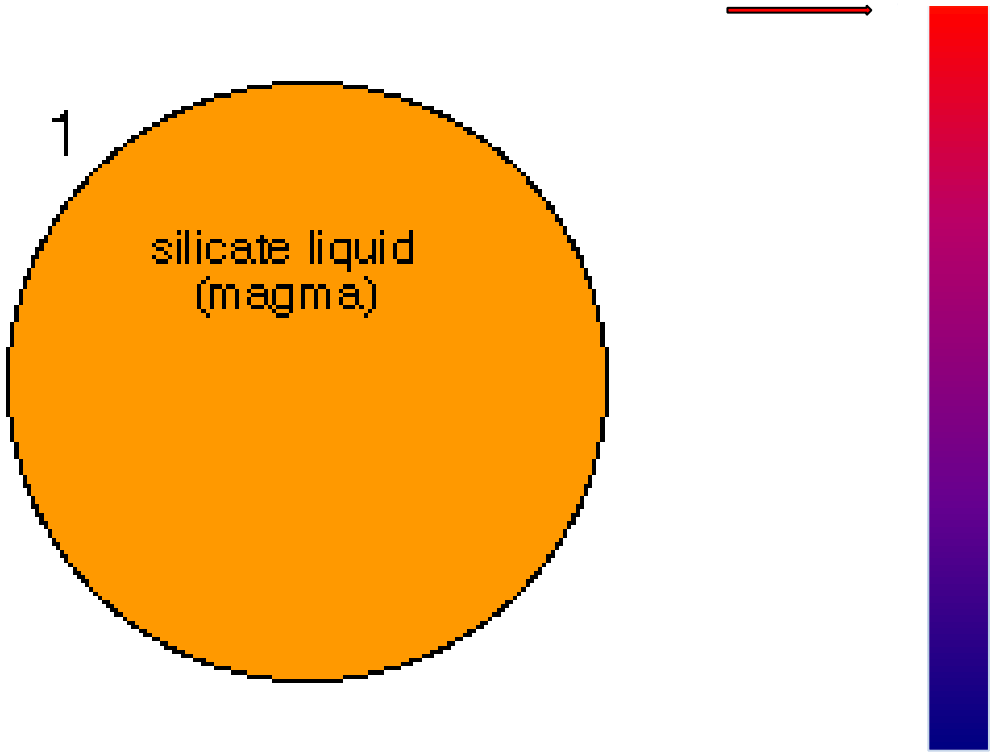
With temperature decreasing, two sets of silicates form:

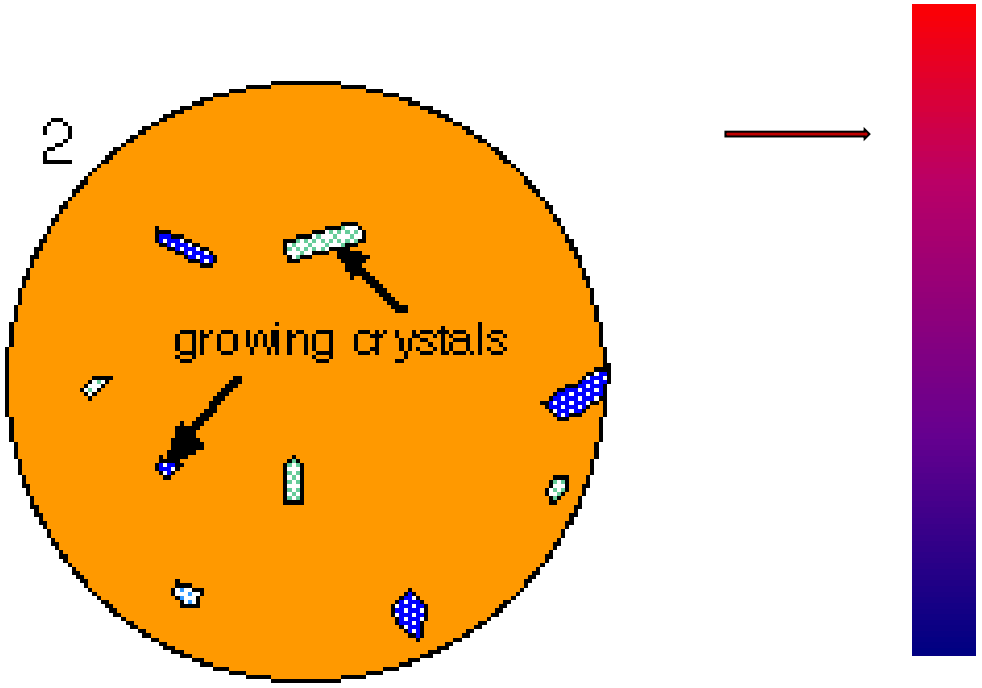
- the MAFIC TEAM discontinuous series (olivine→ pyroxene→ amphibole → Biotite
- the PLAGIOCLASE TEAM
- The last to crystallize at lower temperature, the last minerals to crystallize are Quartz, Muscovite and K-feldspar

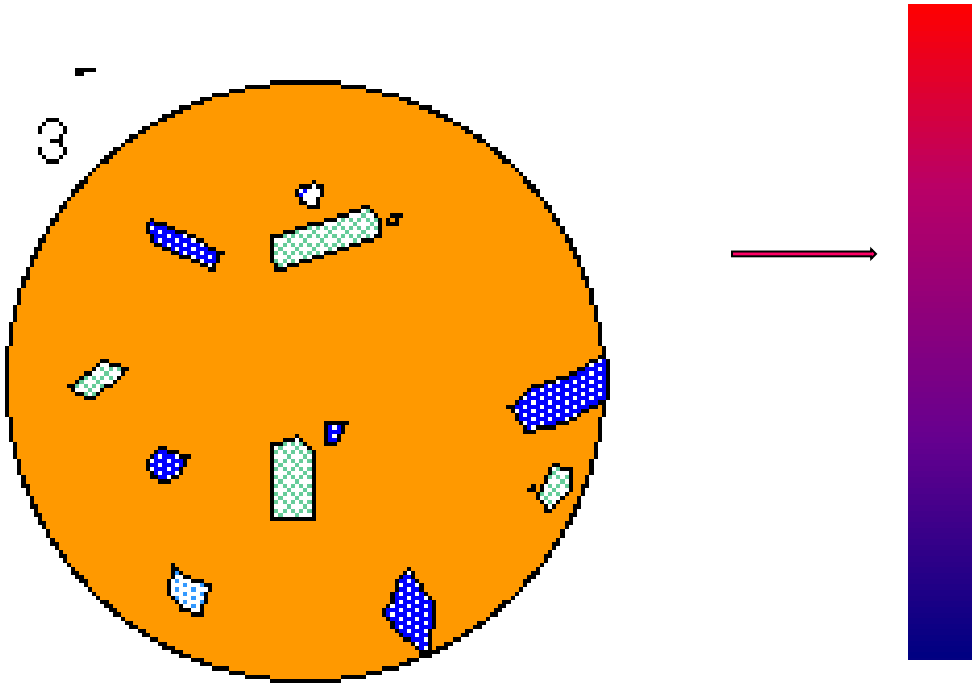


- As Temperature decreases, more minerals crystallize following Bowen's rule




1
silicate liquid
(magma)


2
growing crystals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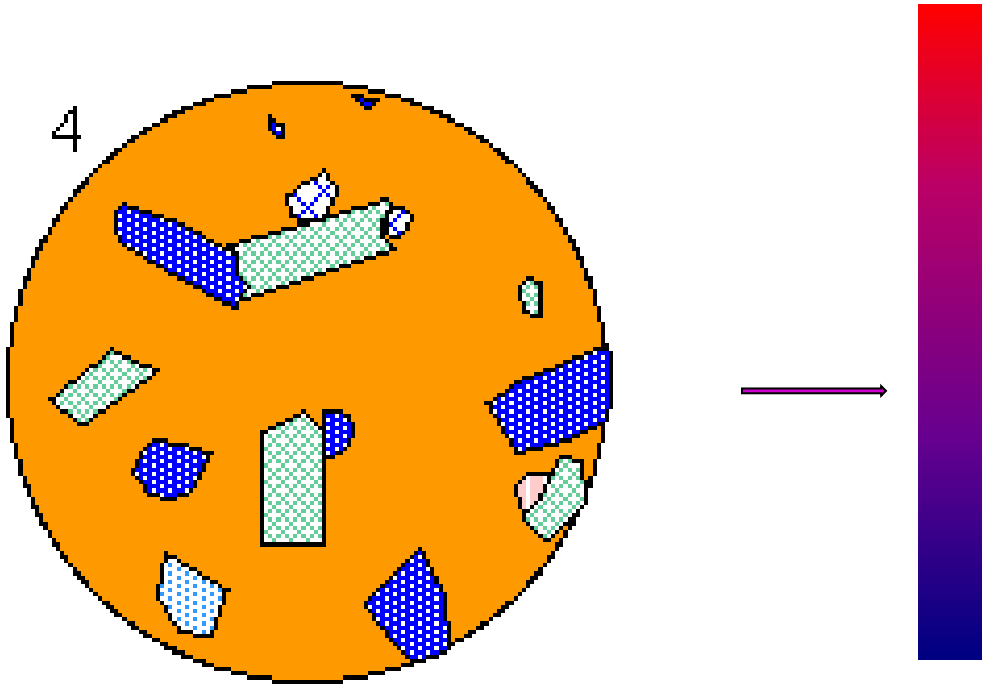
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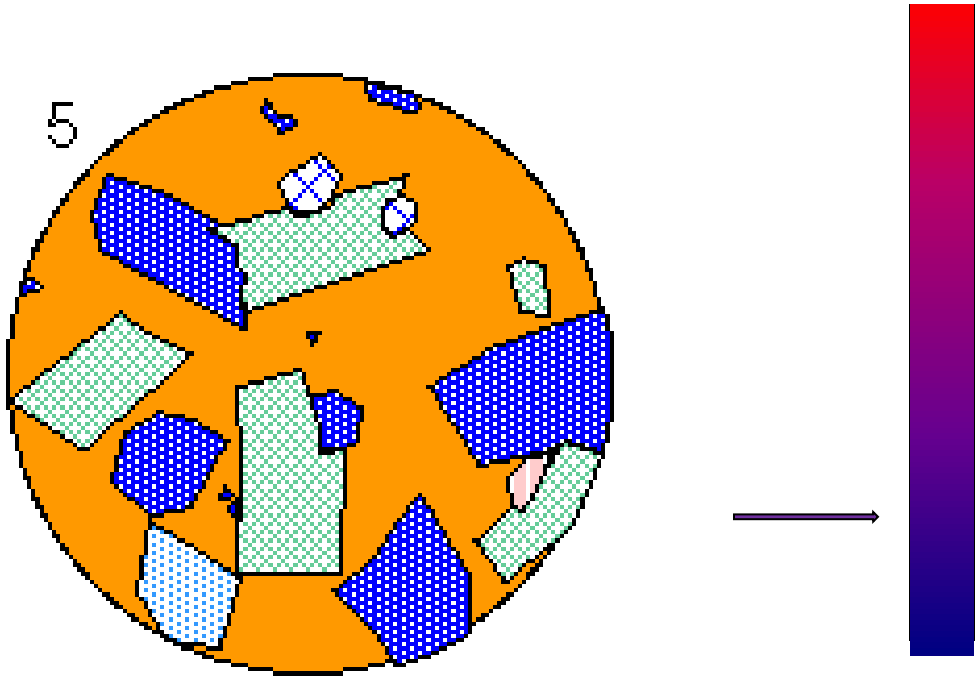
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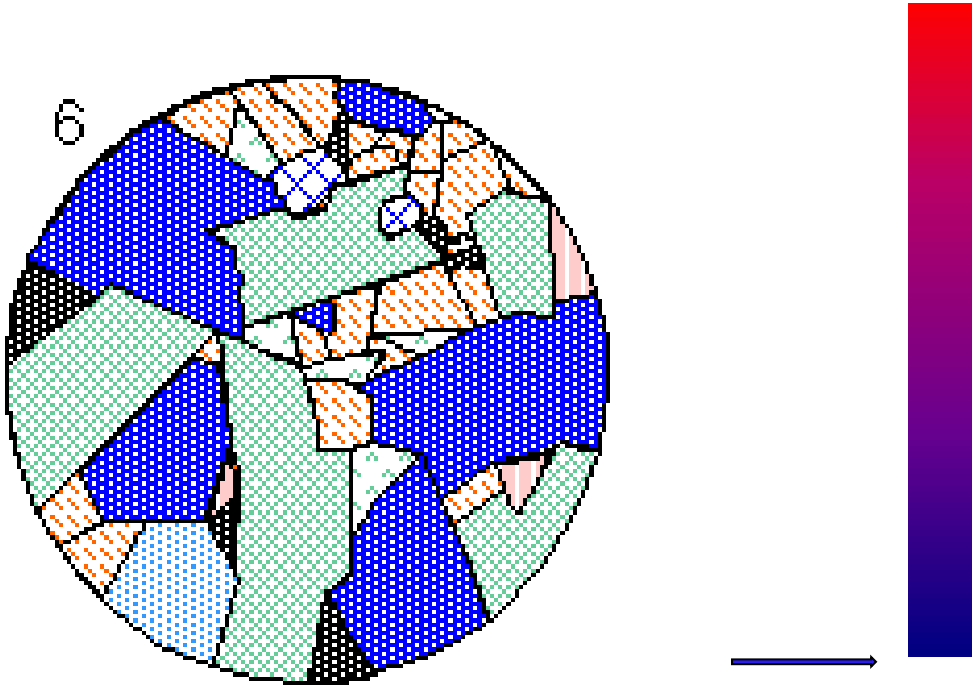
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Texture: appearance of igneous rocks

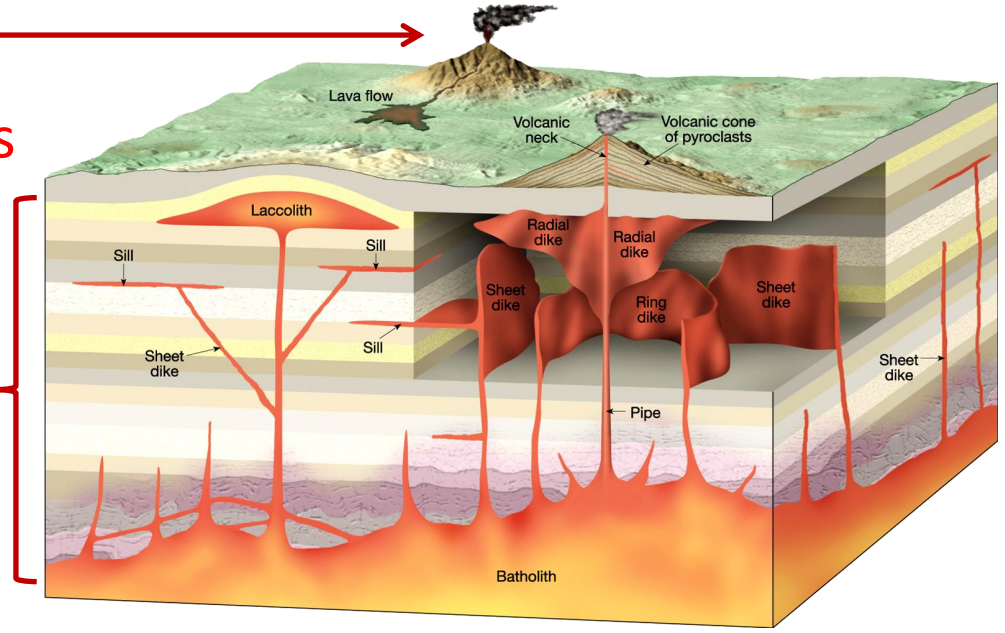
The appearance of igneous rocks depends on how fast the temperature of the magma drops

- Surface cooling

Temperature drops fast

Many crystals form

→ extrusive (volcanic) rocks



- Underground cooling:

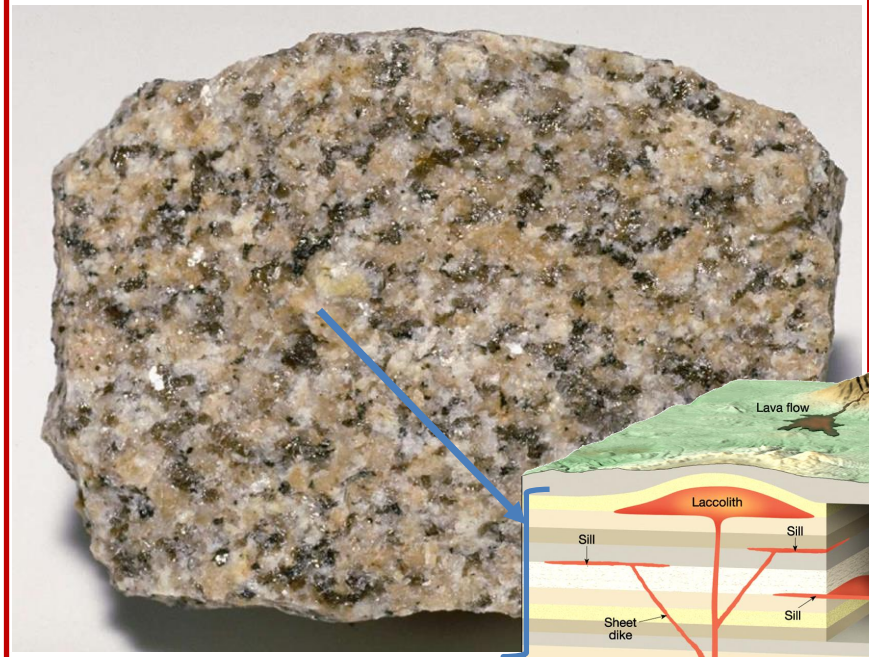
The magma cools down slowly, fewer but larger crystals form

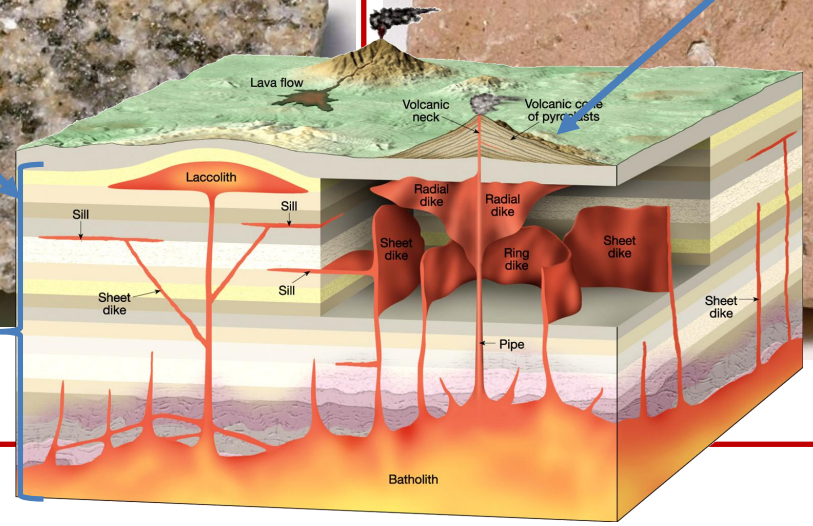
→ Intrusive (plutonic) rocks

Igneous rocks by texture

Slow cooling rate

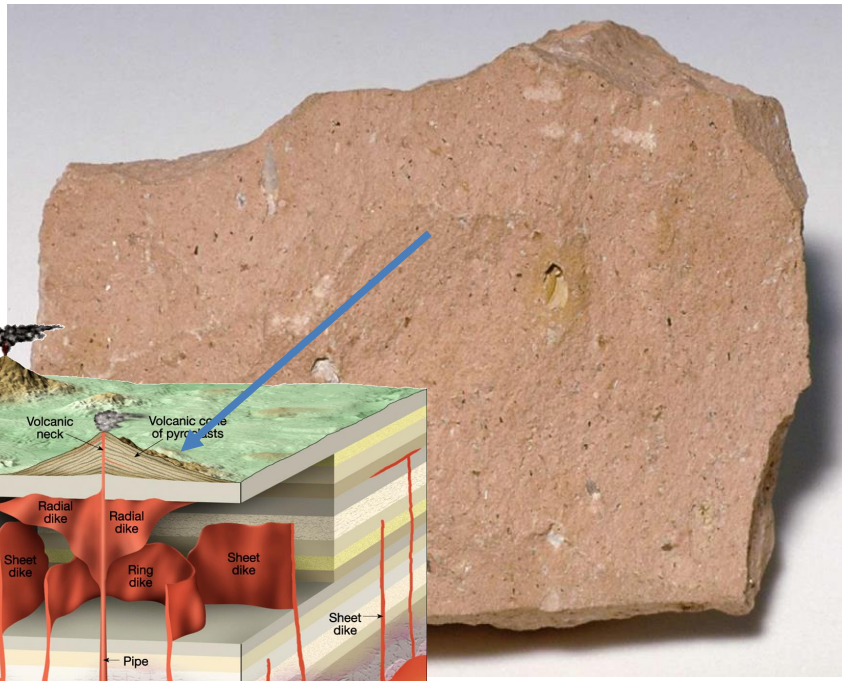
Visible crystals => coarse grained: phaneritic





Fast cooling rate

Microscopic crystals => Fine grained - Aphanitic

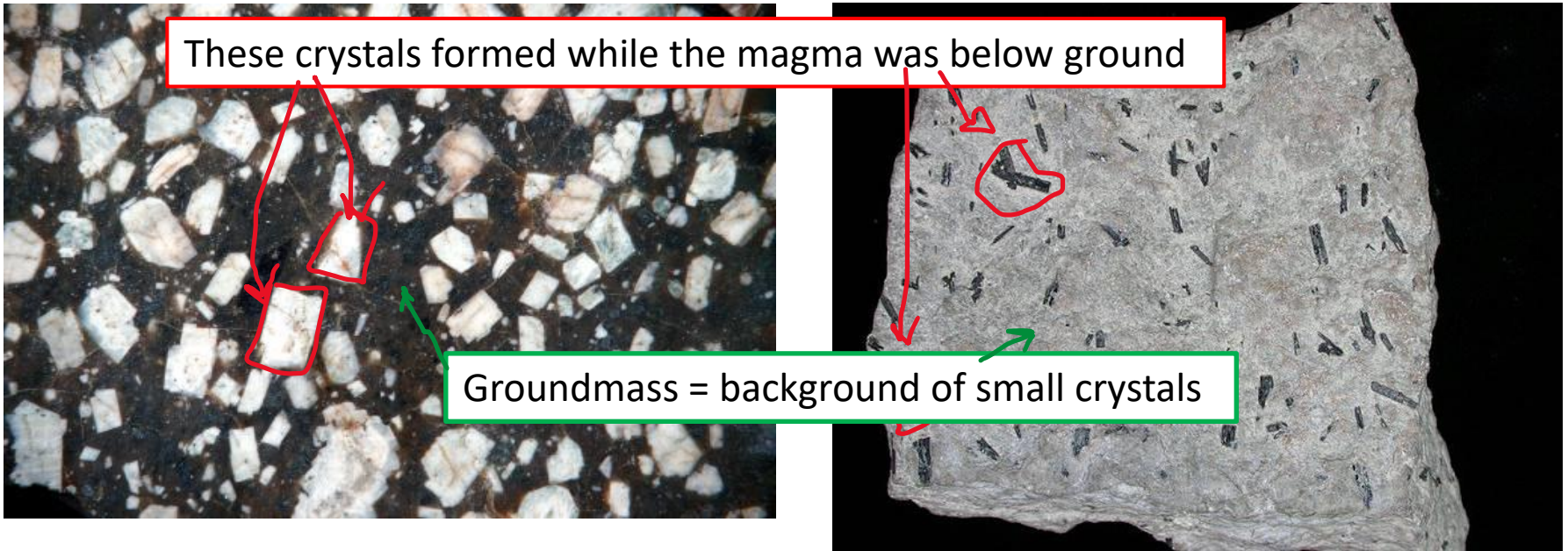


PORPHYRITIC texture (mixed cooling)

STEP 1 - Cooling starts when the magma is below ground – slow cooling forms larger crystals

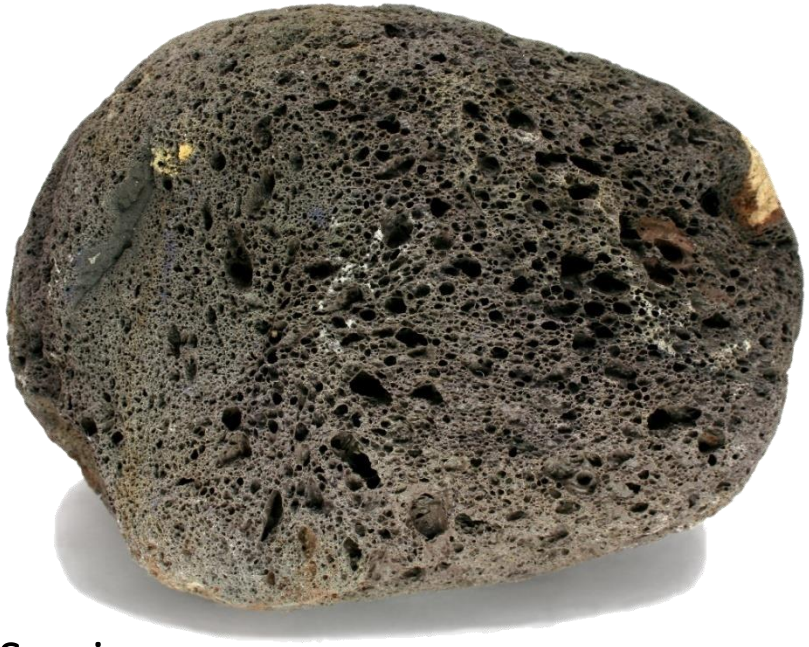
STEP 2 - Gas expands → pressure increases → eruption of lava + the crystals already formed in step 1

- Fast cooling of lava on the surface: crystals remains very small and form the groundmass

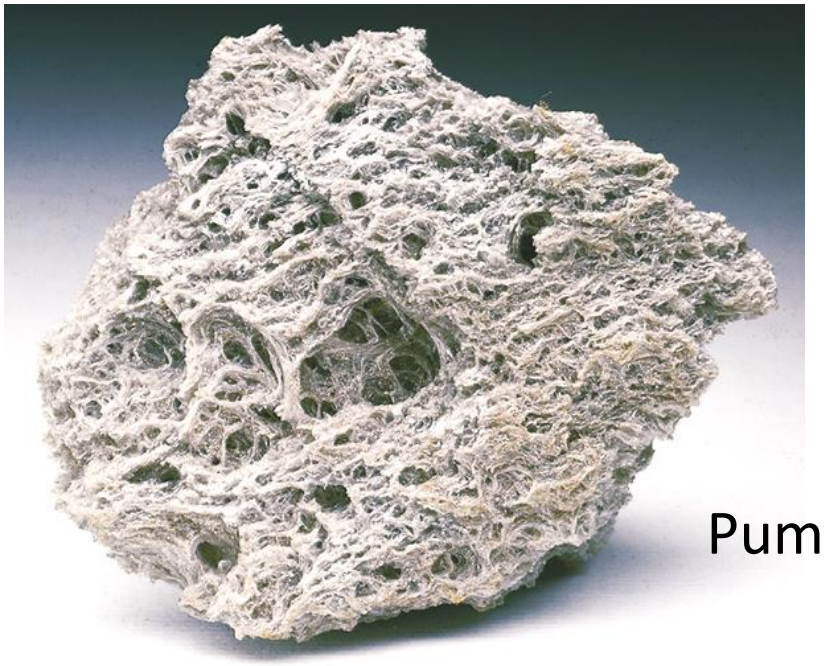


VESICULAR texture: an effect of volatiles

(volatiles) gases escaped, leaving “holes” behind



Scoria

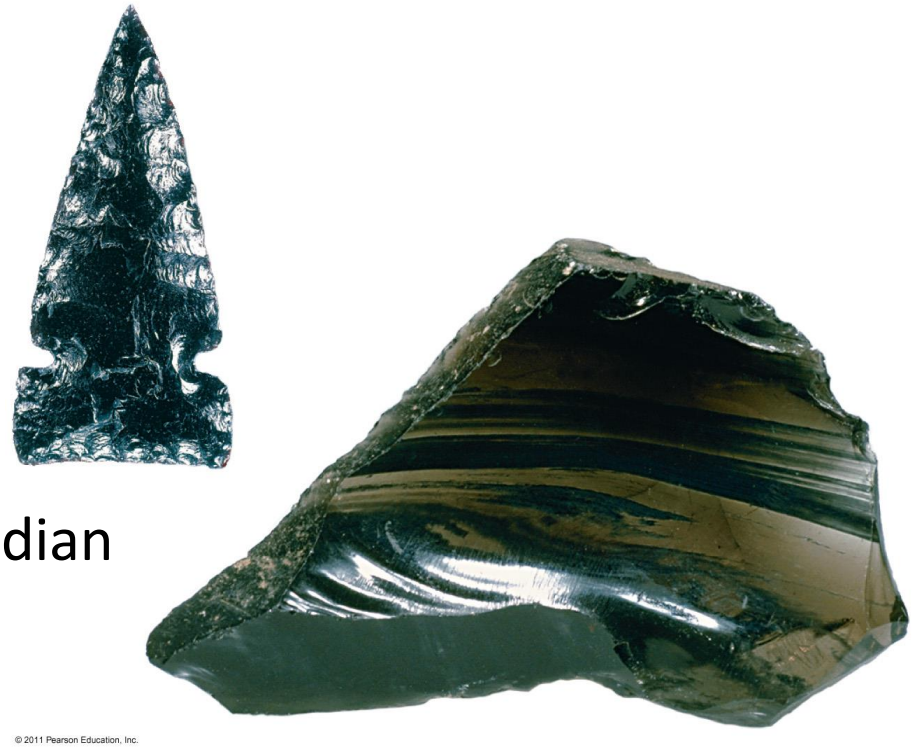


Pumice

The foamy top of a soft drink is a good analogy for the vesicular texture

Glassy texture: Fast cooling and no volatiles

- Crystals don't have "time" to grow → Glass forms



obsidian

a carbonated beverage goes flat by degassing, this is an analogy for the glassy texture

Igneous rocks by composition

The composition of igneous rocks depends on the temperature of crystallization, as shown by the Bowen's series.

The classification depend on the relative amount of mafic and felsic silicates

- Dark (Mafic - ferromagnesian) silicates
  - Contain mostly dark silicates
- Light (Felsic – feldspar and silica) silicates
  - Contain mostly light silicates

Extreme rocks: Ultra-mafic composition

- Composed entirely of Mafic silicates
- Peridotite – is the intrusive rock that makes up most of the Lithospheric mantle

Basaltic Mafic composition

- Dark silicates + calcium-rich feldspar
- Mostly Mafic High density
- These rocks make the oceanic lithosphere
- Gabbro (intrusive)

Basalt (extrusive)

Intermediate (Andesitic) Composition

- Contain at least 35% of either felsic or mafic silicates
- Associated with explosive volcanic activity
- Most common at convergent plate boundaries where plates collide and volcanoes form,

Diorite (intrusive)

Andesite (extrusive)

andesite is mostly porphyritic

FELSIC (Granitic) composition

– Light-colored = Felsic (*fe*ldspar and *si*lica)

– High silica (SiO_2) content

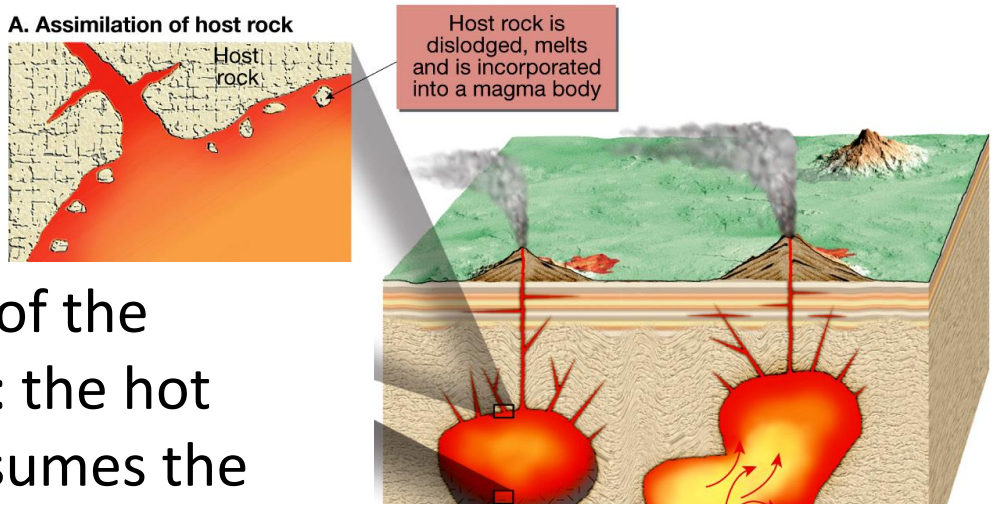
– Most common rock of the continental crust

Granite (intrusive)

Rhyolite – (extrusive)

What else happens to magma on its way to the surface

- In addition to fractional crystallization, magma can interact with local rocks in which it intrudes, assimilating them; it can also mix with new forming magma

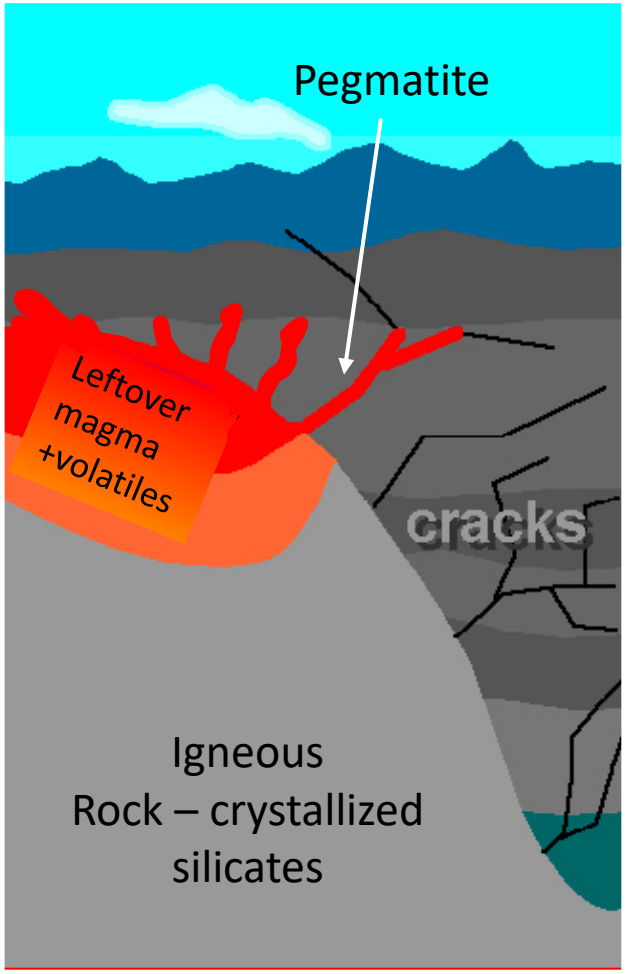


Assimilation of the country rock: the hot magma consumes the rocks around it

Mixing of magmas formed at different points but that ended up nearby

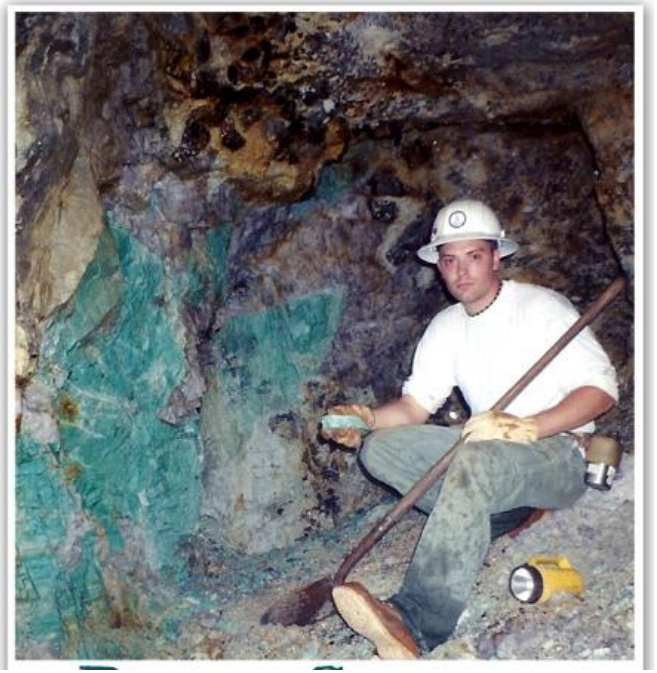
Pegmatites: the leftovers

- When magma doesn't erupt, it crystallizes below the surface, leftovers pools on top of the already crystallized parts
- Magma leftovers consists of
  - Silica tetrahedrons
  - many chemical elements and molecules that did not form the silicates of the Bowen series.
  - volatiles that expand easily, producing fractures in the surrounding rocks.
- This leftover magma seeps into cracks where it crystallizes into rocks with huge crystals called Pegmatite



Importance of Pegmatite

- Minerals of pegmatites are often rare and economically important (gold, silver, copper, Rare Earth Elements-bearing minerals, gems, etc.)



Virginia, Morefield mine
The blue-green mineral is a feldspar

watermelon tourmaline @NMNH

Eudialyte bearing REE

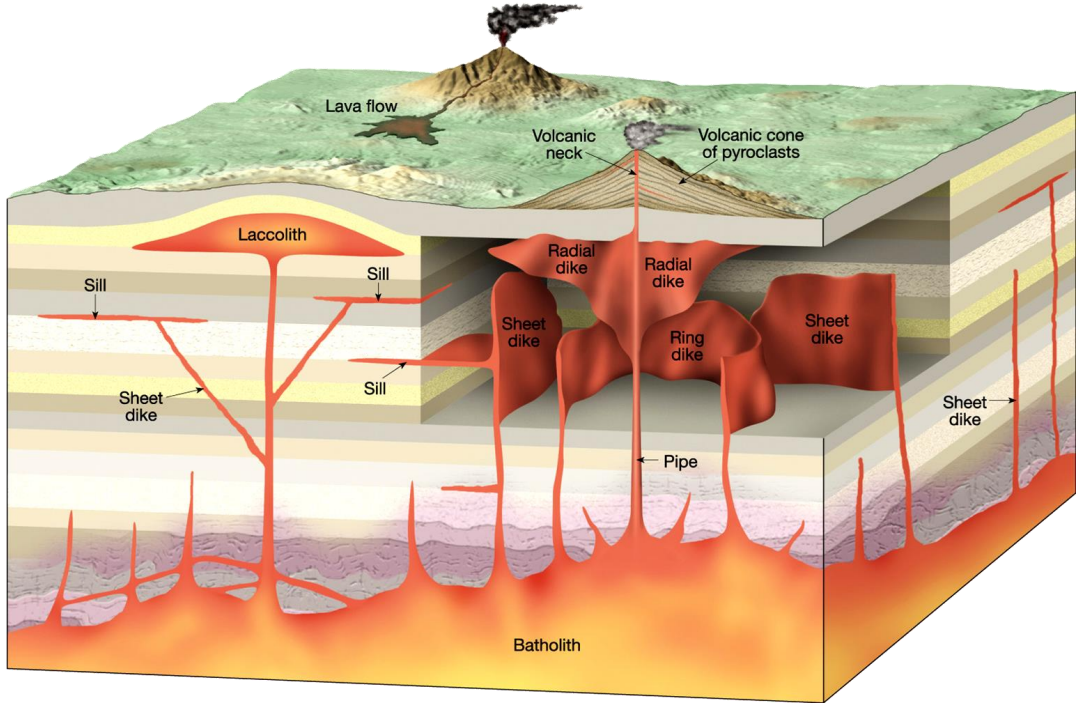
Pegmatite GOLD

- Gold is in the magma but it doesn't form silicates
- Gold concentrates in the magma leftovers and it crystallizes with the last of silica

Native gold is found in paragenesis with quartz

INTRUSIVE STRUCTURES

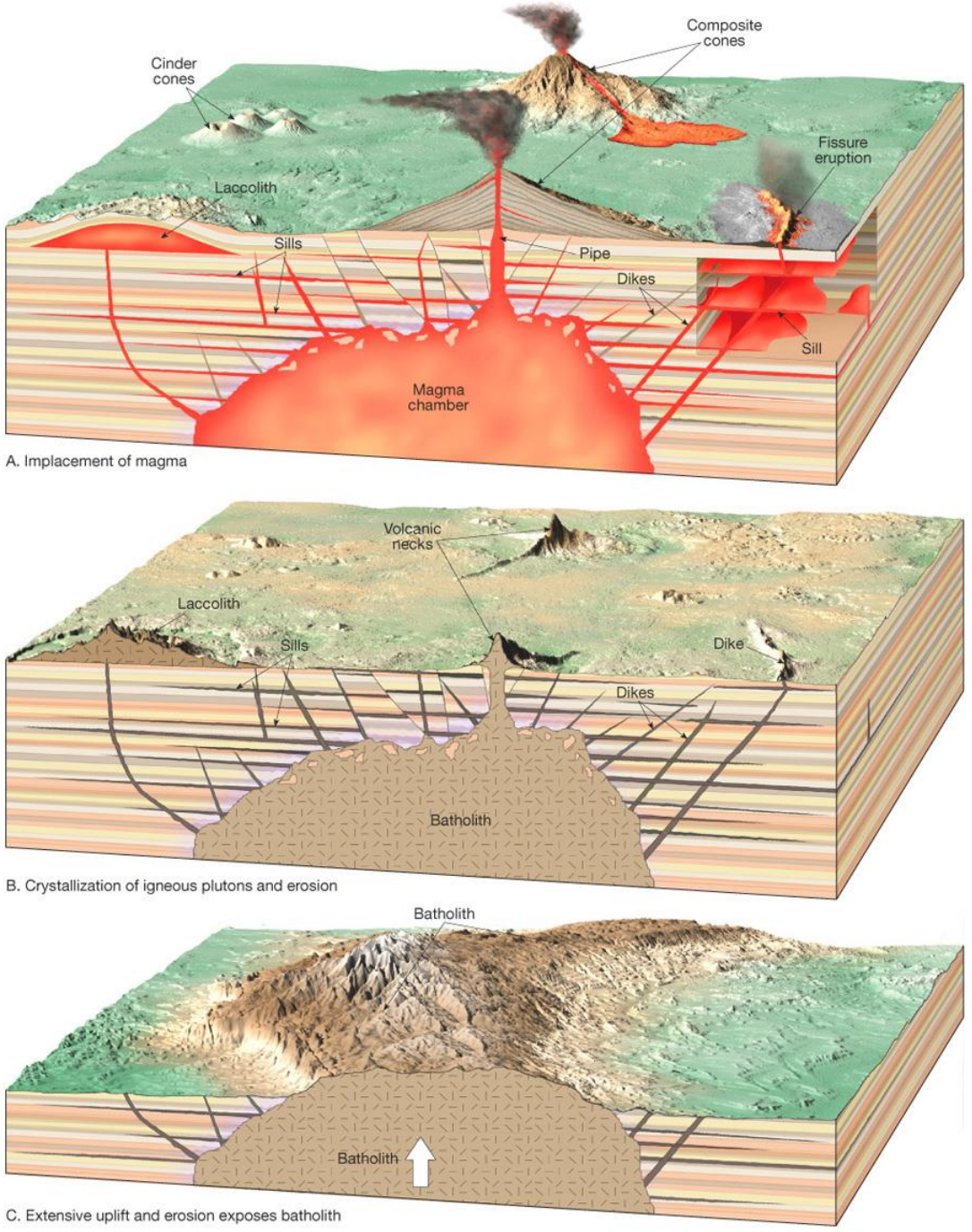
- Most magma never makes it to the surface, only a small percentage of magma erupts
- Magma crystallizes below ground forming large body of rocks called Intrusive Igneous Structures



INTRUSIVE STRUCTURES

As magma stops forming everything cools down.

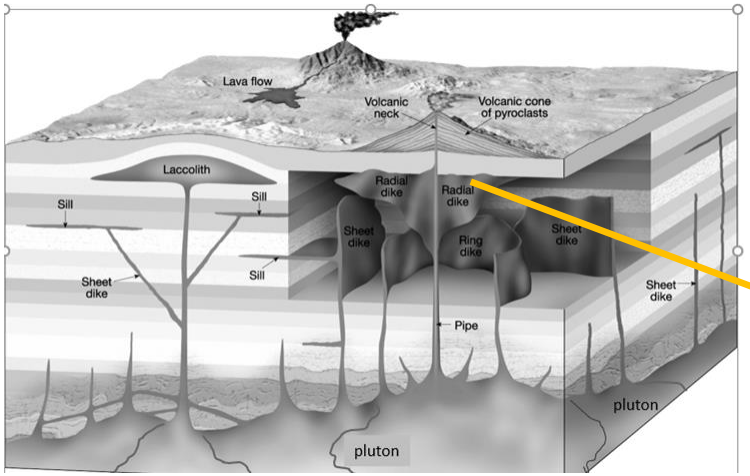
In time, erosion of the surface and uplift by isostasy lithosphere will bring to the surface the intrusive rocks, starting with the shallower ones.

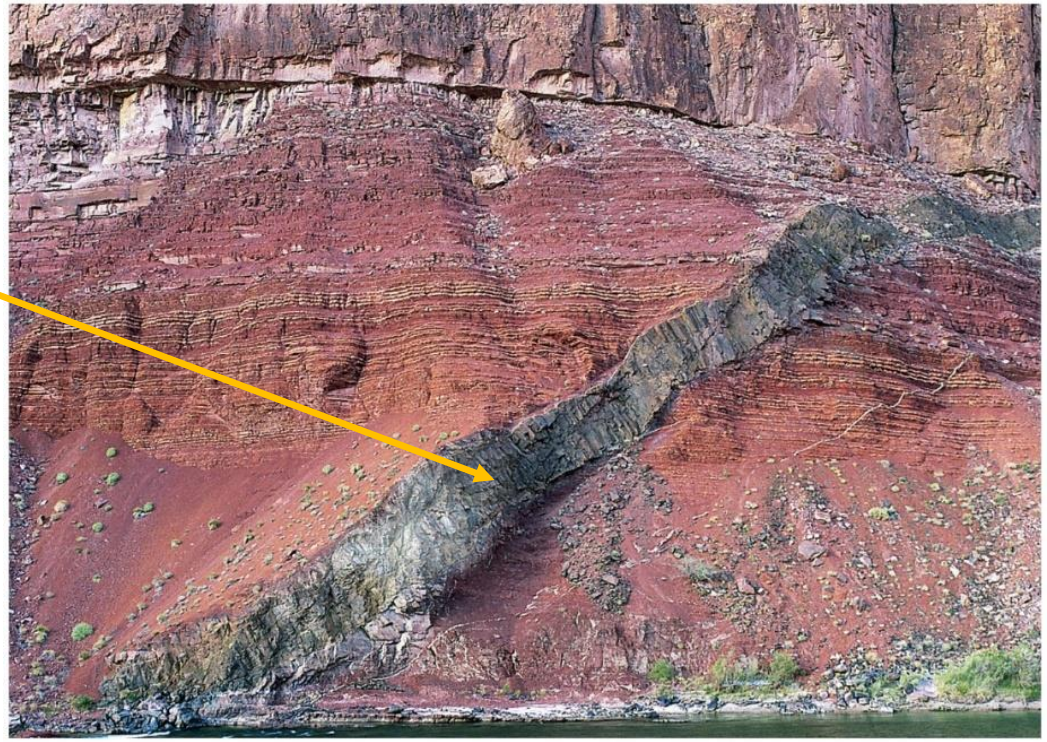


Dikes

A dike forms when ascending magma fills fractures on its way to the surface

dikes have a tabular, irregular shape





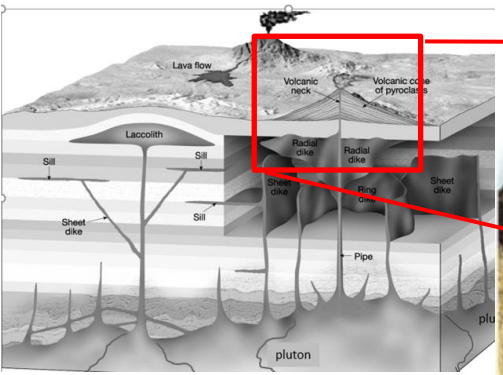
- A dike from Spanish Peaks, Colorado. It looks like a wall, but it is a natural intrusive igneous structure.

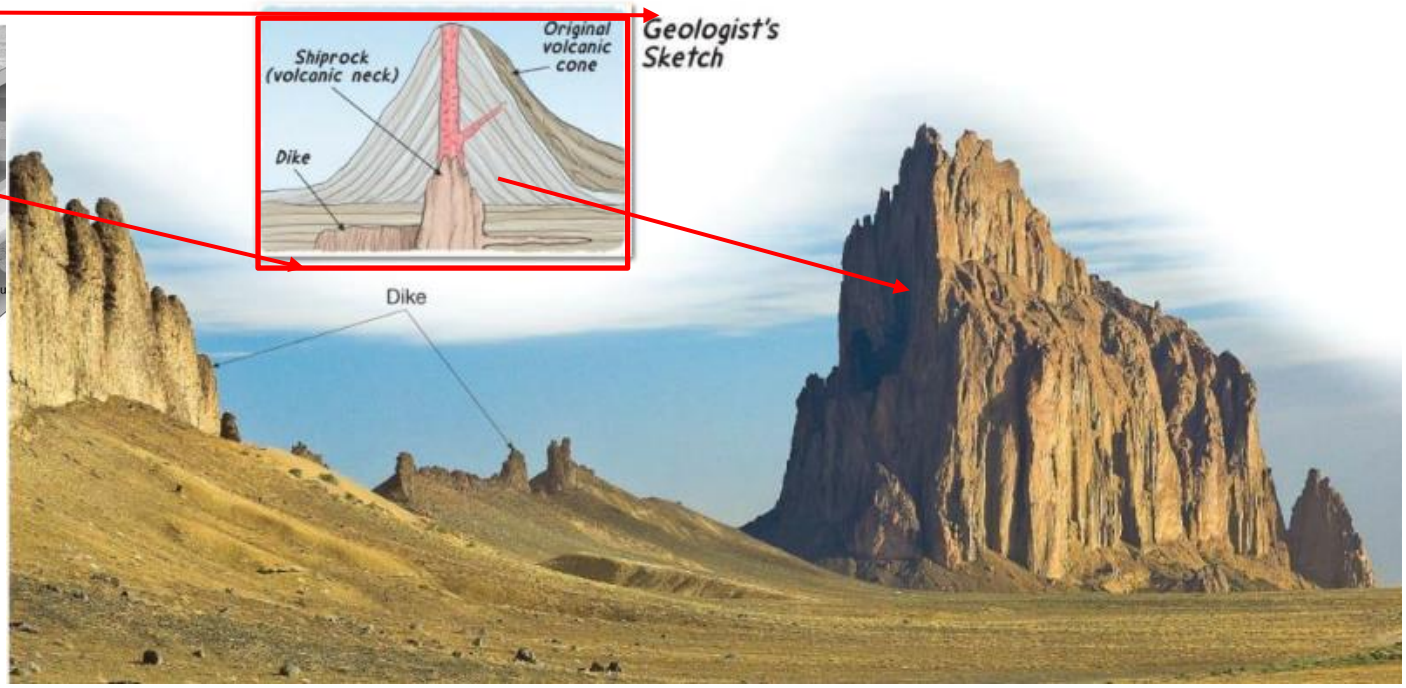
- Dikes always form in group, if you see one, there are other ones nearby

- When the dikes are thin and irregular they are called VEINS

Volcanic necks or plug

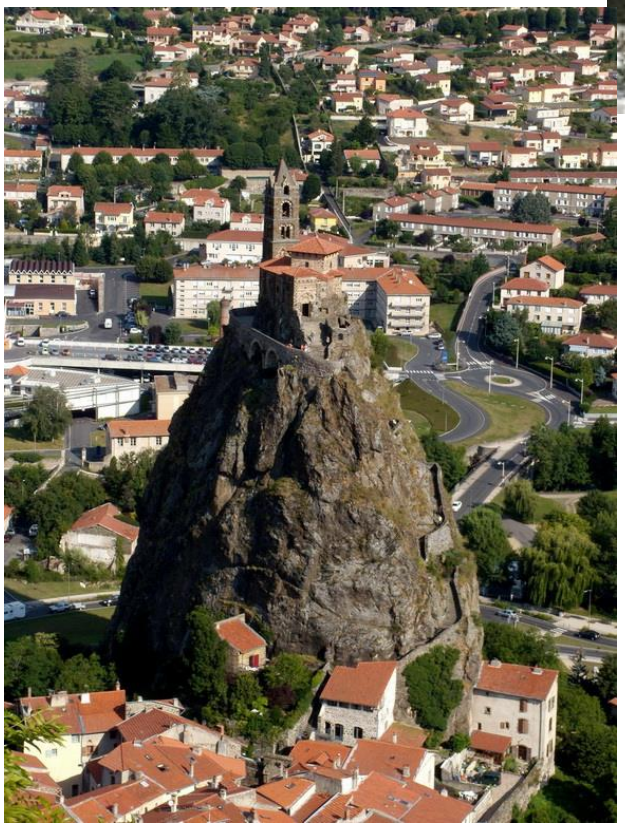
When several dikes join, into one centralized structure, they can break through the crust and erupt to the surface as a conduit for lava that forms a volcano. Once the volcano erodes away, the leftover of the conduit becomes visible as a volcanic neck/plug where it made a volcano.





Shiprock, NM is an example of a volcanic neck. The volcano weathered and the neck remained

Devil's Tower National Monument, W



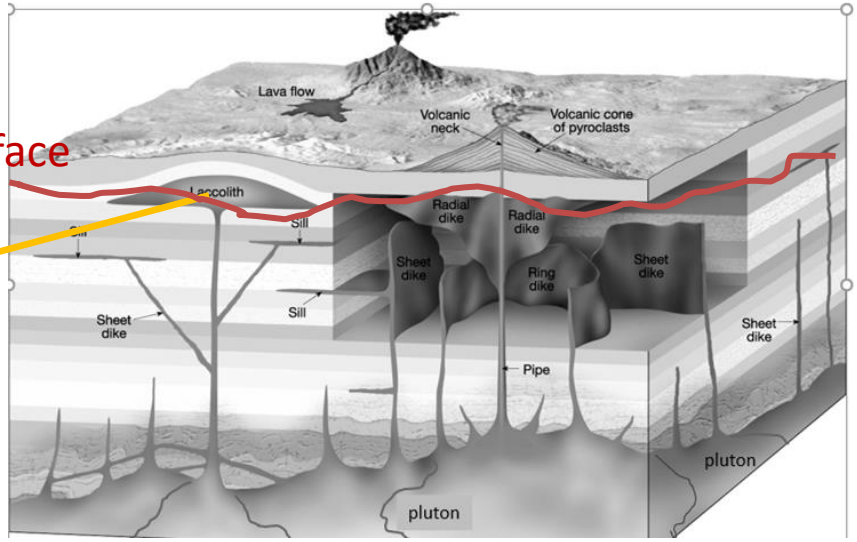
San Michel D'Aguilhe, France

More of these unique landforms

Sills and Laccoliths

- Magma spreads between layers of rocks forming shallow intrusive rocks that form in between layers of country rocks

Erosion surface

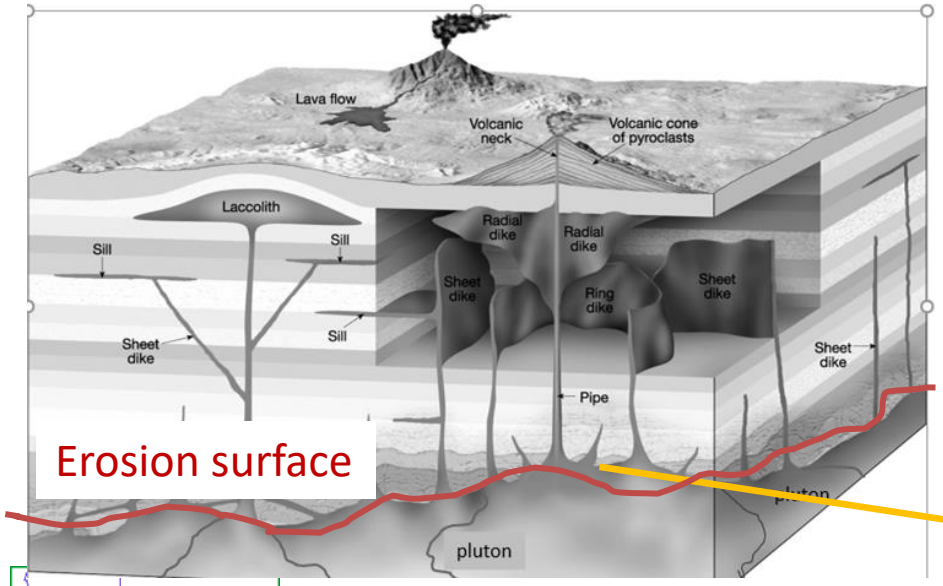


Building stone quarries in Fairfax

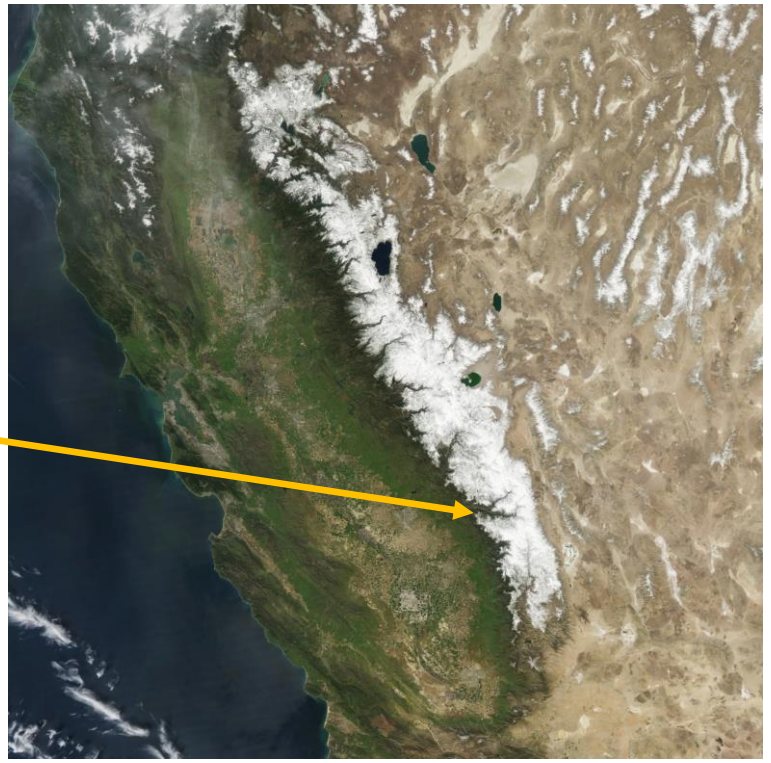
These rocks are very important mineral resource

Plutons and batholits

- Plutons are the deepest portions of the crystallized magma. st
- Many plutons together form a Batholith
- It can take a 100 million years, but eventually, even the deeper Igneous structures like plutons and batholiths can be brought to the surface by erosion and isostasy



Sierra Nevada Igneous Rock batholith




Yosemite half dome is part of the Sierra Nevada

Old Rag Mt. in the Blue Ridge > 1 by old Batholith. Once it too was a magma chamber