GGY3020

IGNEOUS PETROLOGY

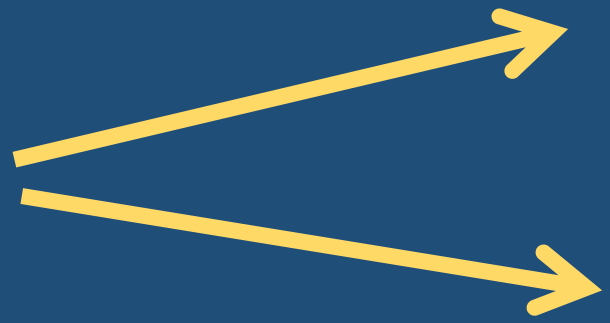
The Earth

and

its Materials

(GGY3020)

Dr. Sakuwaha K



Structure of the Earth

Plate tectonics

Minerals

Igneous rocks

Sedimentary rocks

Metamorphic rocks

Mineral resources

Energy resources

LECTURE

Magma and Igneous rocks

TOPICS TO BE COVERED:

- Magma formation
- Magma composition…
- Classification of igneous rocks
- Common Igneous rocks

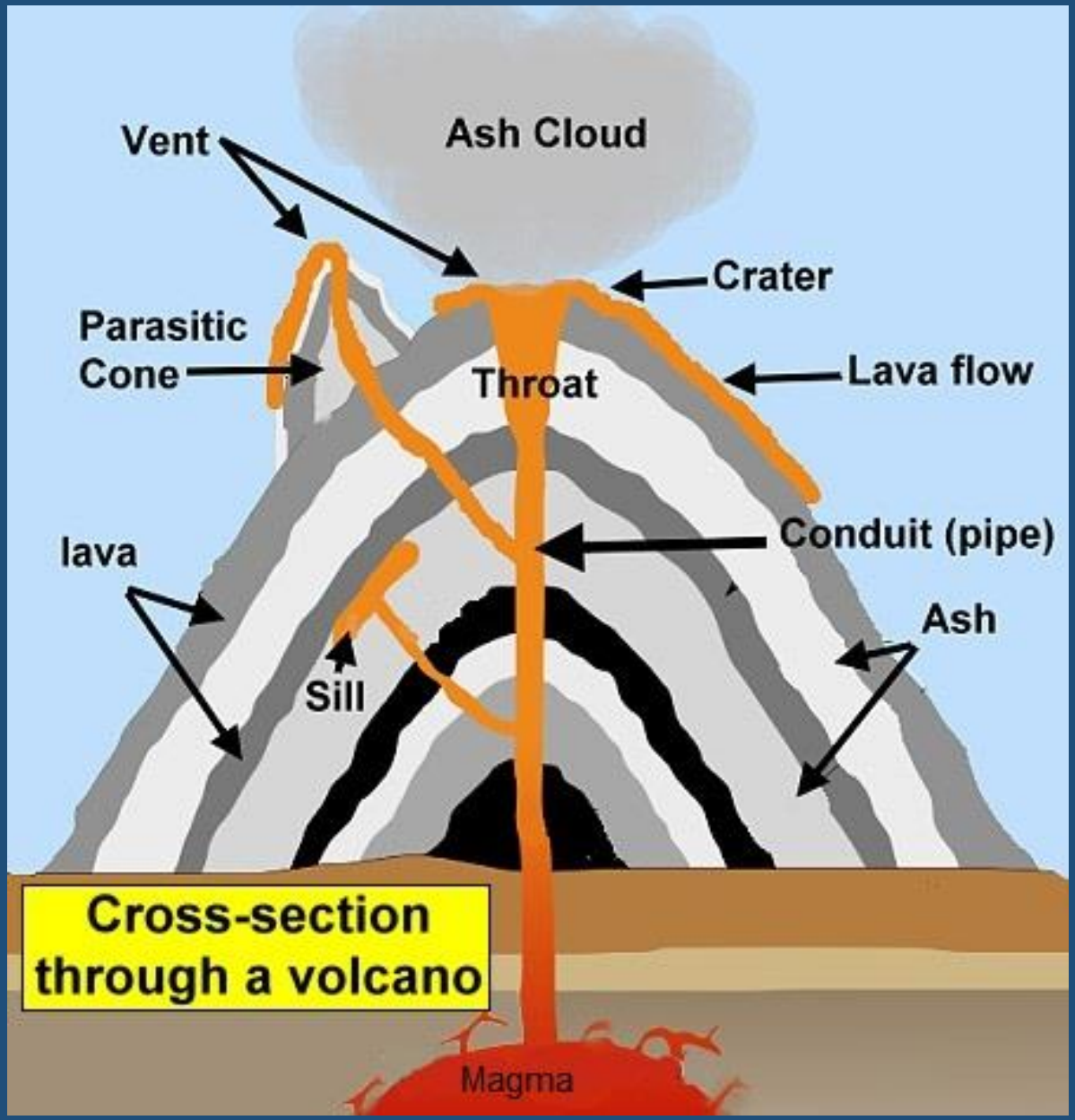
COURSE PHILOSOPHY

- What do we hope to accomplish by studying igneous rocks?
- How do we distinguish igneous rocks from other rock types?

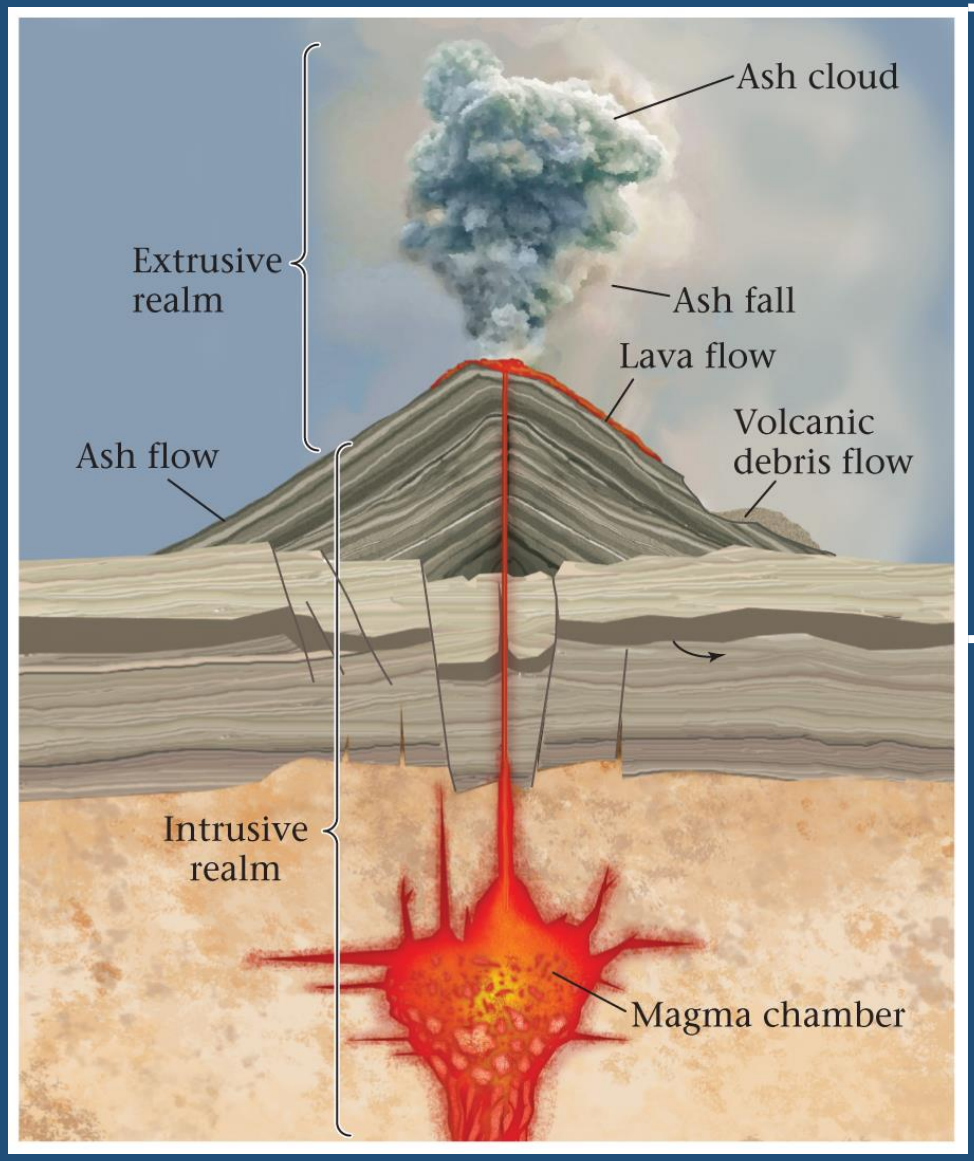
LEARNING TO STUDY IGNEOUS ROCKS HAS MUCH IN COMMON WITH LEARNING A NEW LANGUAGE: DEFINITIONS

- **Petrology:** The branch of geology dealing with the genesis of rocks
- **Igneous rock** is a rock which has solidified from molten material (magma) derived below the Earth surface.
- Igneous petrologists study processes that are involved in melting of different source rocks to generate magmas and evolution of these magmas that eventually give rise to a wide variety of igneous rocks.
- This part of the course focuses on understanding the igneous nomenclature, magmatism and origin of diverse igneous rocks.

Anatomy of a Volcano



MAGMA AND IGNEOUS ROCKS



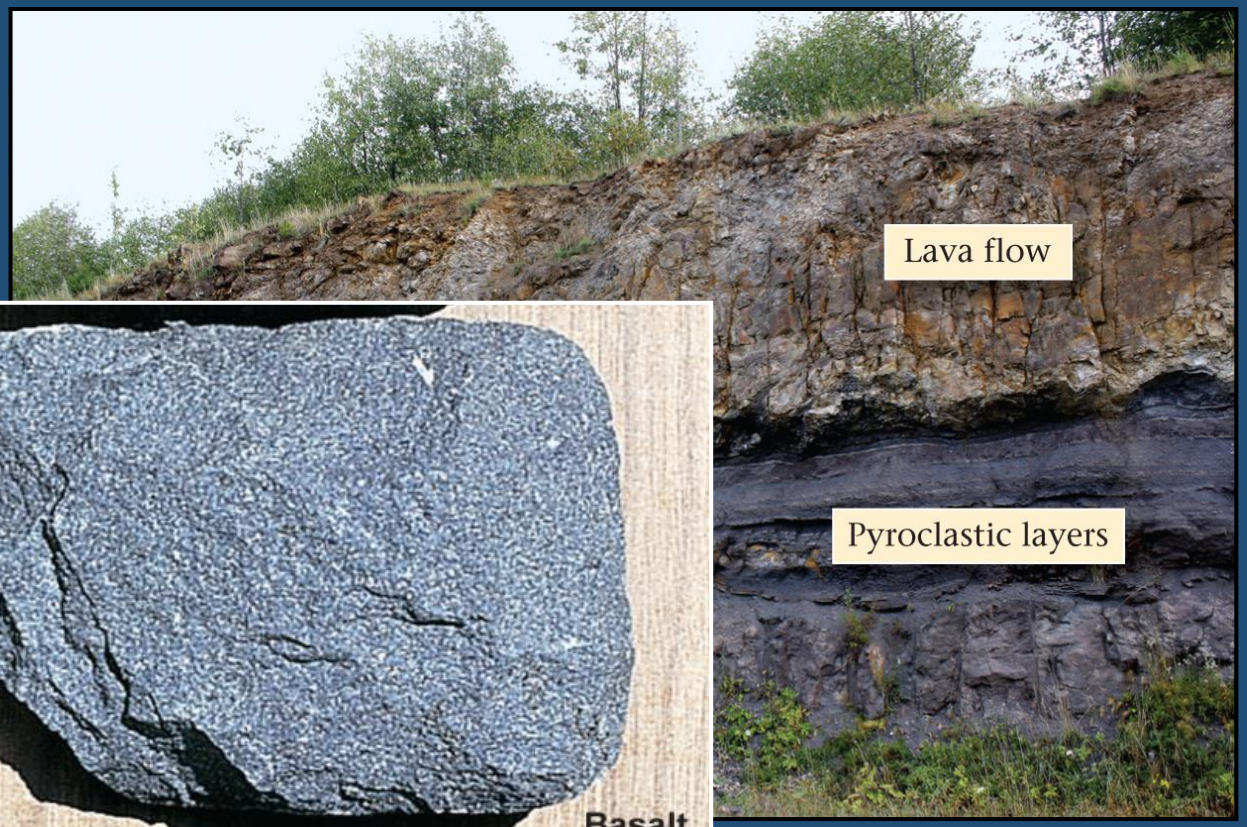
Extrusive Igneous rocks: formed by freezing of lava above ground

Pyroclastic rocks: lithification of ash and volcanic debris

Intrusive Igneous rocks: slow solidification of magma intruded in ancient rocks.

MAGMA AND IGNEOUS ROCKS

Extrusive rocks include lava flows and pyroclastic layers.



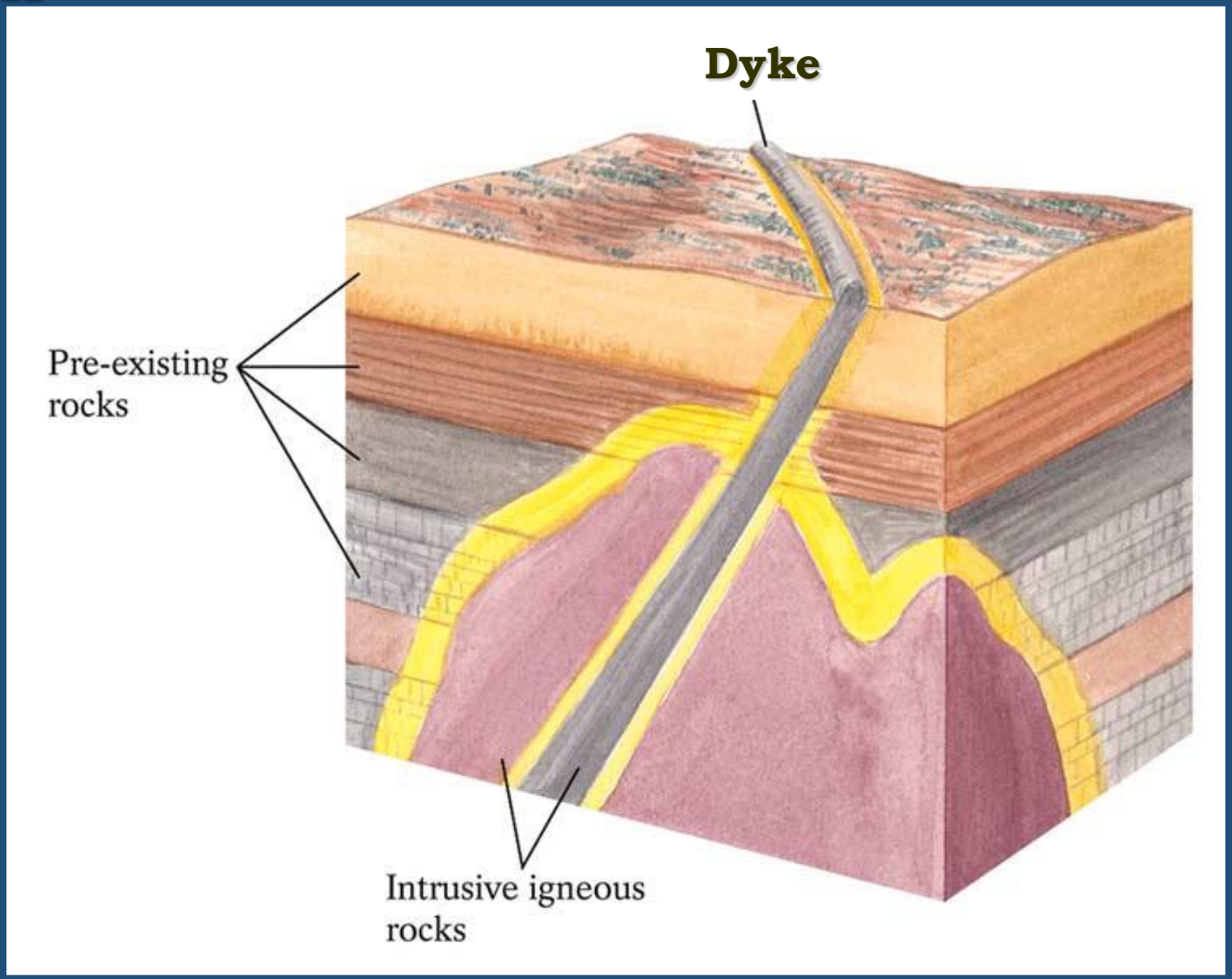
Lava sometimes flows long distances, engulfing anything and everything it encounters. Here, a basaltic lava flow has crossed a road in Hawaii.

MAGMA AND IGNEOUS ROCKS

Over time, lava flows can accumulate one on top of another to create a volcano and raise the level of the landscape. The red coloration derives from a high iron (Fe) content in the lava.

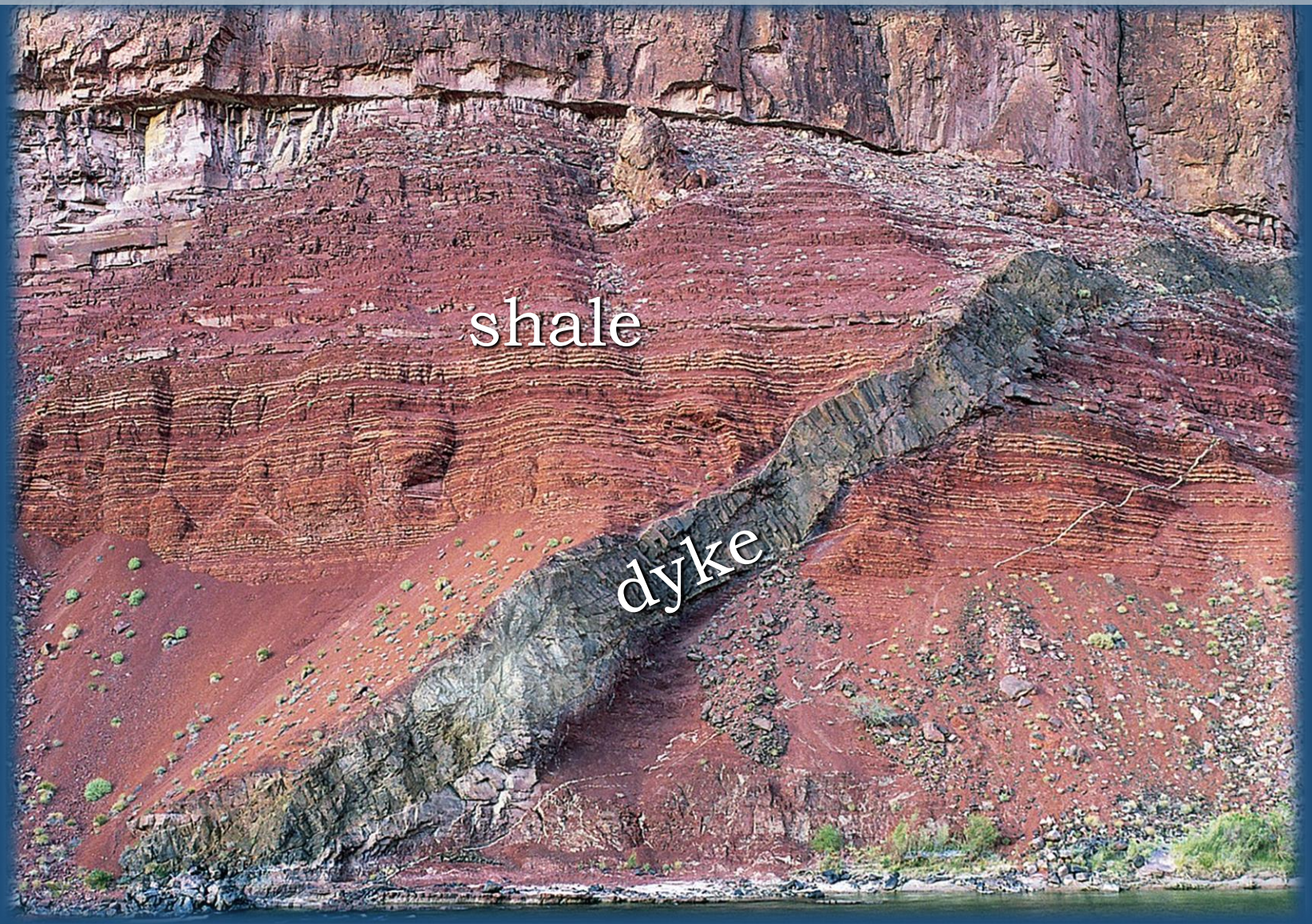
MAGMA AND IGNEOUS ROCKS

Dyke is a fine-grained linear intrusion that cross-cuts (is discordant to) the preexisting rock



MAGMA AND IGNEOUS ROCKS

Dyke cross-cutting (discordant to) a sedimentary rock…

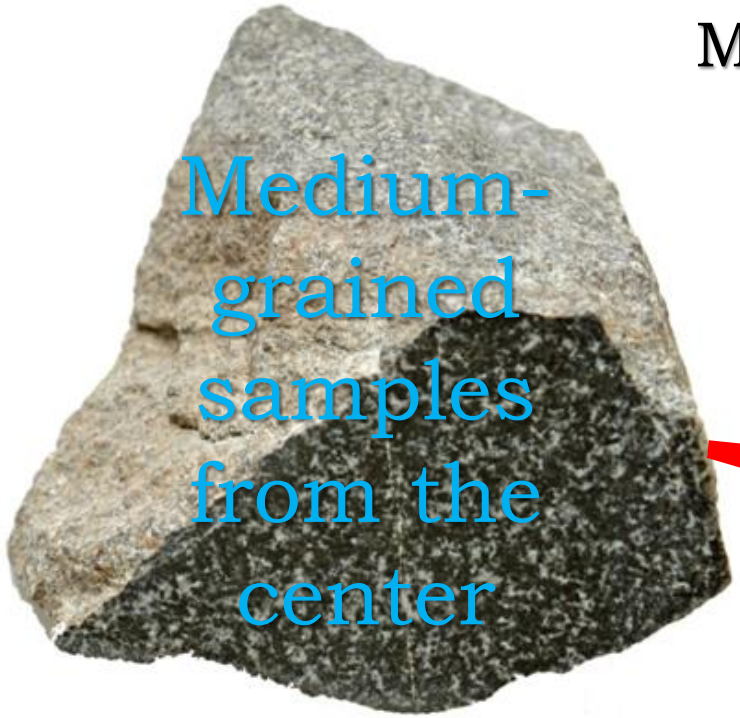


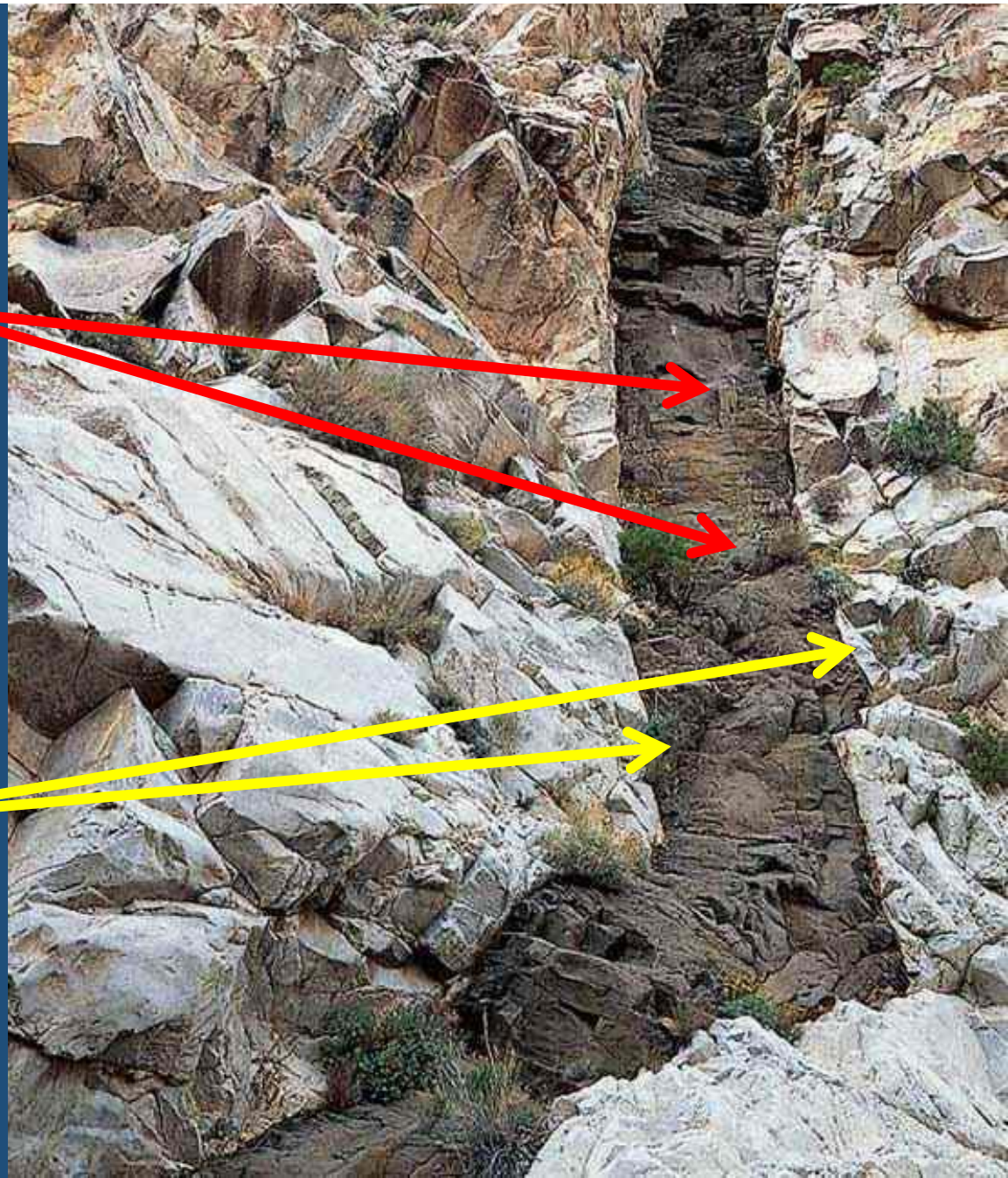
MAGMA AND IGNEOUS ROCKS

Usually, mafic dykes are made up of plagioclase and pyroxene and the rock name is dolerite or diabase

They are shallow intrusive bodies

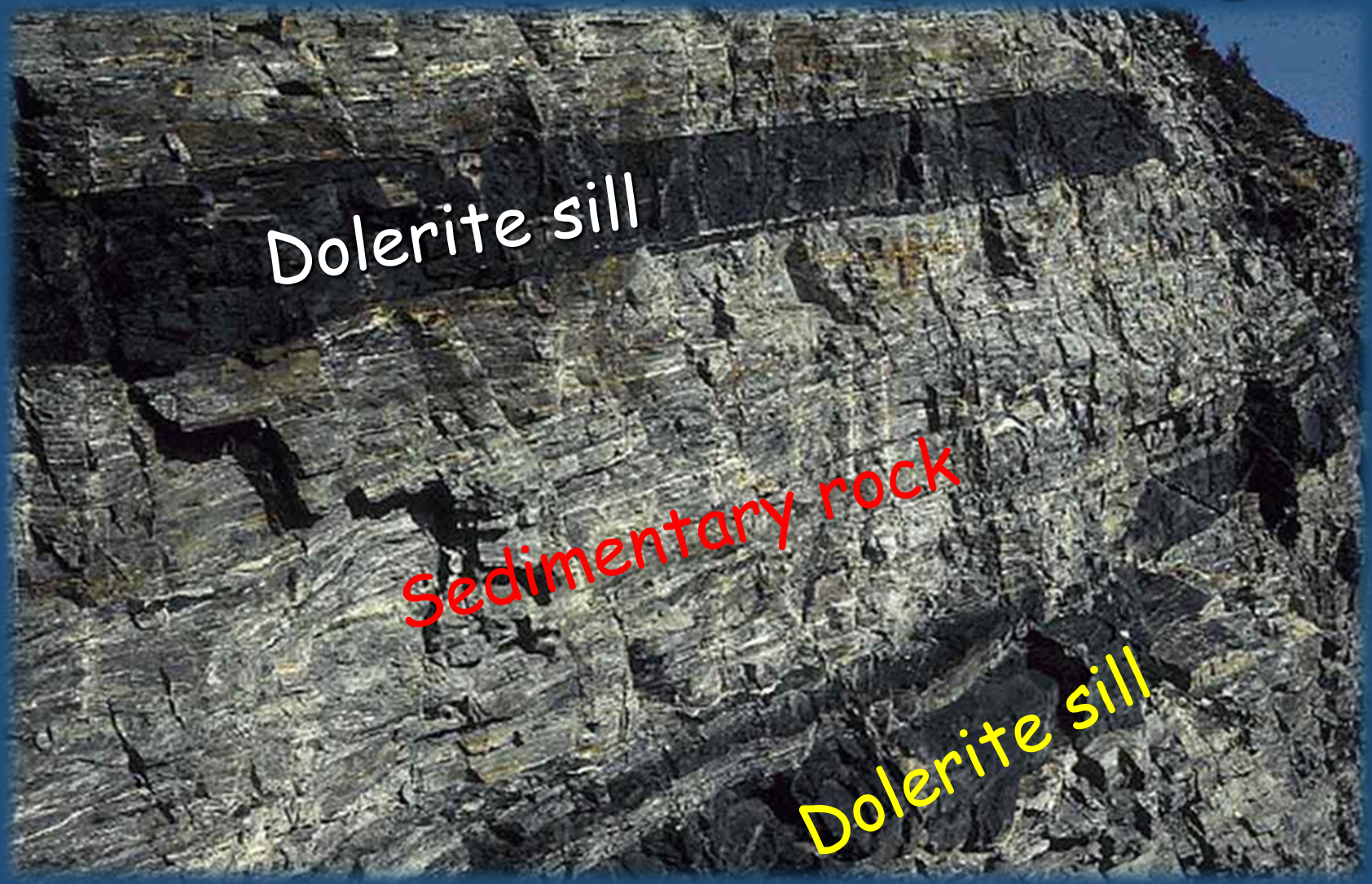
MAGMA AND IGNEOUS ROCKS

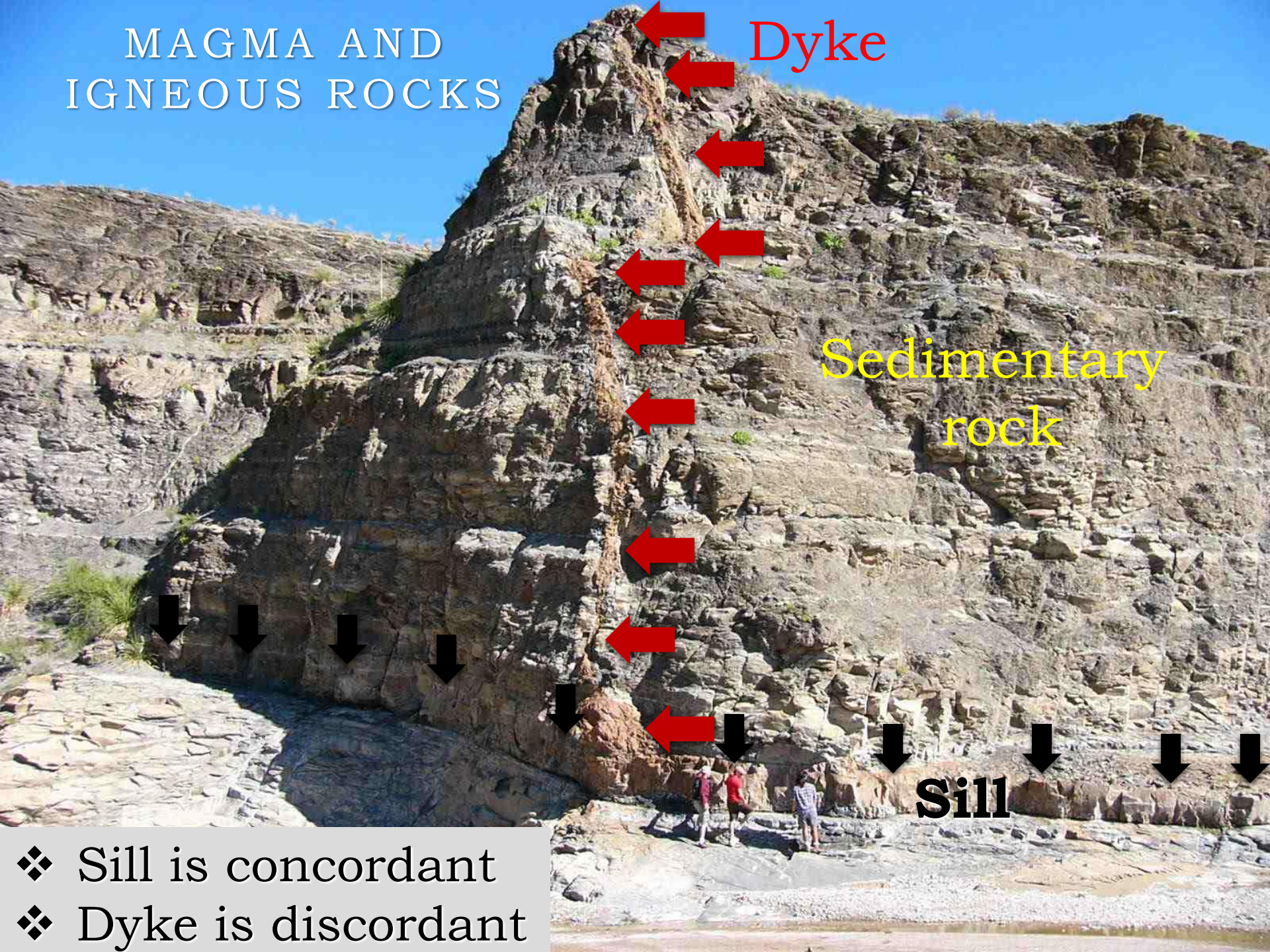




MAGMA AND IGNEOUS ROCKS

A sill is a fine-grained linear intrusion parallel (concordant) to the preexisting rock





- Sill is concordant
- Dyke is discordant

MAGMA AND IGNEOUS ROCKS

Magma formation process

Melt rocks need heat

- Inherited from Earth's early days
- Compression of the inner layers
- Friction of the sinking materials
- Collisions
- Radioactive elements decay

PECULIAR PHYSICAL CONDITIONS

DECOMPRESSION

RISING MAGMA

ADDITION OF VOLATILES

MAGMA AND IGNEOUS ROCKS

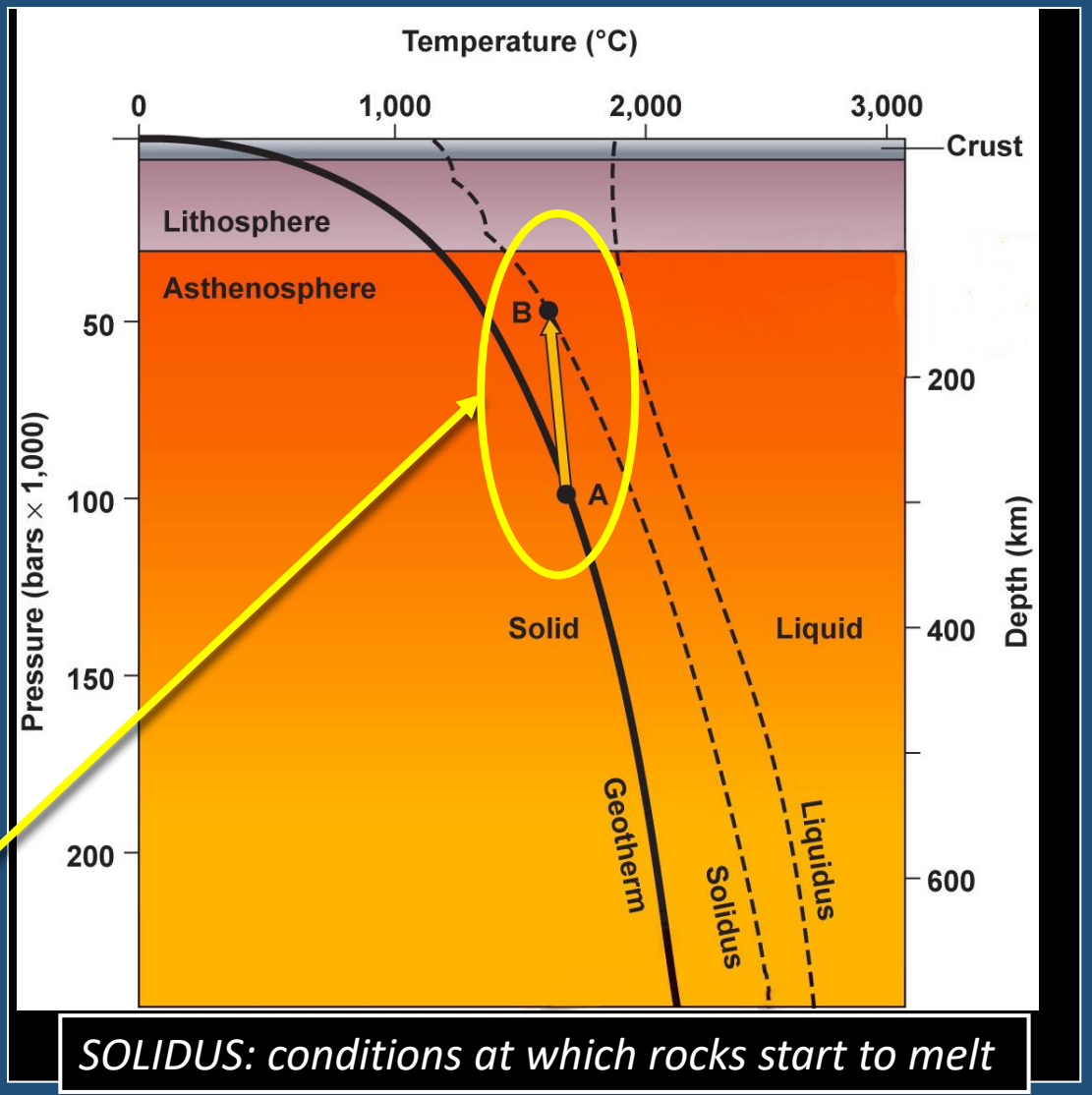
Magma formation process

DECOMPRESSION

Geotherm: temperature as a function of depth

Rocks are kept solid by high pressure. When the pressure decreases, melting ensues.

When a hot rock at high pressure is moved to a shallower crustal level (from A to B), the decrease in pressure may cause the rock to melt.

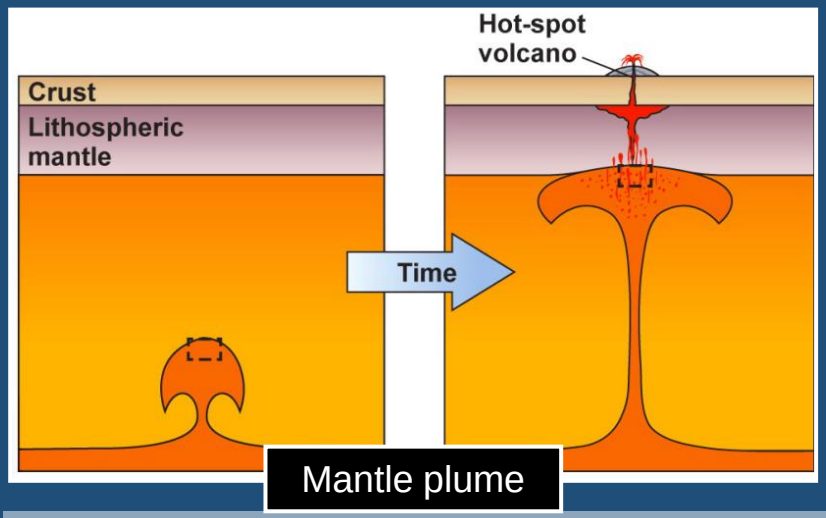


SOLIDUS: conditions at which rocks start to melt

MAGMA AND IGNEOUS ROCKS

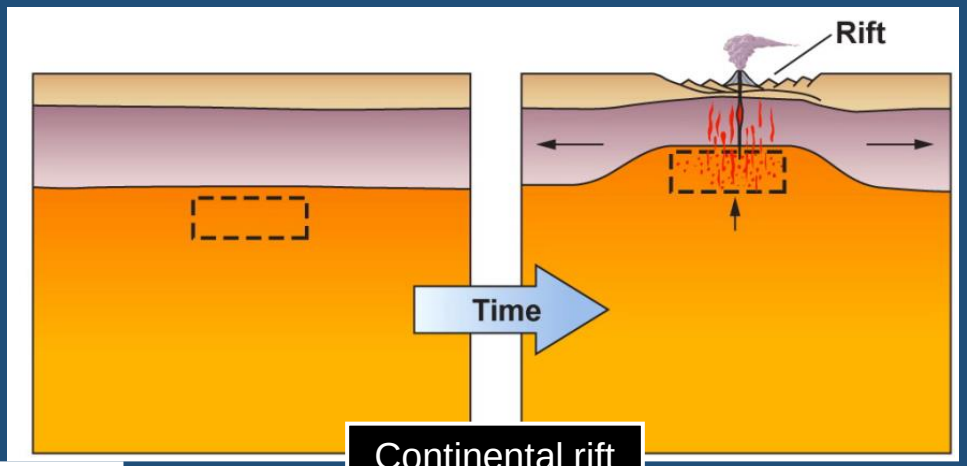
Magma formation process

The conditions leading to decompression melting occur in several different geologic environments. In each case, a volume of hot asthenosphere (outlined by dashed lines) rises to a shallower depth, and magma (red dots) forms.



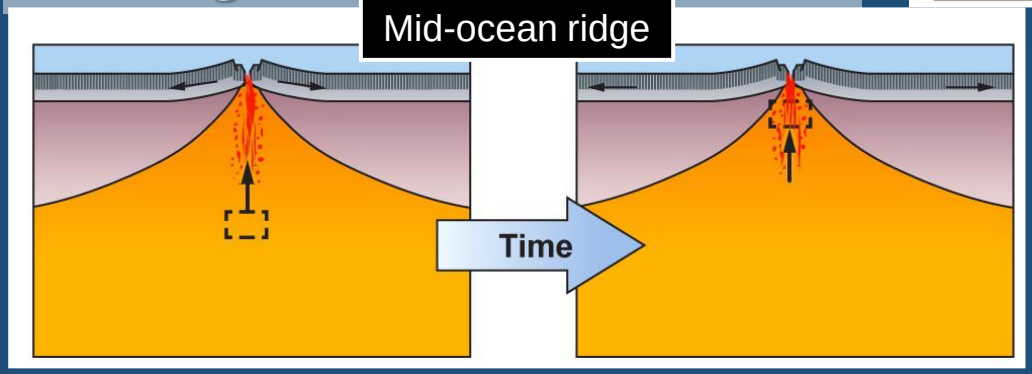
Mantle plume

Although the base of the crust is hot enough to melt rock, the rock doesn't melt because the pressure is too high.



Continental rift

Mid-ocean ridge

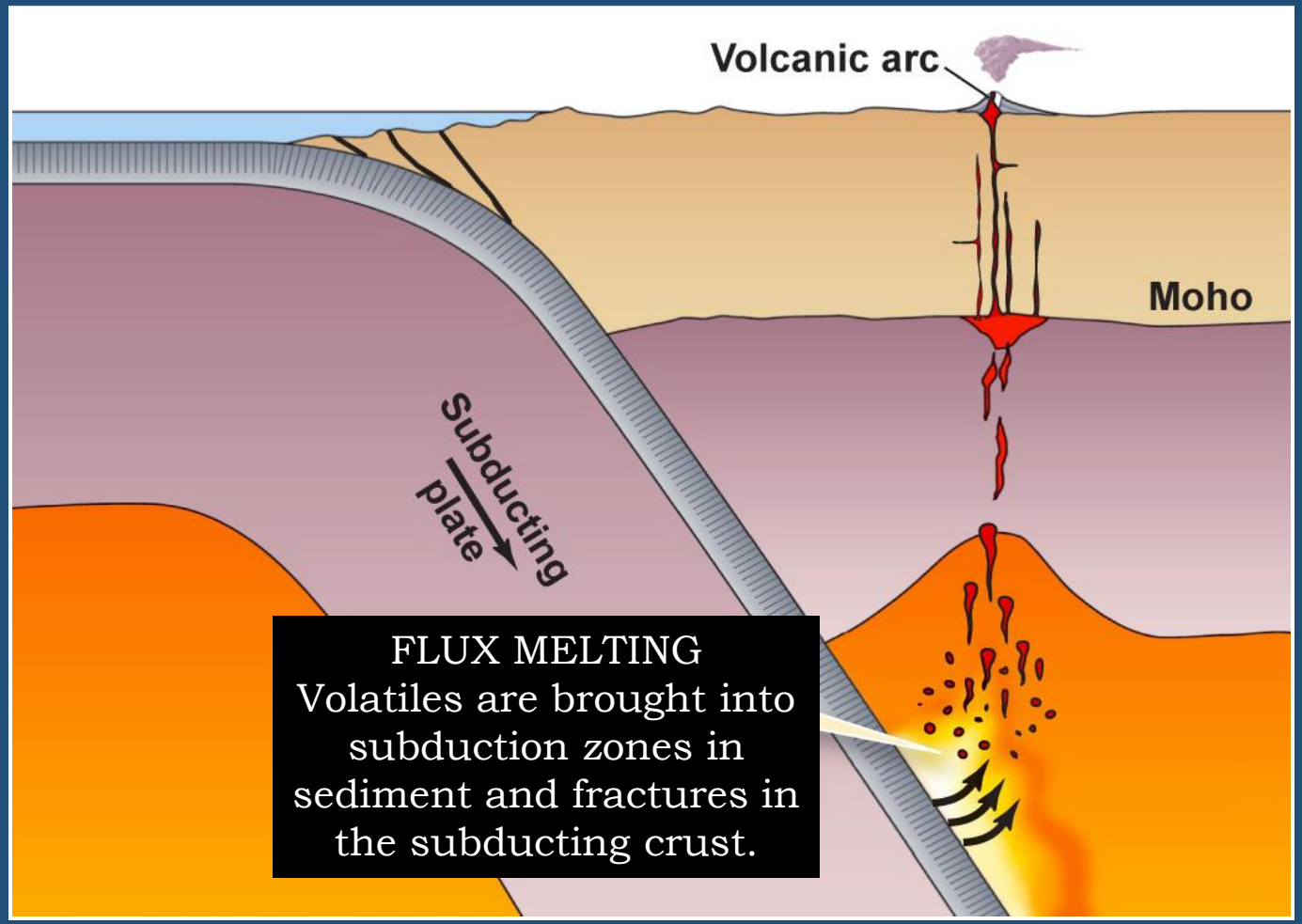


Pressure drops when hot rock is carried to shallower depths. This can happen at mantle plumes, beneath rifts, and under mid-ocean ridges.

MAGMA AND IGNEOUS ROCKS

Magma formation process

ADDITION OF VOLATILES



Flux melting occurs when volatiles are introduced into the hot mantle.

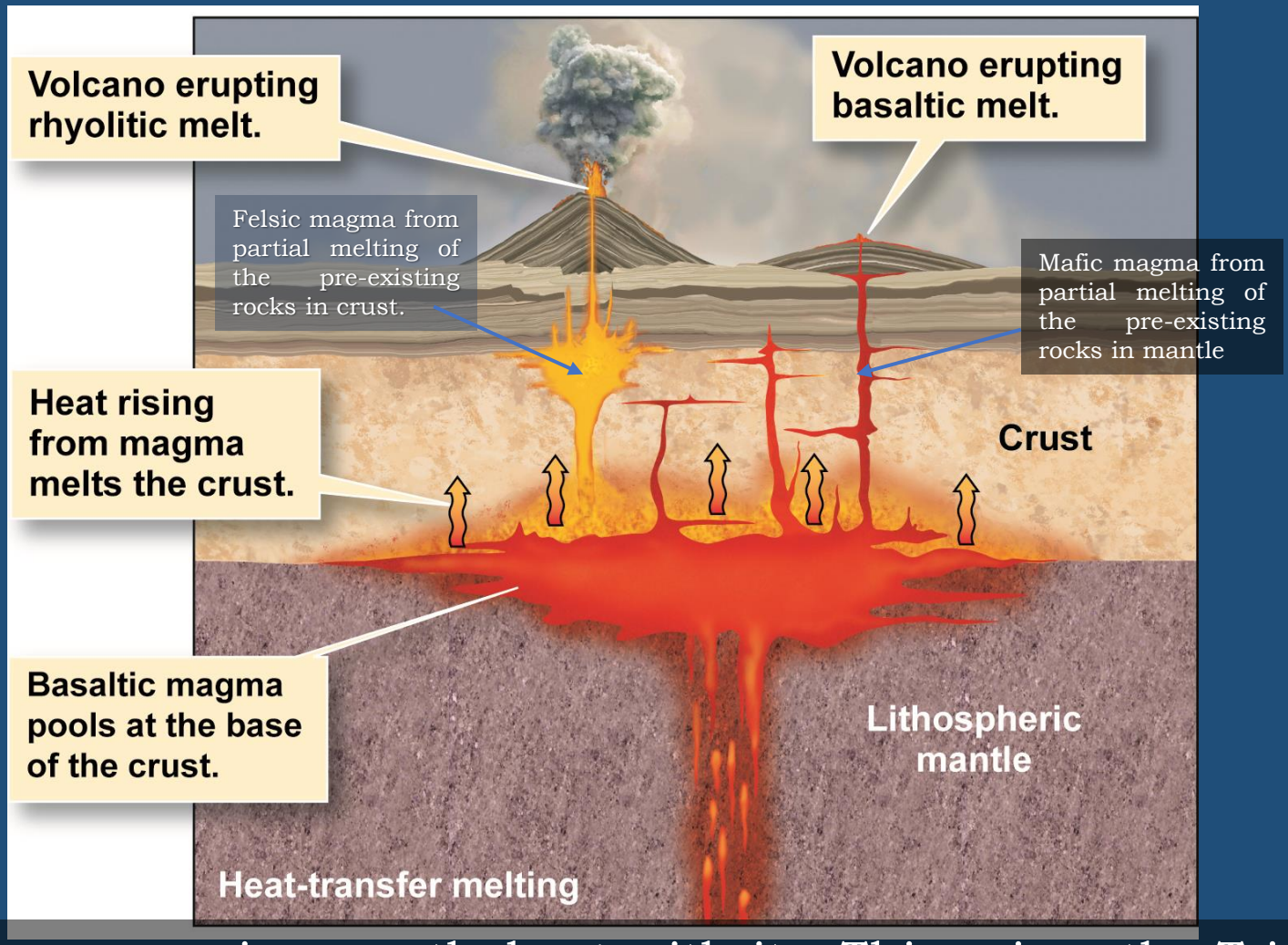
Volatiles lower the melting T of a hot rock.

Common volatiles include H_2O and CO_2.

MAGMA AND IGNEOUS ROCKS

Magma formation process

RISING MAGMA



Rising magma carries mantle heat with it. This raises the T in nearby crustal rock, which melts. This is called heat-transfer melting.

MAGMA AND IGNEOUS ROCKS

Composition of magma

Magmas can vary widely in composition, but in general they are made up of only eight elements; O, Si, Al, Ca, Fe, Mg, Na, and K.

A **dry magma** has scarce volatiles
A **wet magma** may contain up to 15% volatiles.

The most common gases associated with magma include: water vapor (H_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), nitrogen (N_2), and hydrogen (H_2).

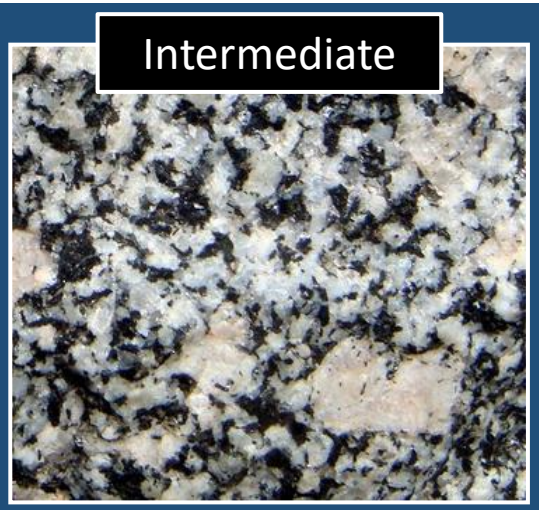
MAGMA AND IGNEOUS ROCKS

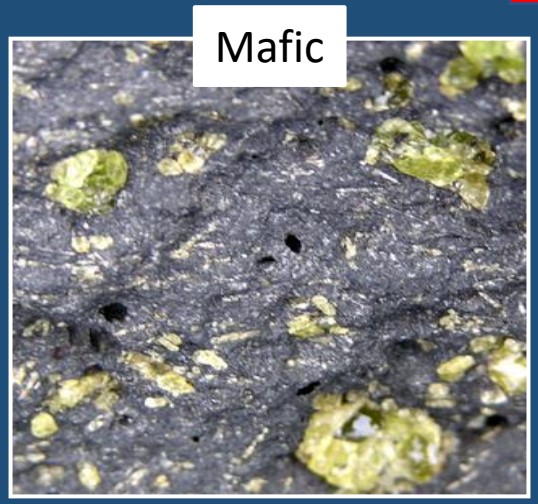
Composition of magma

INCREASE FeO, MgO

Type	Density	Temperature	% SiO_2 Viscosity
Felsic	Very low	Very low (600 to 850° C)	66 to 76% SiO_2 Very High: Explosive eruptions.
Intermediate	Low	Low	52 to 66% SiO_2 High: Explosive eruptions.
Mafic	High	High	45 to 52% SiO_2 Low: thin, hot runny eruptions.
Ultramafic	Very high	Very high (up to 1300° C)	38 to 45% SiO_2 Very low.

INCREASE SiO_2





MAGMA AND IGNEOUS ROCKS

Composition of magma

Magma composition is determined by a number of factors.

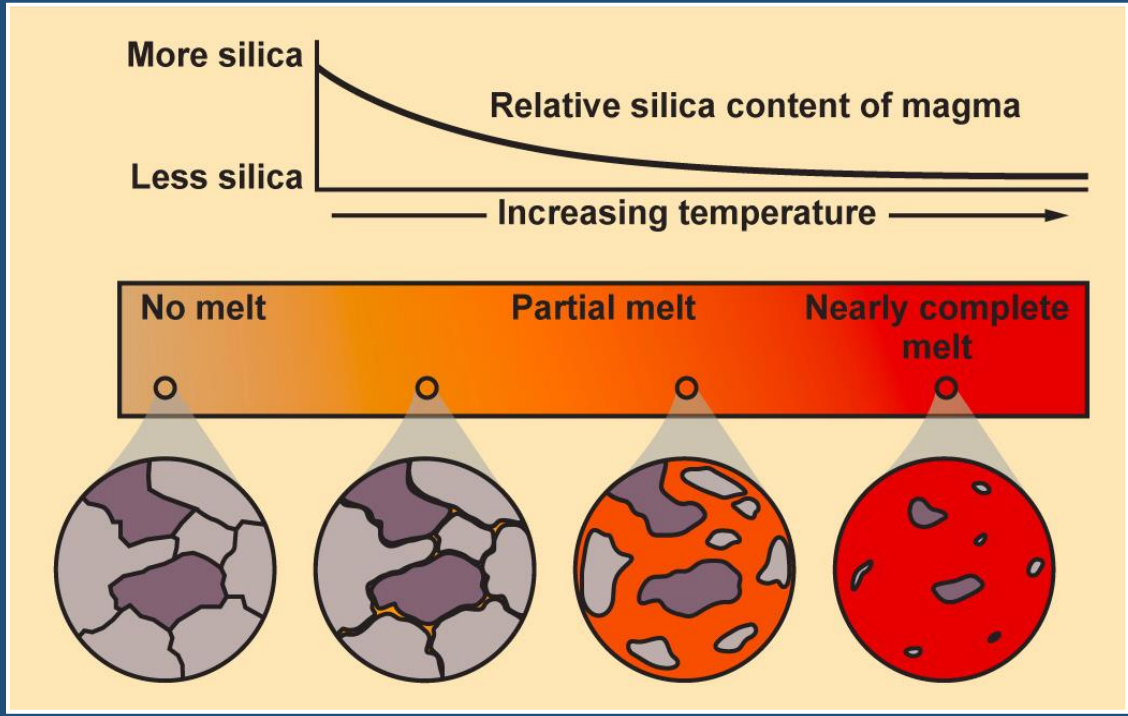
1. The most important is the composition of the **initial source rock**. For instance, a mantle source will produce ultramafic and mafic magmas. A crustal source will generate mafic, intermediate, and felsic magmas.

2. The **partial melting** of initial source rock. Magma carries away silica and the remnant is more mafic.

Partial melting yields a silica-rich magma.

Removing a partial melt from its source creates a magma that differs from the original.

Magma formed during the late stage contains less silica!



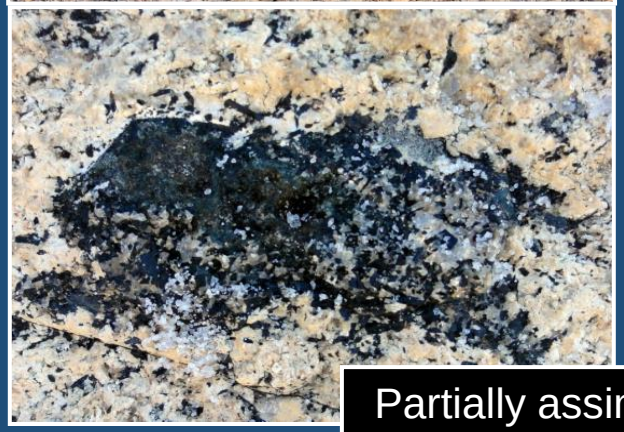
MAGMA AND IGNEOUS ROCKS

Composition of magma

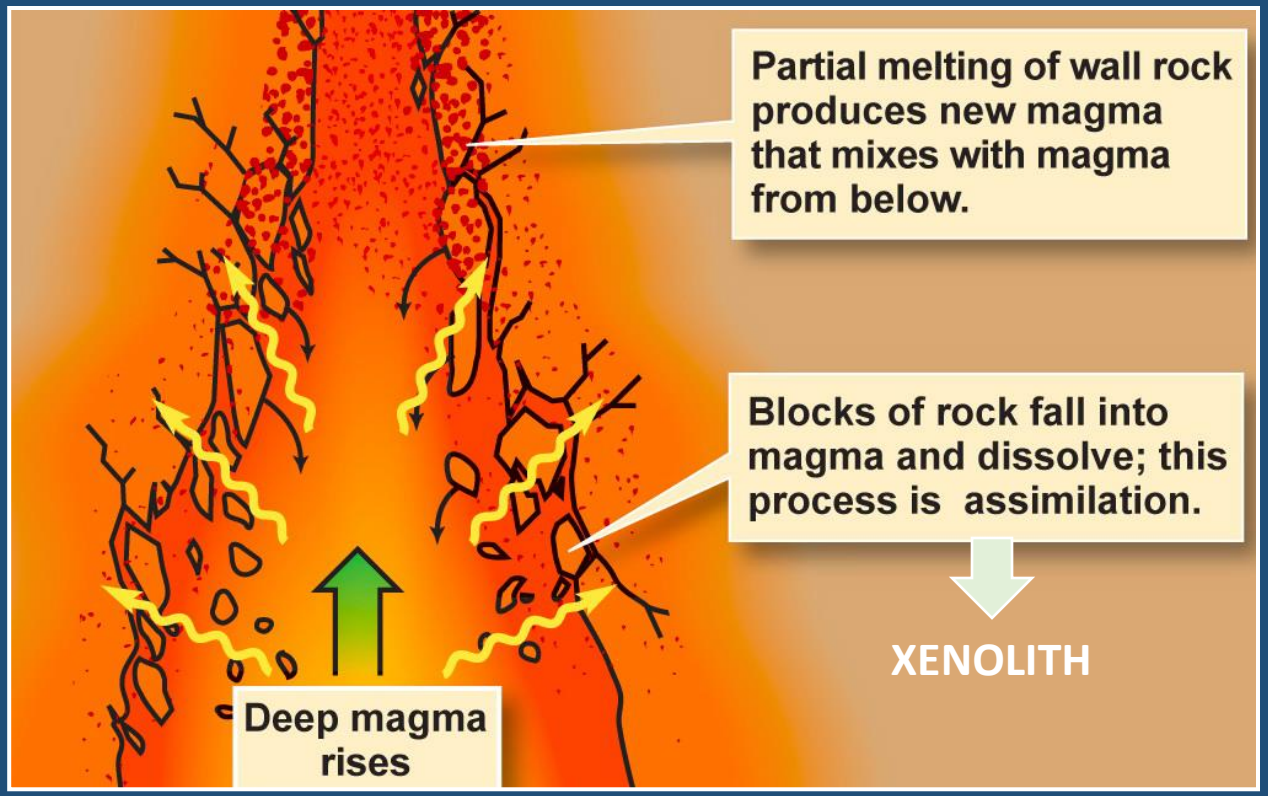
Magma composition is determined by a number of factors.

3. Magma in the magma chamber incorporate chemicals from the wall rocks. This process is called **assimilation**.

Unmelted xenolith



Partially assimilated xenolith

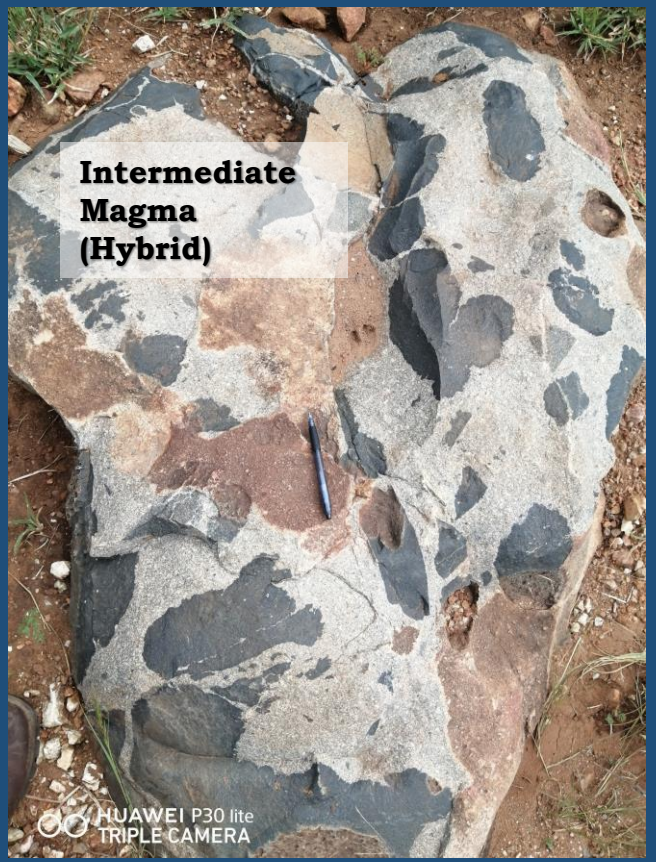


MAGMA AND IGNEOUS ROCKS

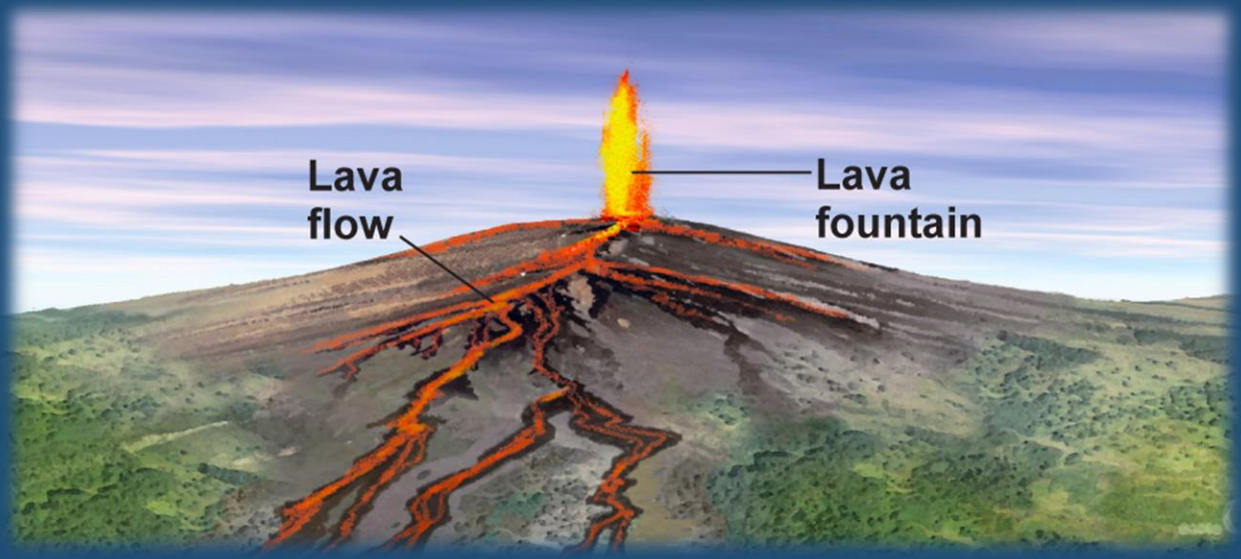
Composition of magma

Magma composition is determined by a number of factors.

4. When different magma come into contact, they may mix. The result combines the characteristics of the two. Often **magma mixing** is incomplete, resulting in blobs of one rock type suspended within the other.



MAGMA AND IGNEOUS ROCKS



Magma movement is governed by viscosity, which depends on temperature, volatile content, and % silica content.

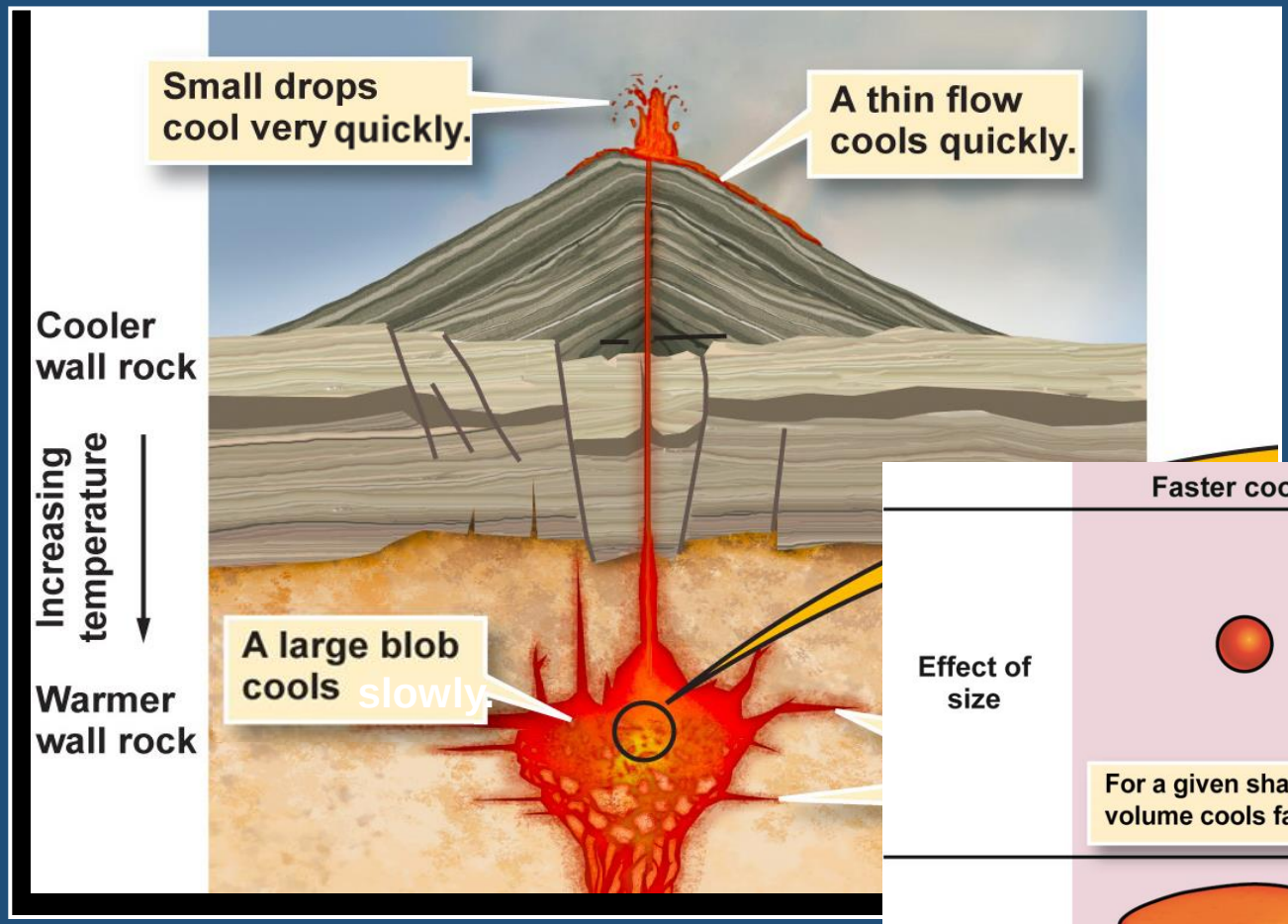
Hotter—lower viscosity
Cooler—higher viscosity

More volatiles—lower viscosity.
Fewer volatiles—higher viscosity.

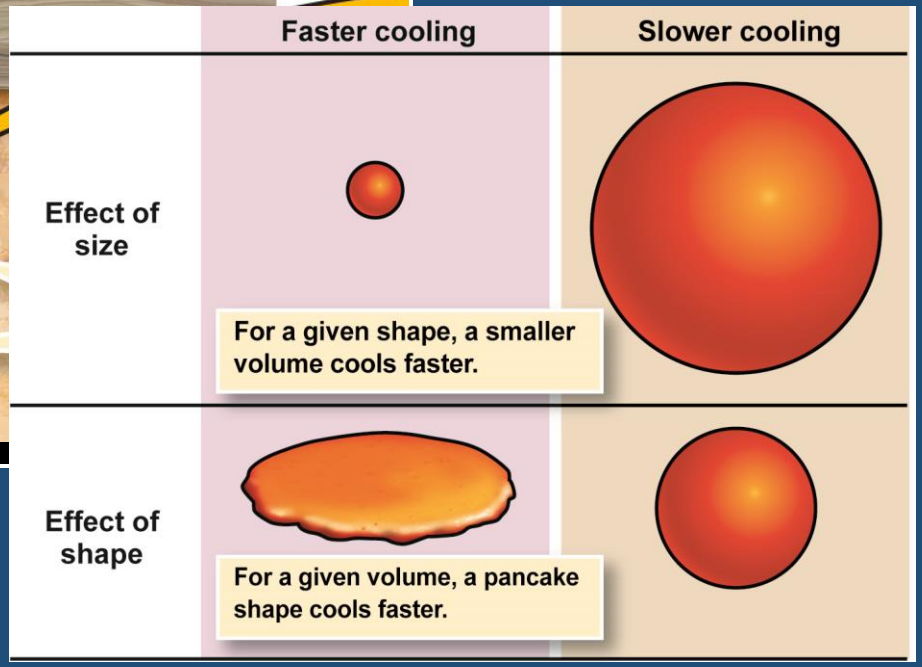
Less SiO_2 (Mafic)—lower viscosity.
More SiO_2 (Felsic)—higher viscosity.c

MAGMA AND IGNEOUS ROCKS

From magma to igneous rocks



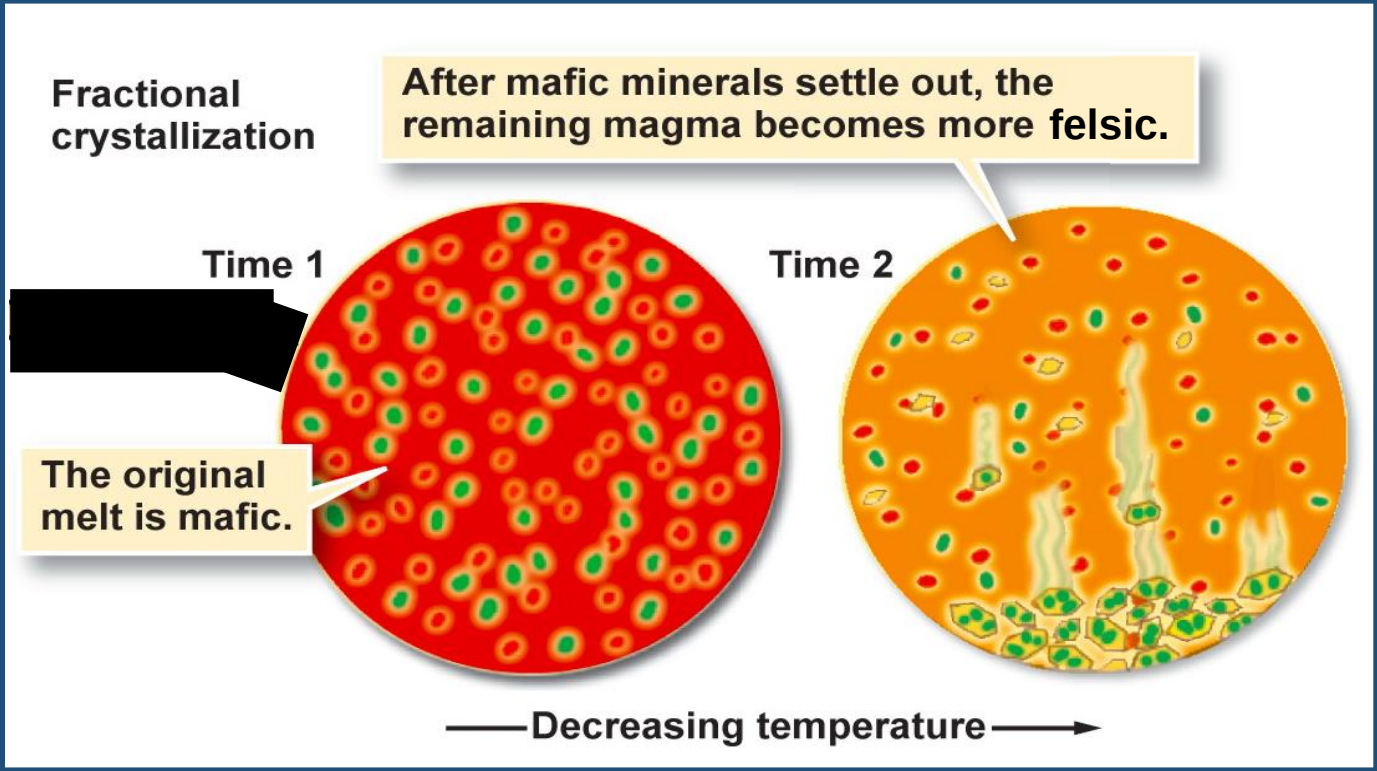
Cooling rate depends upon depth, shape, and groundwater interaction (or lack thereof).



Circulating groundwater removes heat.

MAGMA AND IGNEOUS ROCKS

From magma to igneous rocks



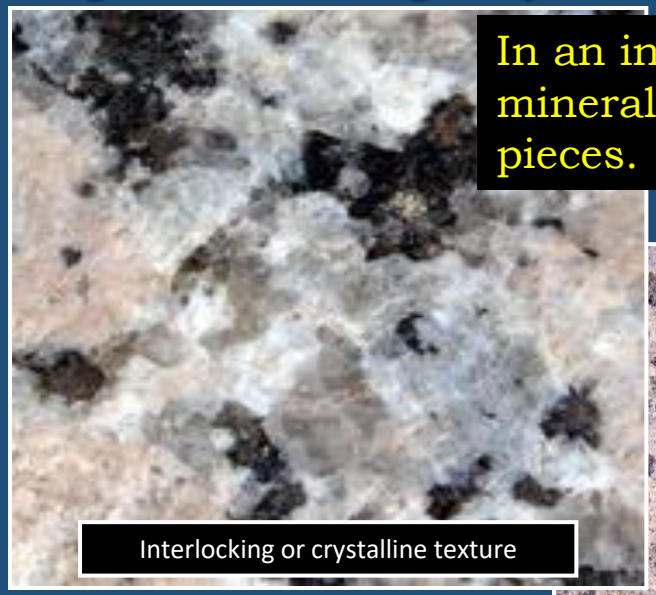
- Crystals that form early settle out of the melt by gravity.
- The composition of the remaining melt changes : Fe, Mg, and Ca are removed as early formed mafic minerals settle out.
- The remaining melt becomes enriched in Si, Al, Na, and K.
- Crystals that form later (at lower T) are depleted in Fe, Mg, and Ca and enriched in Si, Al, Na and K.

MAGMA AND IGNEOUS ROCKS

Igneous rocks classification

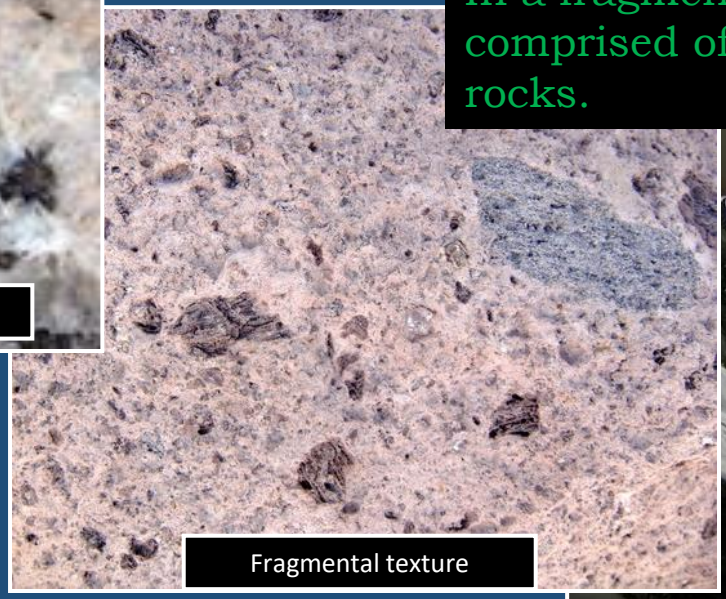
Igneous rocks are described by the **colour** and **texture** (size, shape, and arrangement) of the component minerals. Textures include interlocking, fragmental, and glassy.

In an interlocking (or, crystalline) texture, mineral crystals fit together like jigsaw puzzle pieces.



Interlocking or crystalline texture

In a fragmental texture, the rock is comprised of pieces of preexisting rocks.



Fragmental texture

Glassy texture

A glassy texture is composed of solid glass or glass shards.

Igneous rock textures

Glassy texture - Rapid cooling of lavas generate glassy texture with no orderly crystalline structure

Obsidian is a volcanic rock with glassy texture

Obsidian in the field…

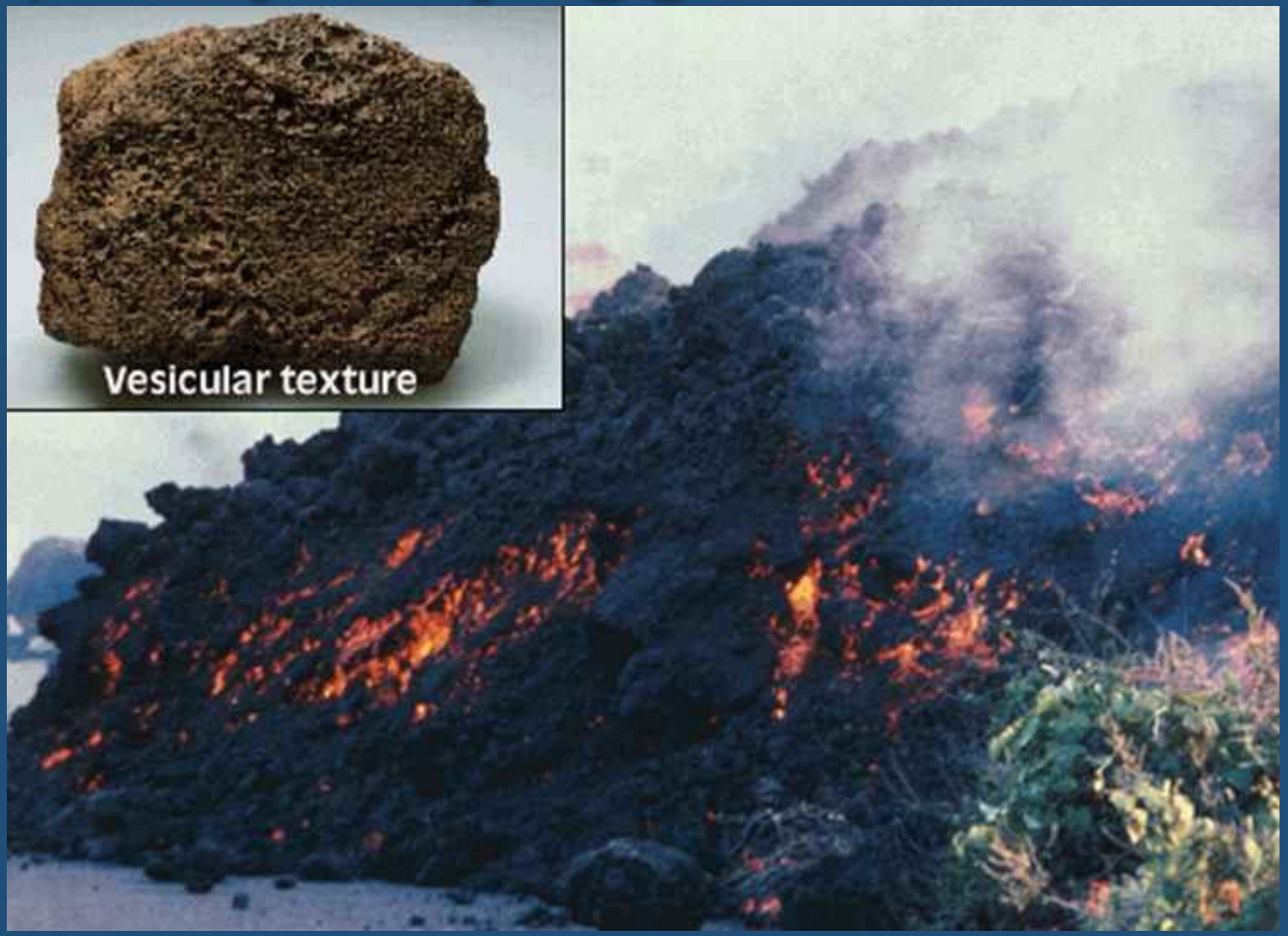
Aphanitic texture is shown by rocks that cooled fast like volcanic rocks and intrusive rocks like dykes and sills

Glassy texture

Aphanitic texture

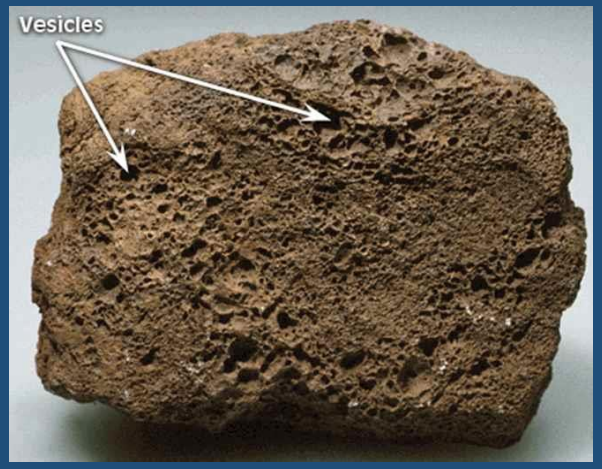
Vesicular texture

Vesicular texture - Volcanic rocks that form near the surface of lava flows have voids (holes) left by escaping gas bubbles…



Textures

Glassy texture



Vesicular texture

Phaneritic texture

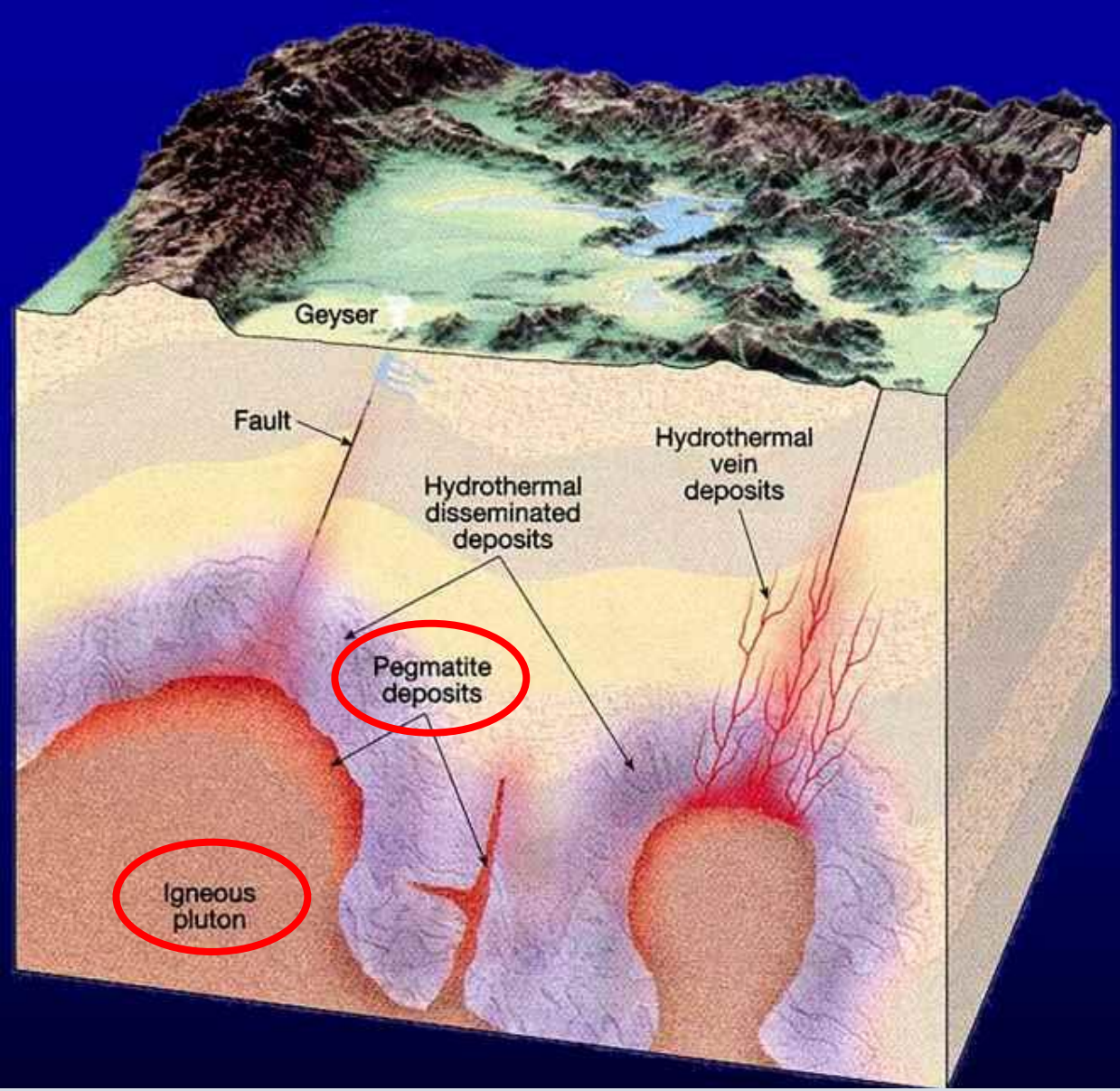
Pegmatitic texture

A pegmatitic texture is one in which the mineral grains are exceptionally large (coarse-grained)

by slow cooling and high water (H_2O) content

During the late stages of formation of a granite, felsic minerals dominate, and the rock becomes coarse grained (>2 cm), forming a pegmatite

Samples collected from a pegmatite…

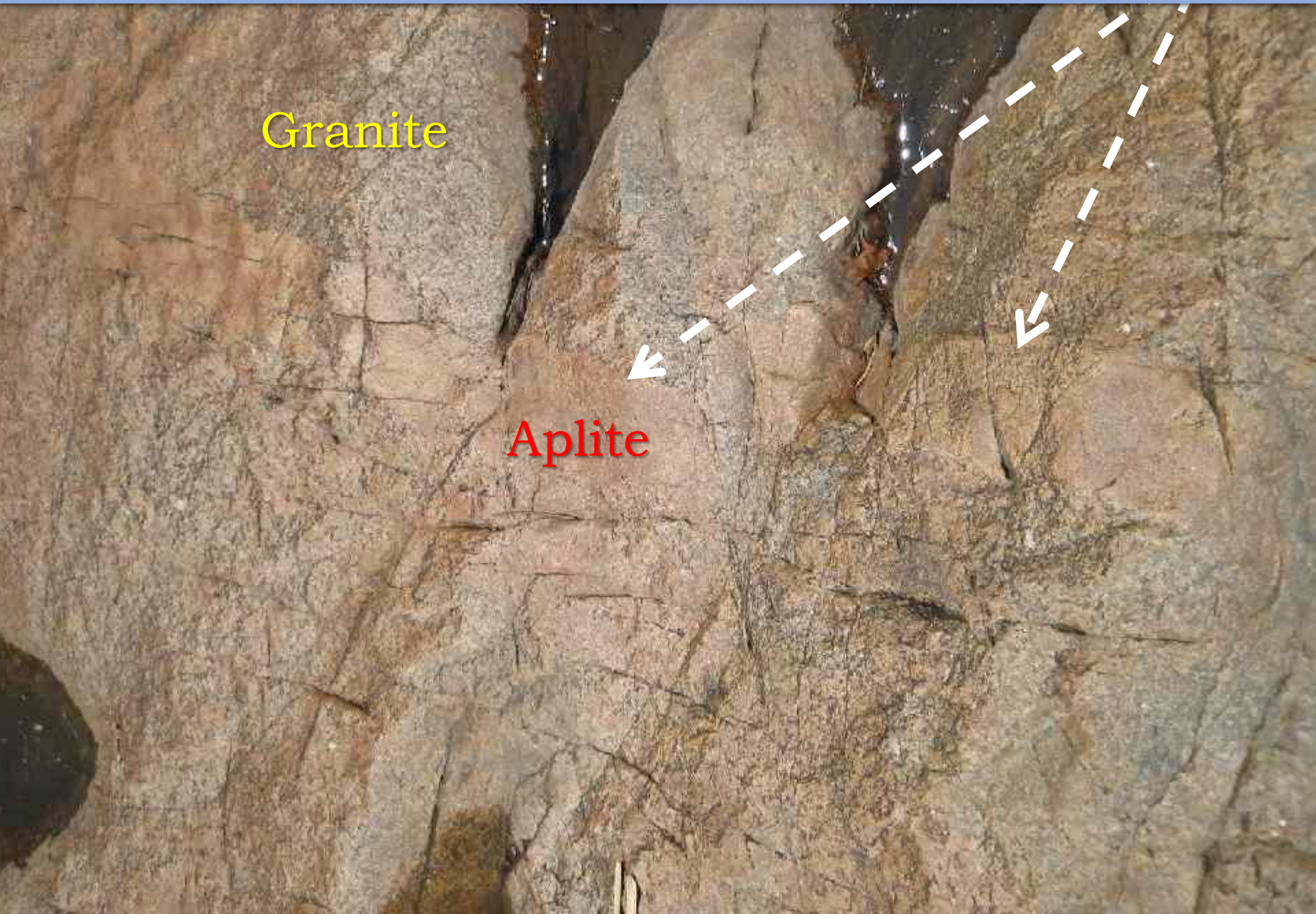


8 cm tourmaline crystals from pegmatite

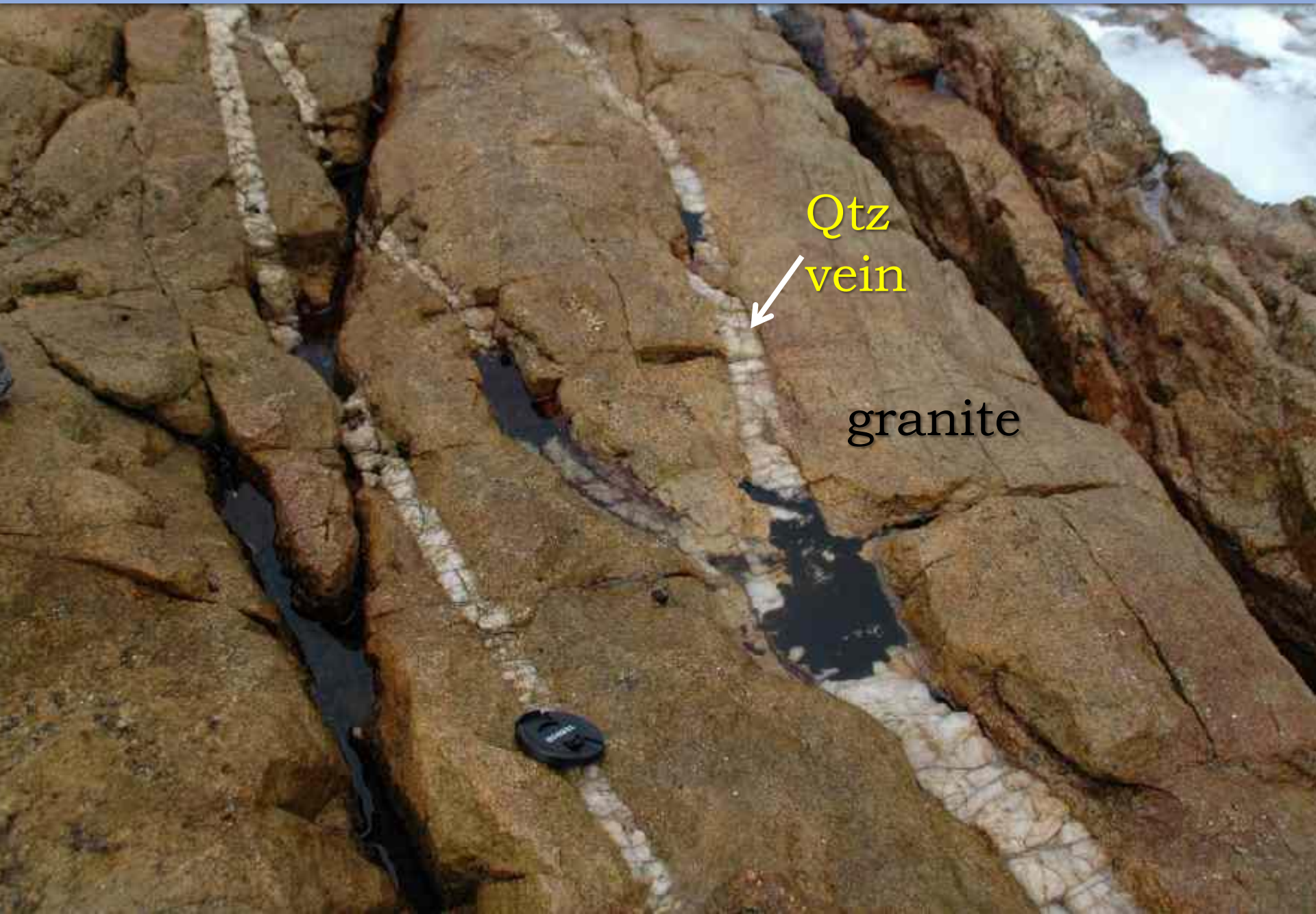
5 mm gold from a hydrothermal deposit

Pegmatites are known to contain Mineralization…

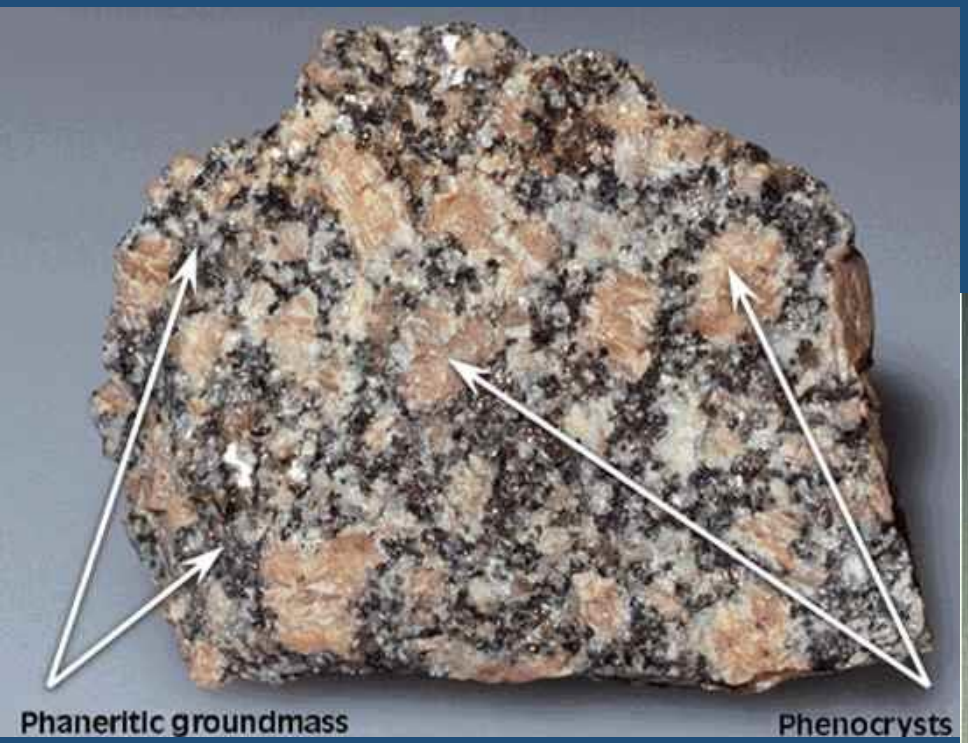
Fine grained variety of pegmatite is termed aplite



Veins made up entirely of quartz – Quartz veins



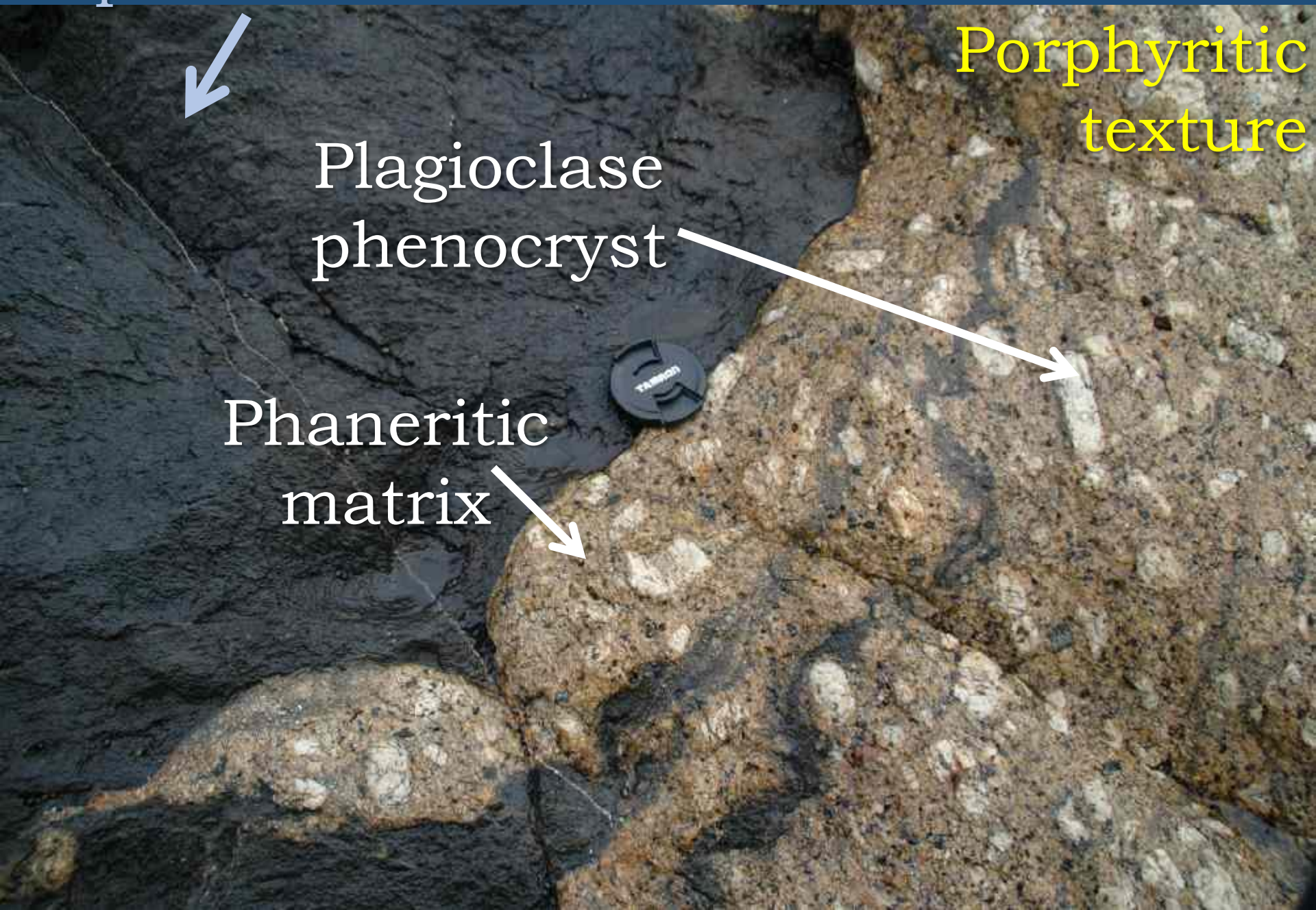
Porphyritic texture (two grain sizes)

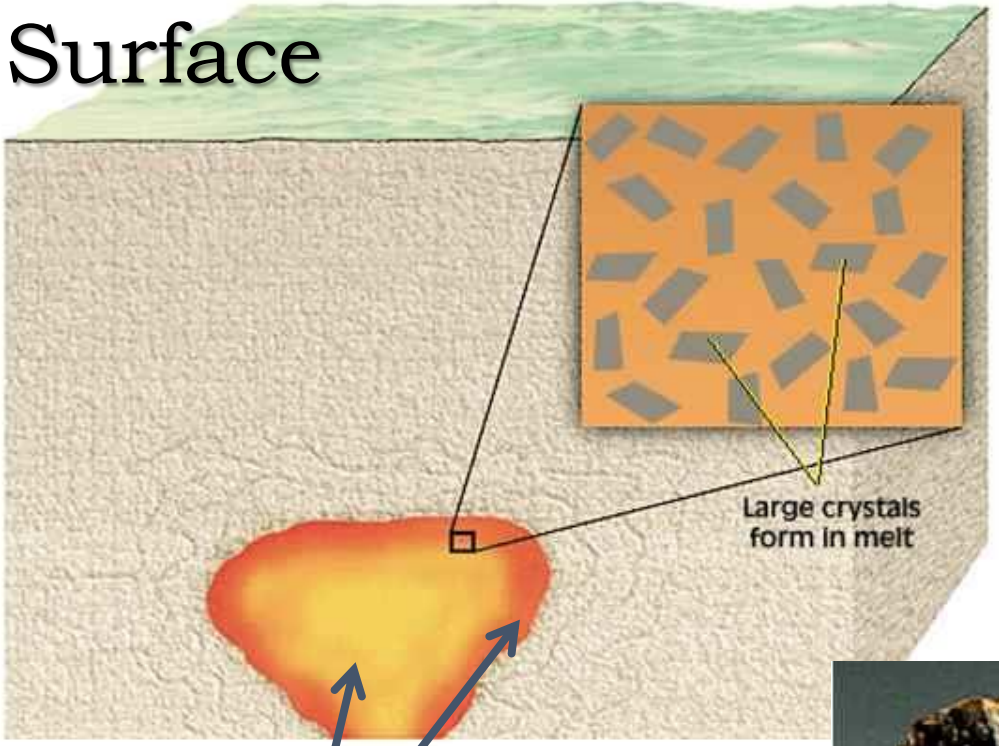


Groundmass/matrix

Phenocrysts

Aphanitic texture

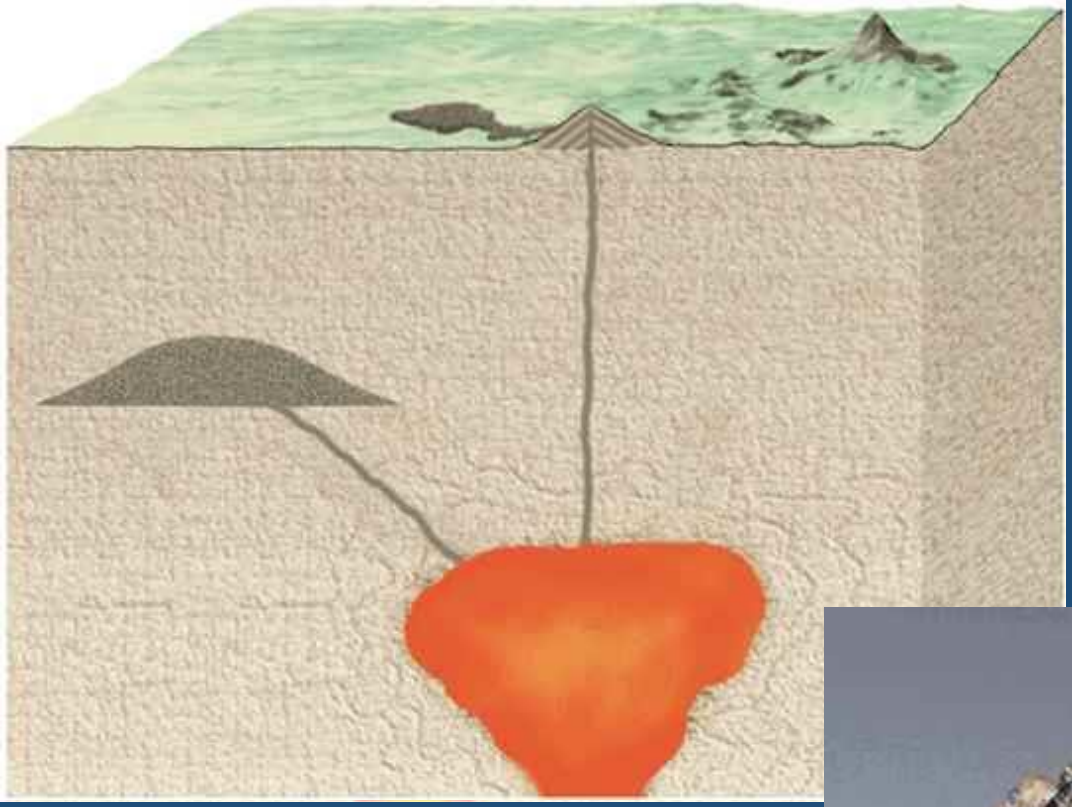




Certain minerals crystallize and grow before others begin to form…

The magma migrate to a new environement where cooling takes place rapidly…

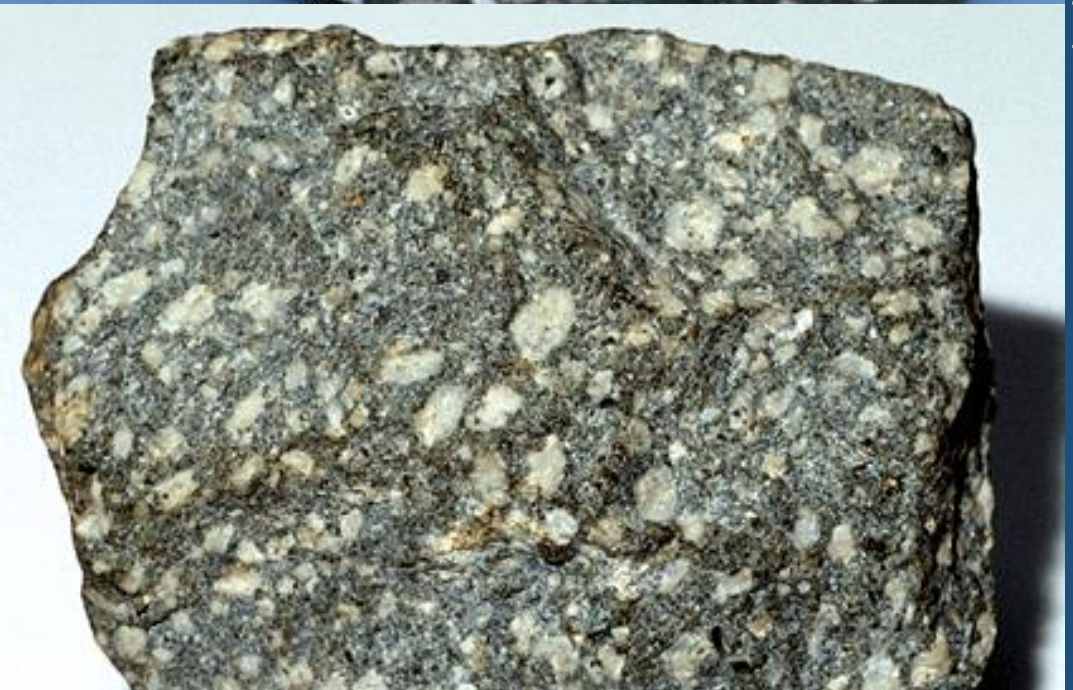
<u>Aphanitic-porphyritic</u>



The magma may migrate to a smaller intrusive body
- cooling slower than the above
- visible crystals

<u>Phaneritic-porphyritic</u>

What is a porphyry?



A porphyry is a rock with 2 distinct sizes of crystals

reflecting 2 distinct stages of crystallization:

1) early slow growth of large crystals called phenocrysts

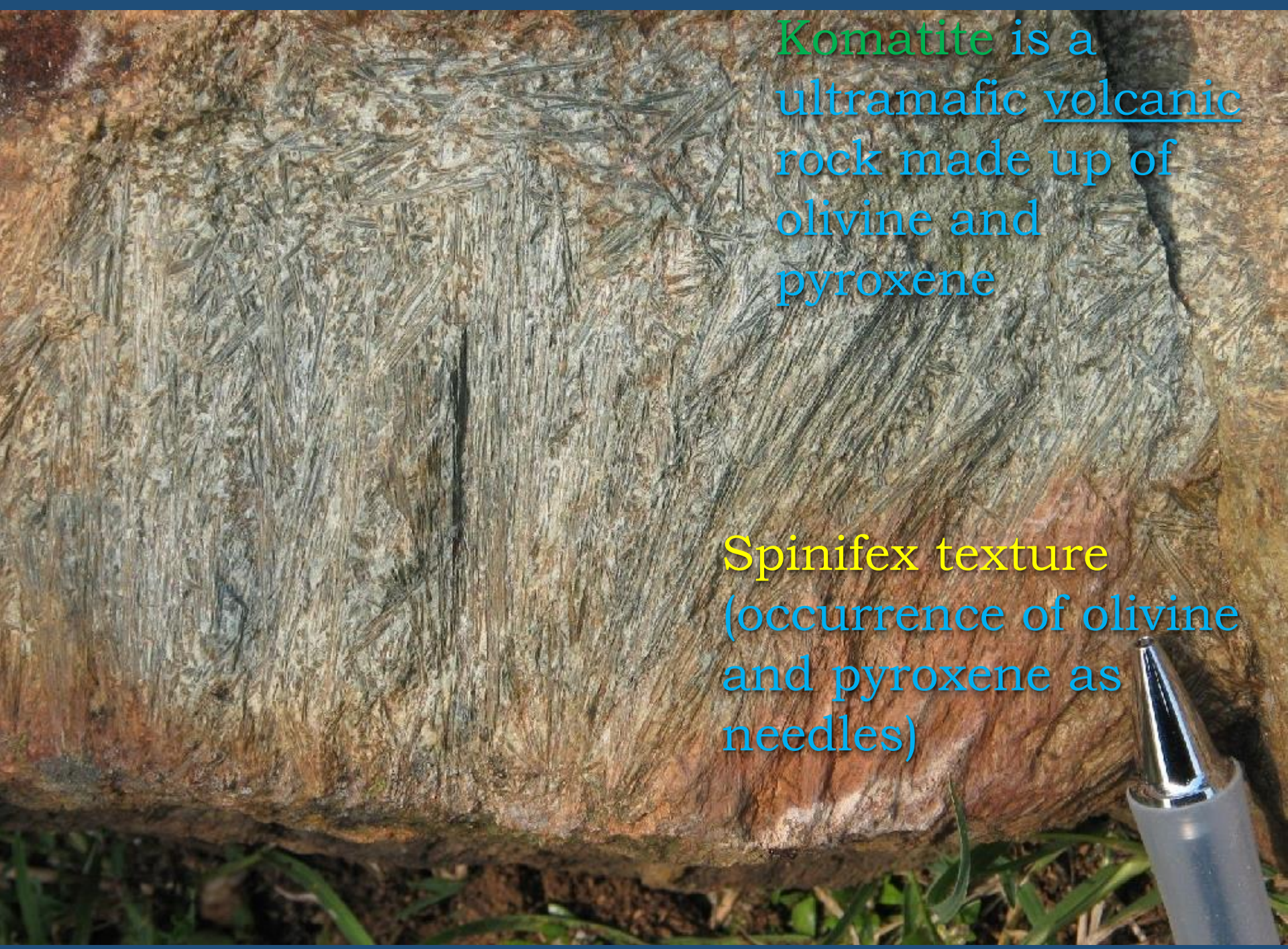
2) later rapid growth of small crystals as groundmass or matrix

Common igneous rocks

To every plutonic rock, there is an equivalent volcanic rock…

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
	Aphanitic (fine-grained)	Rhyolite	Andesite	Basalt	Komatiite (rare)
	Porphyritic	"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts			Uncommon
	Glassy	Obsidian (compact glass) Pumice (frothy glass)			
	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%

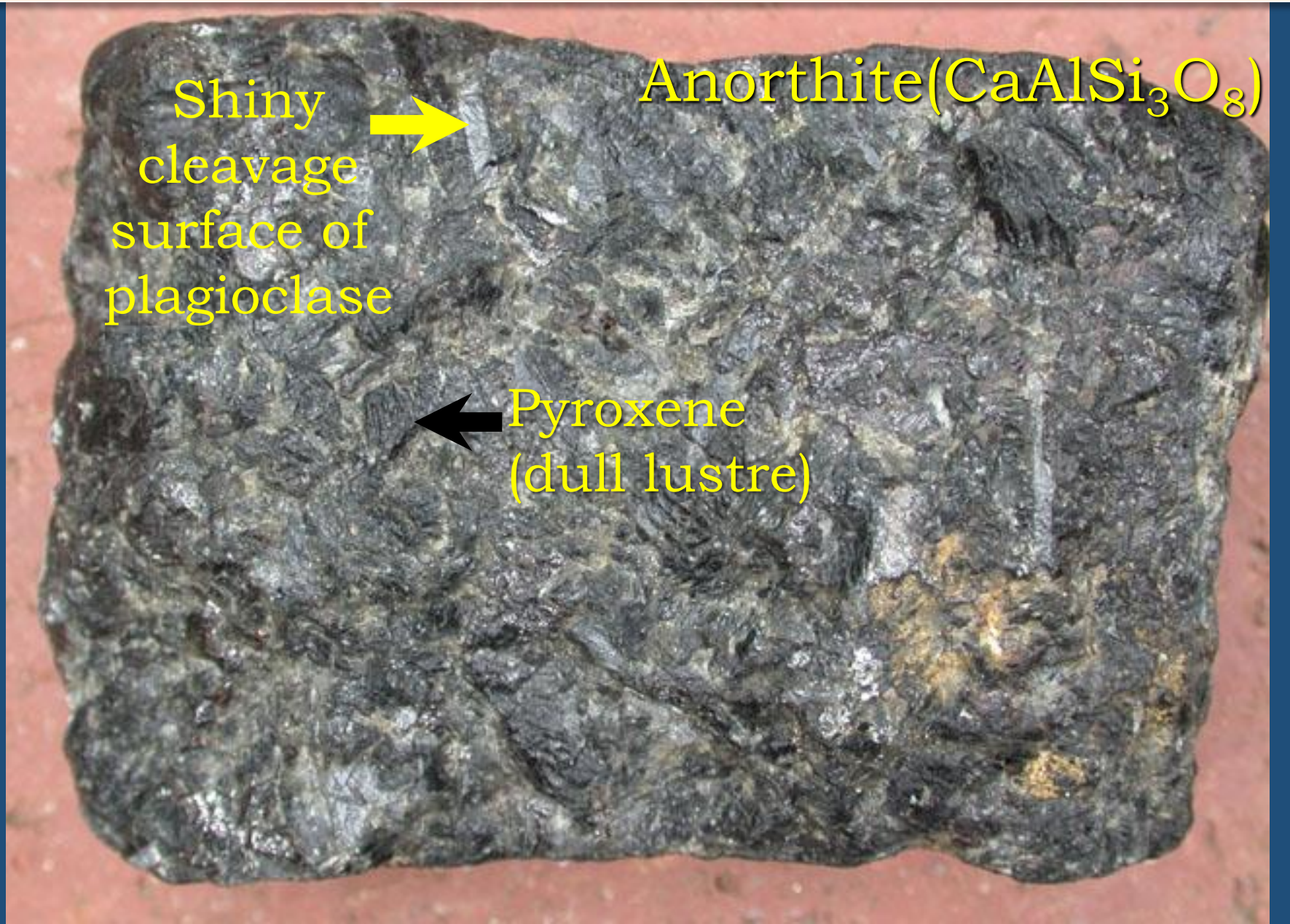
Peridotite is a ultramafic plutonic rock made up of olivine and pyroxene


Komatite is a ultramafic volcanic rock made up of olivine and pyroxene
Spinifex texture (occurrence of olivine and pyroxene as needles)

To every plutonic rock, there is an equivalent volcanic rock…

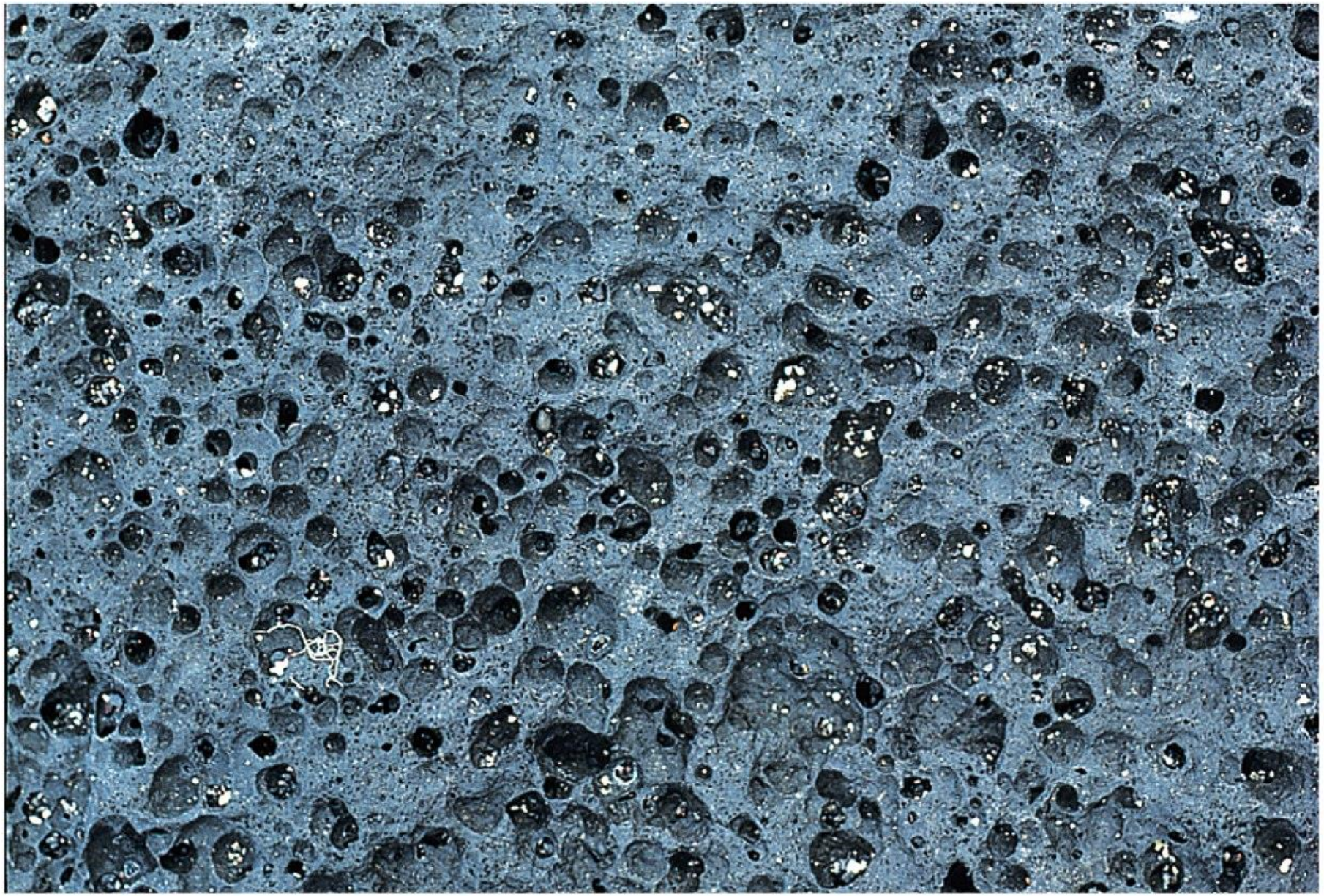
Chemical Composition		Granitic (Felsic)	Andesitic (Intermediate)	Basaltic (Mafic)	Ultramafic
Dominant Minerals		Quartz Potassium feldspar Sodium-rich plagioclase feldspar	Amphibole Sodium- and calcium-rich plagioclase feldspar	Pyroxene Calcium-rich plagioclase feldspar	Olivine Pyroxene
Accessory Minerals		Amphibole Muscovite Biotite	Pyroxene Biotite	Amphibole Olivine	Calcium-rich plagioclase feldspar
TEXTURE	Phaneritic (coarse-grained)	Granite	Diorite	Gabbro	Peridotite
	Aphanitic (fine-grained)	Rhyolite	Andesite	Basalt	Komatiite (rare)
	Porphyritic	"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts			Uncommon
	Glassy	Obsidian (compact glass) Pumice (frothy glass)			
	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%

Gabbro is a mafic plutonic rock composed dominantly of plagioclase and pyroxene (plagioclase is calcic – hence dark)



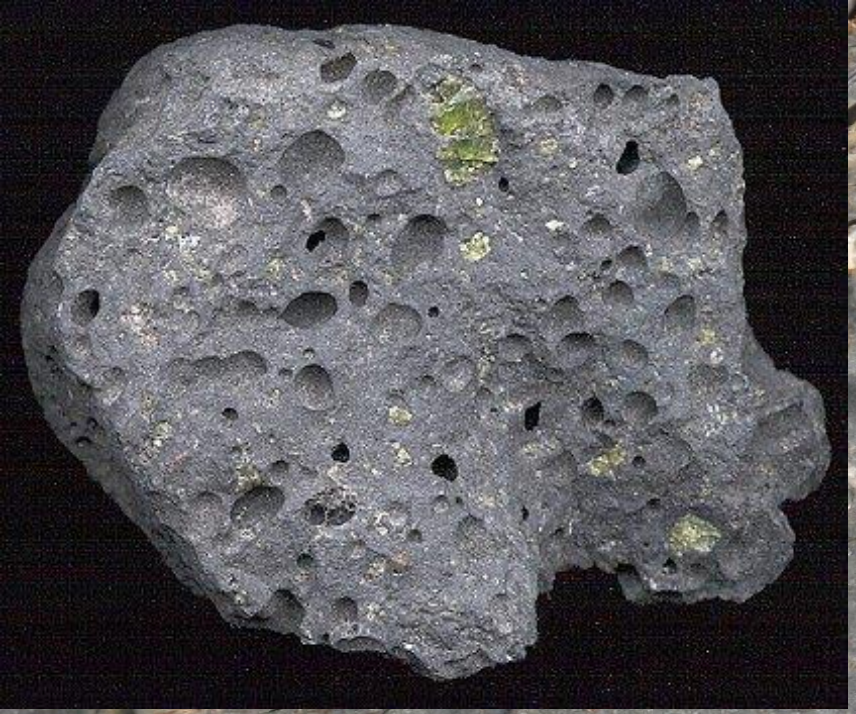
Gabbro is a mafic plutonic rock composed dominantly of plagioclase and pyroxene (here plagioclase is sodic, lighter)

Basalt is a mafic volcanic rock made up dominantly of plagioclase and pyroxene



~0.25 m

Vesicular basalt



Amygdaloidal basalt....

Vesicles filled with carbonate minerals

To every plutonic rock, there is an equivalent volcanic rock…

		Granitic (Felsic)	Andesitic (Intermediate)	Basaltic (Mafic)	Ultramafic
Chemical Composition					
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
	Aphanitic (fine-grained)	Rhyolite	Andesite	Basalt	Komatiite (rare)
	Porphyritic	"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts			Uncommon
	Glassy	Obsidian (compact glass) Pumice (frothy glass)			
	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%

Diorite is a intermediate plutonic rock with approximately equal amounts of plagioclase and amphibole

Grey color

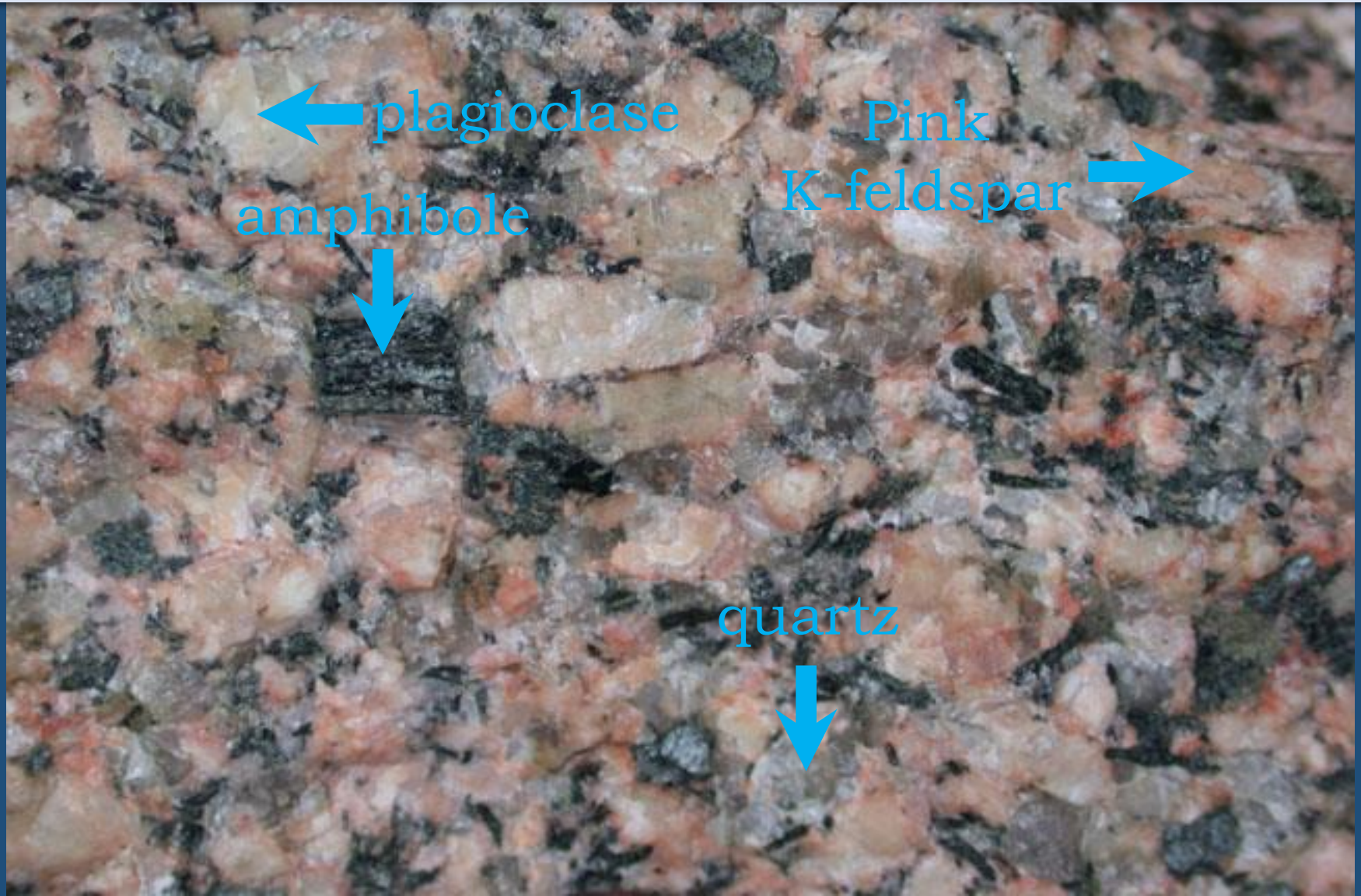
Andesite is an intermediate volcanic rock made up dominantly of plagioclase and amphibole

Andesite often show porphyritic texture

To every plutonic rock, there is an equivalent volcanic rock…

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
	Aphanitic (fine-grained)	Rhyolite	Andesite	Basalt	Komatiite (rare)
	Porphyritic	"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts			Uncommon
	Glassy	Obsidian (compact glass) Pumice (frothy glass)			
	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%

Granite is a felsic plutonic rock made up dominantly of K-feldspar and quartz, with less plagioclase feldspar



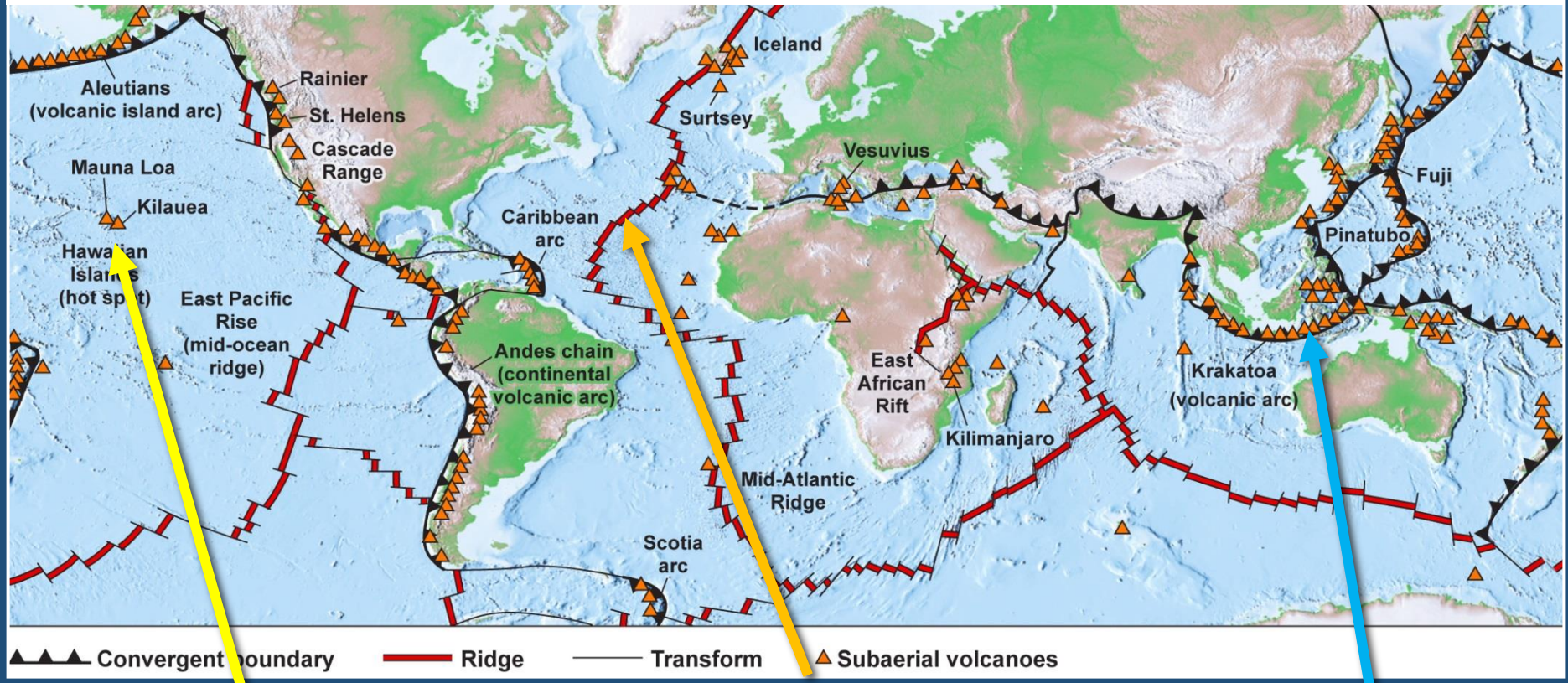
Rhyolite is a felsic volcanic rock made up dominantly of K-feldspar and quartz, with little plagioclase

Pink to red color

4. MAGMA AND IGNEOUS ROCKS

Volcanic activity

Igneous activity occurs mostly at tectonic-plate boundaries. Mantle plume hot spots, like Hawaii, are independent of tectonic control.



Mantle plume hot spots build volcanoes independent of tectonic plate boundaries.

Most igneous activity occurs along the mid-ocean ridge. Almost all of this activity occurs below sea level.

Volcanic arcs decorate the overriding plate of subduction zones.

End of
Igneous rocks