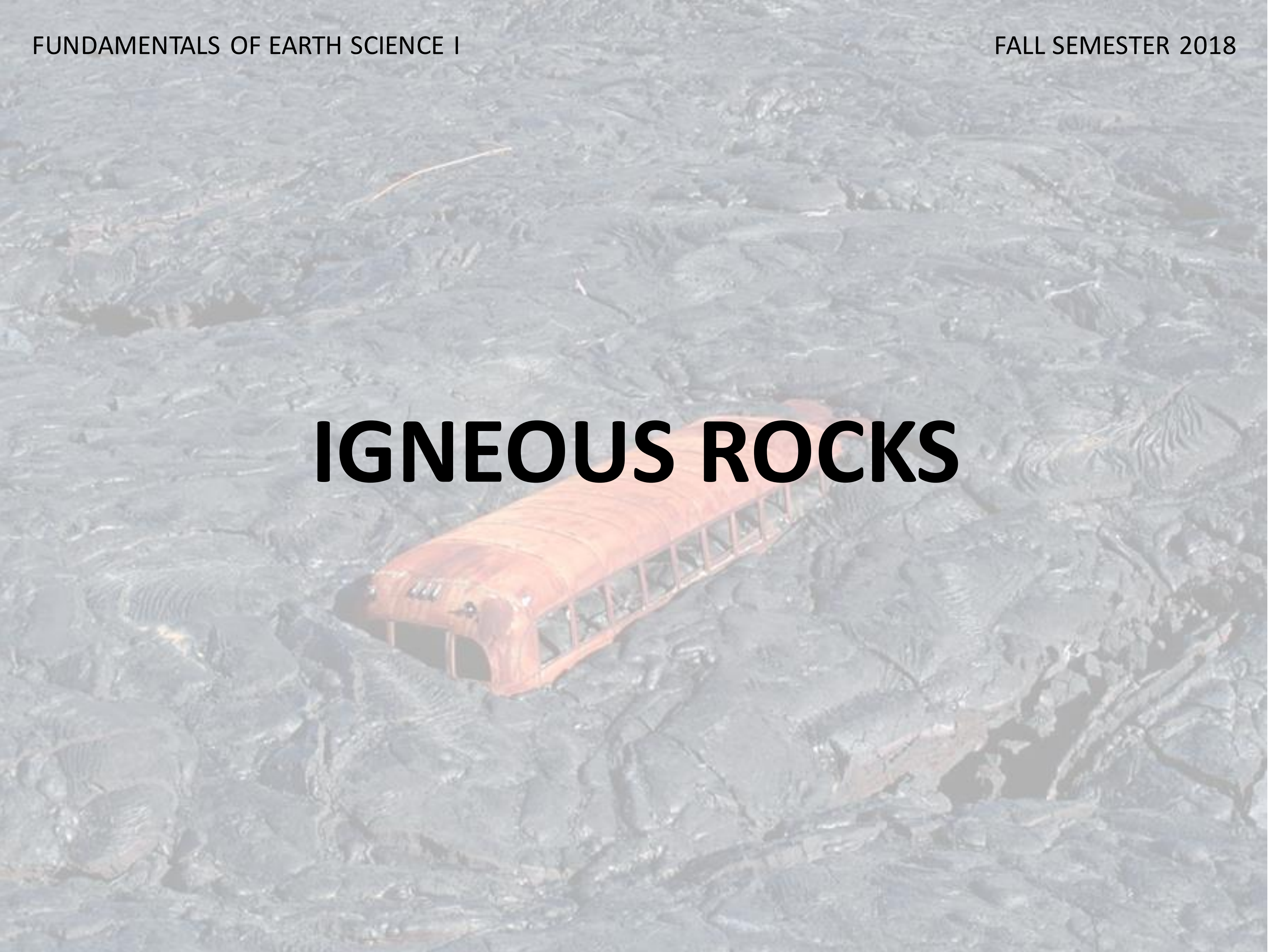
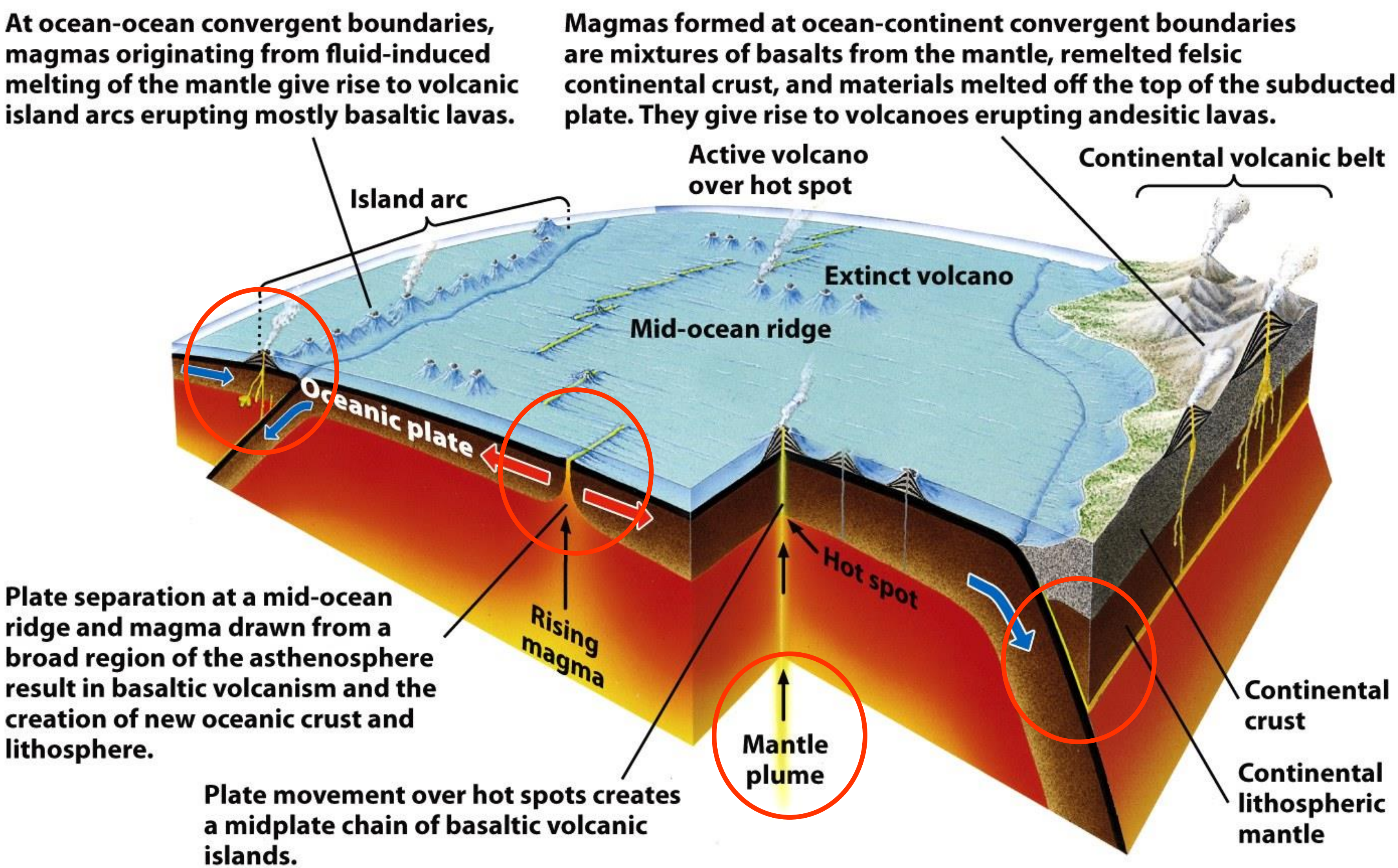


IGNEOUS ROCKS

✶ Where do igneous rocks form?



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✶ Classification of igneous rocks

1. TEXTURE

Cooling of **magma/lava**
Crystallization of minerals
Formation of an **igneous rock**

Slow cooling **within the lithosphere**

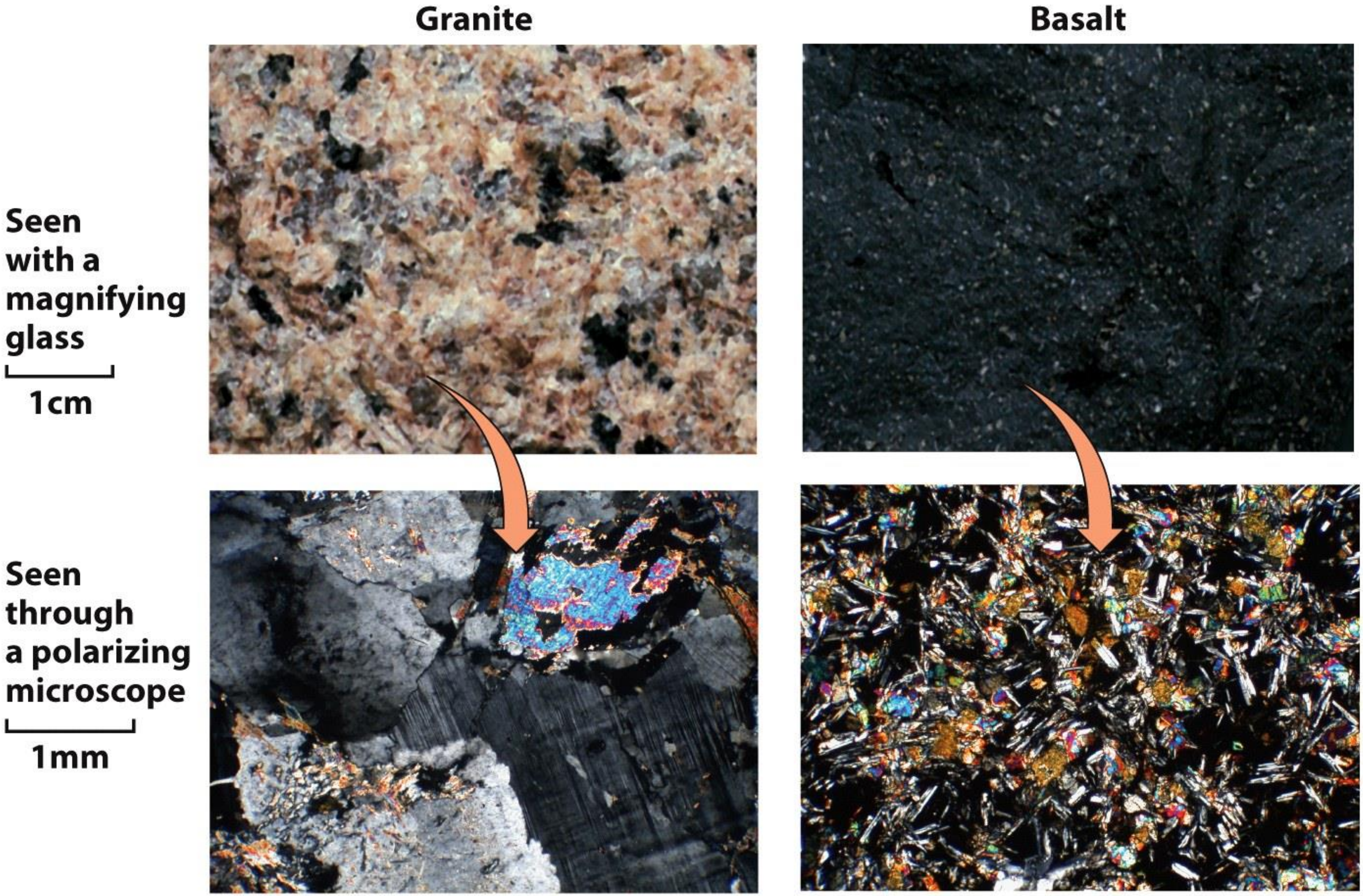
INTRUSIVE IGNEOUS ROCKS
Coarser-grained texture

e.g. granite

Rapid cooling near or on **Earth's surface**

EXTRUSIVE IGNEOUS ROCKS
Finer-grained texture

e.g. basalt



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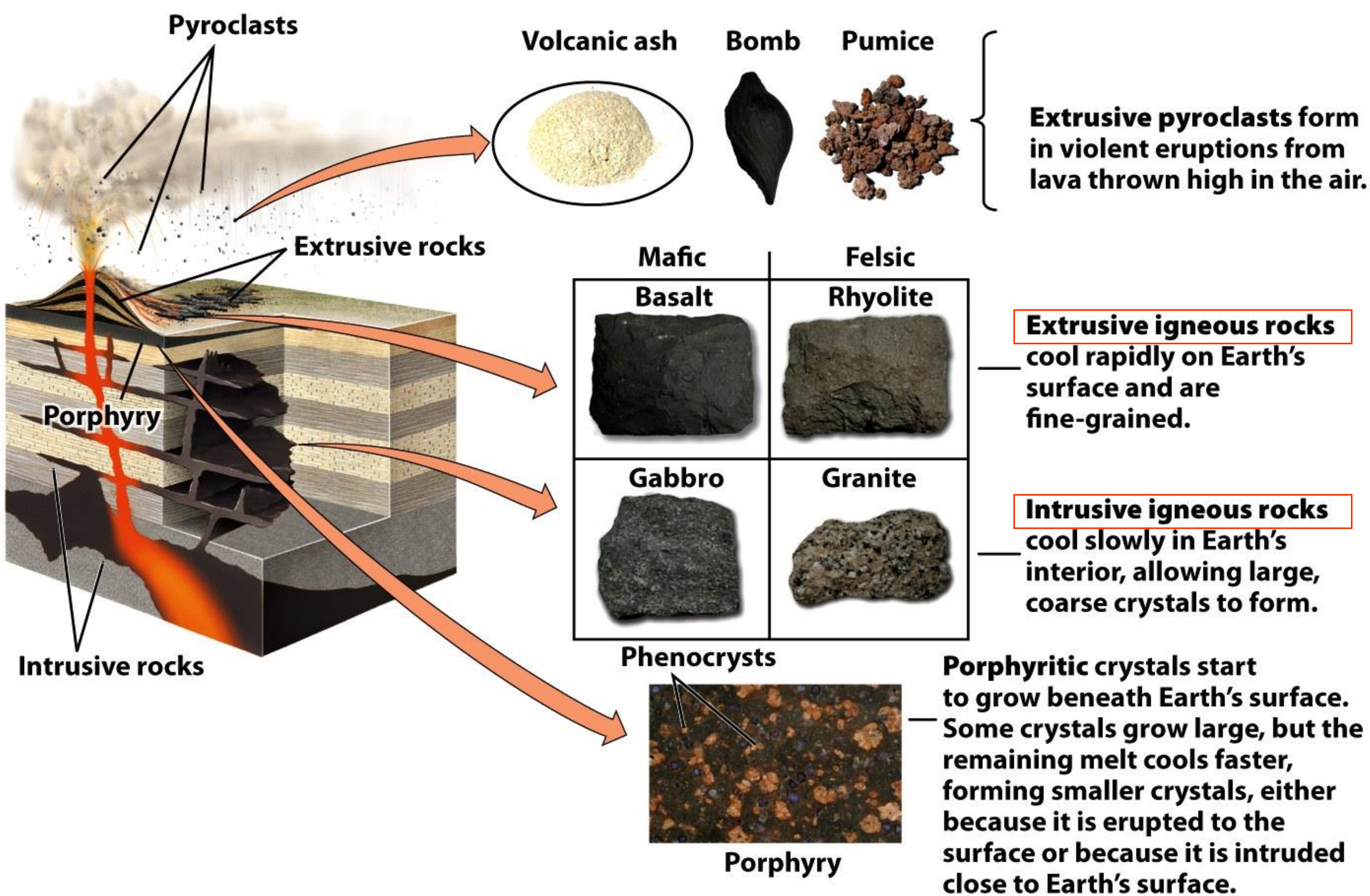
Different types of igneous rocks identified based on the texture



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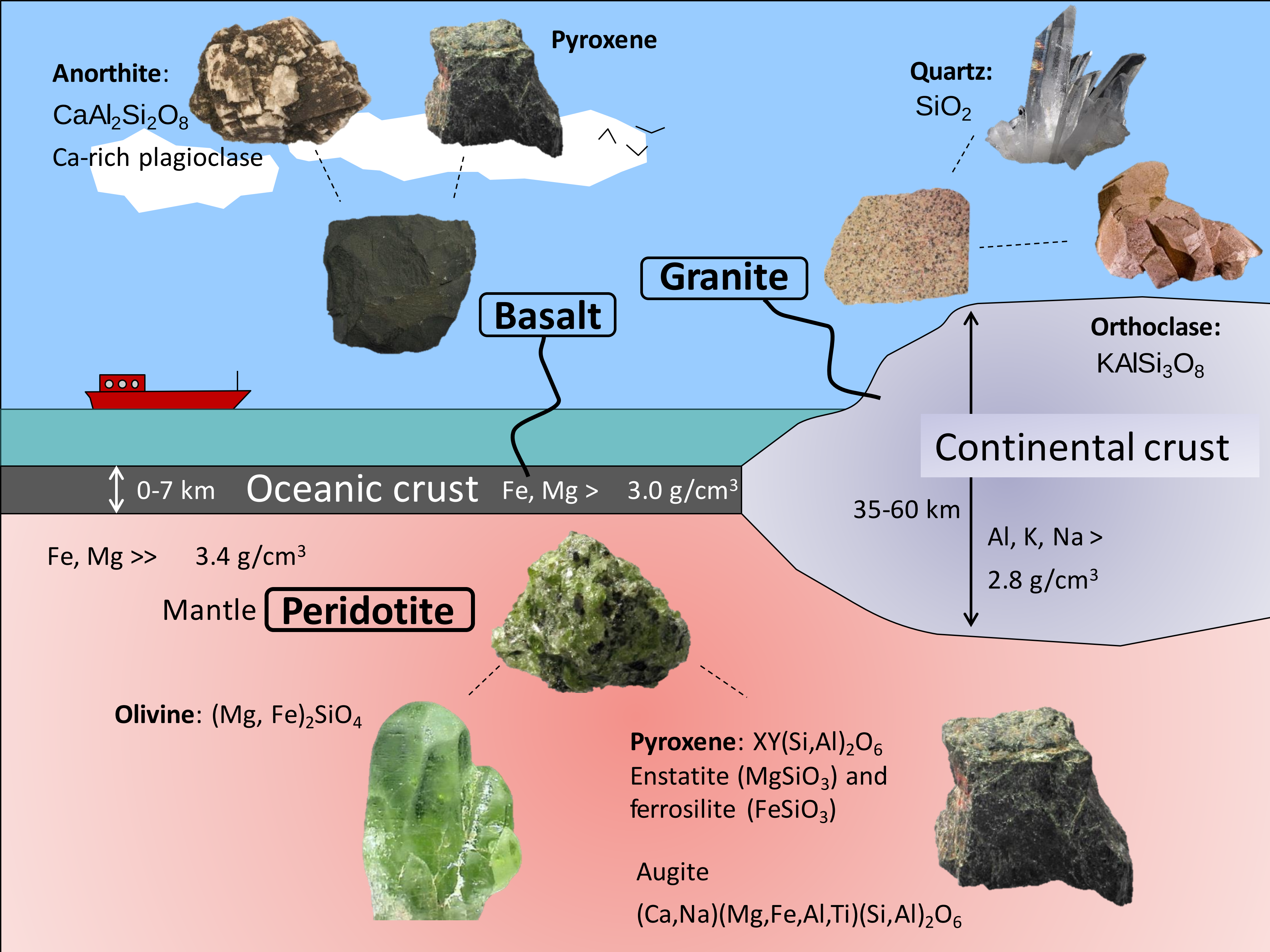
Felsic vs. **mafic** compositions

Felsic : feldspar-silica | **Mafic : magnesium-ferric**

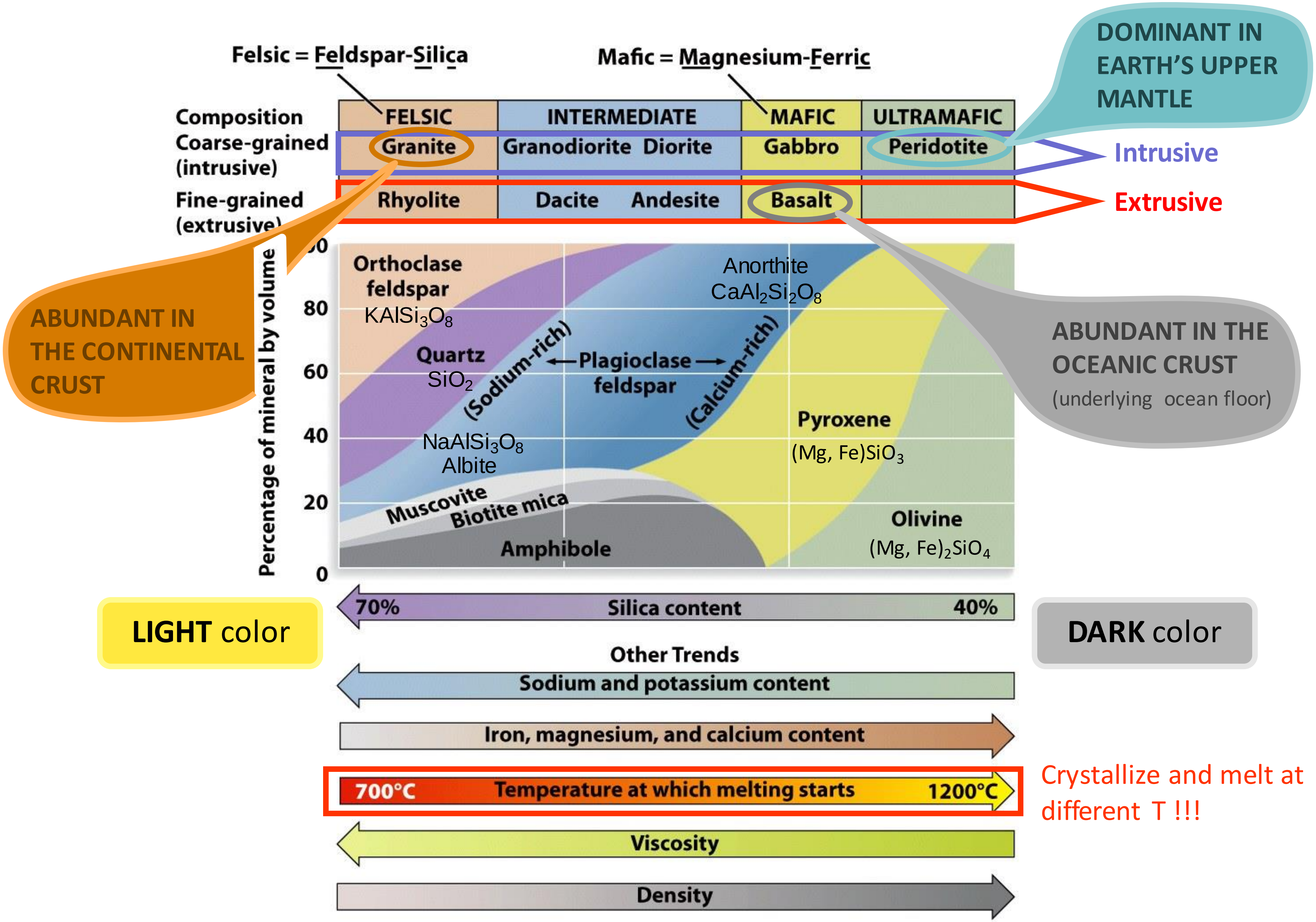
FELSIC	**MAFIC**
*Igneous rocks enriched in **SiO2** and silicates rich in **Al, K, Na***	*Igneous rocks enriched in silicates rich in **Fe, Mg***
Quartz (SiO_2)	*Biotite (mica)*
Orthoclase (K-rich feldspar)	*Amphibole group*
Plagioclase (Na/Ca-rich feldspar)	*Pyroxene group*
Muscovite (K-rich mica)	*Olivine*
***Example**: granite (continental crust)*	***Example**: basalt (oceanic crust)*
Light color	***Dark color***

←————————————————→

CONTINUUM



Anorthite:
$CaAl_2Si_2O_8$
Ca-rich plagioclase
Pyroxene
Quartz:
SiO_2
Granite
Basalt
Orthoclase:
$KAlSi_3O_8$
Continental crust
0-7 km
Oceanic crust
Fe, Mg >
3.0 g/cm^3
35-60 km
Al, K, Na >
2.8 g/cm^3
Fe, Mg >>
3.4 g/cm^3
Mantle
Peridotite
Olivine: $(Mg, Fe)_2SiO_4$
Pyroxene: $XY(Si,Al)_2O_6$
Enstatite ($MgSiO_3$) and
ferrosilite ($FeSiO_3$)
Augite
$(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$



http://www.gso.uri.edu/lava/MagmaProperties/properties.html

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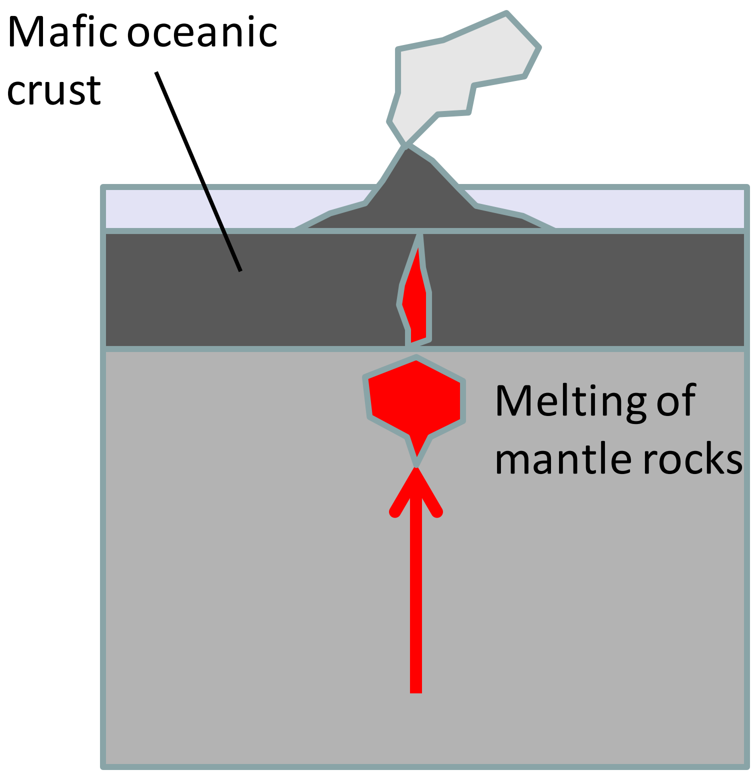
Production of **basaltic magmas** at oceanic hot spots

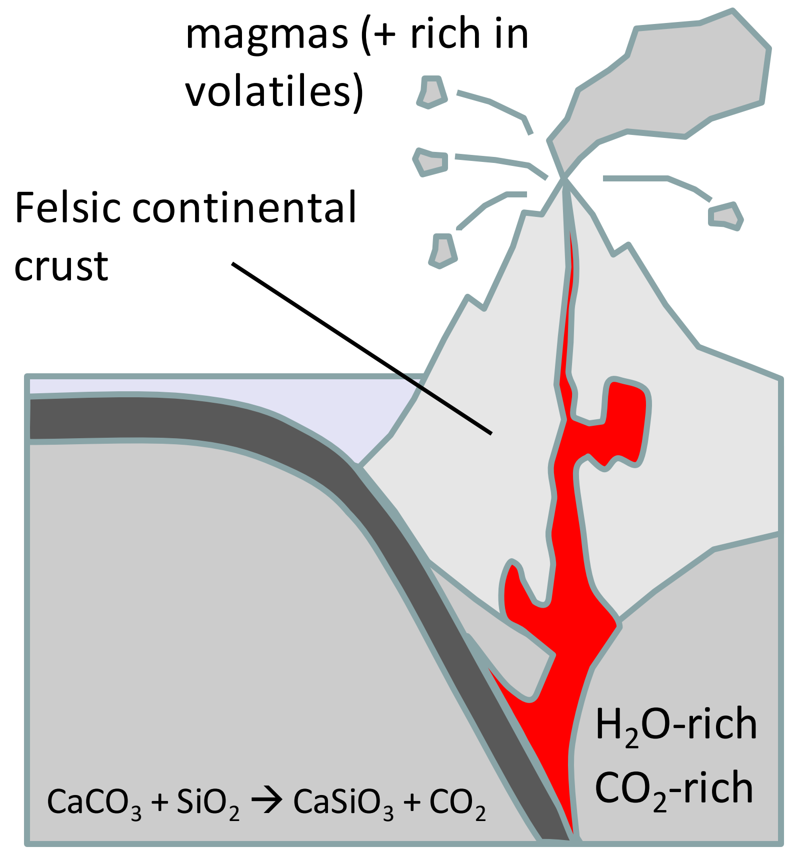
Low-viscosity magmas



LOW RISK OF EXPLOSION

Production of more **felsic magmas** at ocean-continent subduction zones

High-viscosity magmas (+ rich in volatiles)



HIGH RISK OF EXPLOSION

Basaltic volcanism (mafic composition)

Shield volcanoes Hawaii hot spot

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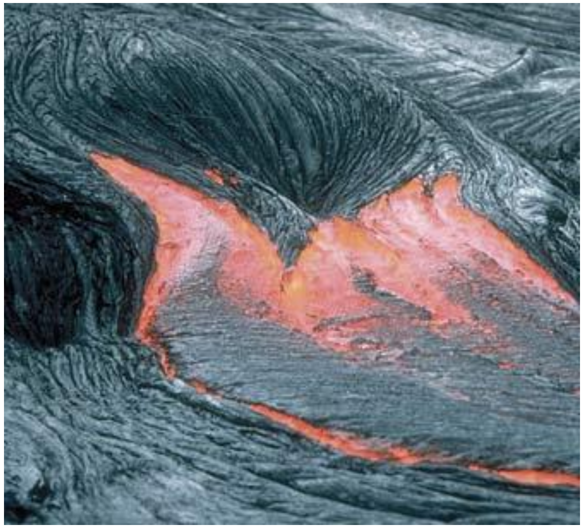
“PAHOEHOE” LAVA



www.britannica.com

“AA” LAVA

www.britannica.com

“PILLOW” LAVA

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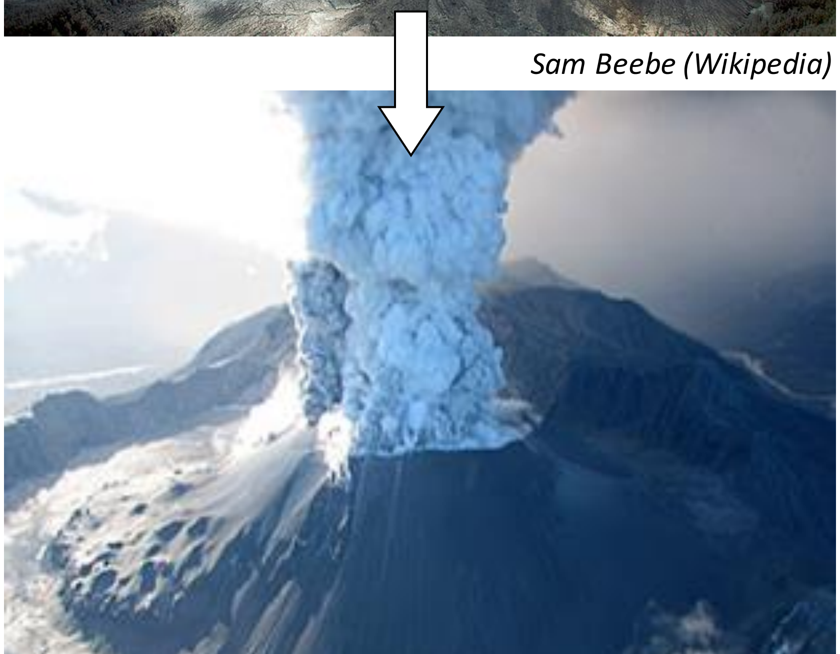
Rhyolitic volcanism (felsic composition)

Volcanic domes

MOUNT CHAITÉN (Chile)

Sam Beebe (Wikipedia)



USGS

RHYOLITIC LAVA DOME (Oregon, USA)

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✶ Processes of magma formation

Factors controlling magma production:

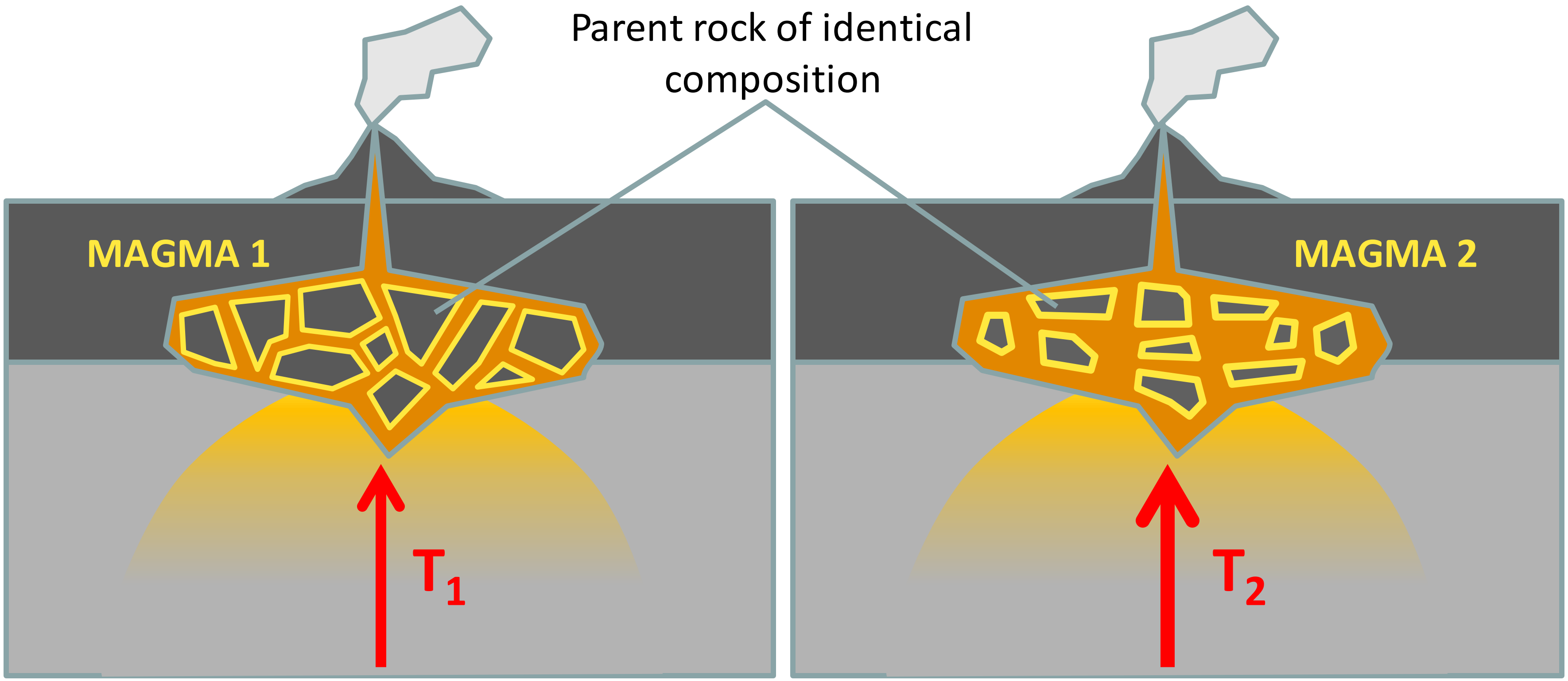
1. **Temperature**
   - All minerals do not melt at the same temperature (felsic vs. mafic)

2. **Pressure**
   - Lower pressures result in lower melting temperatures
     → Lowering the pressure facilitates melting!

3. **Water content**
   - Increased water content results in lower melting temperatures
     → Adding water facilitates melting!

1. Role of temperature

Different minerals melt at different temperatures



Temperature 1 (T_1) < Temperature 2 (T_2)

% melting 1 < % melting 2

Composition of partial melt 1 (magma 1) ≠ **composition** of partial melt 2 (magma 2)

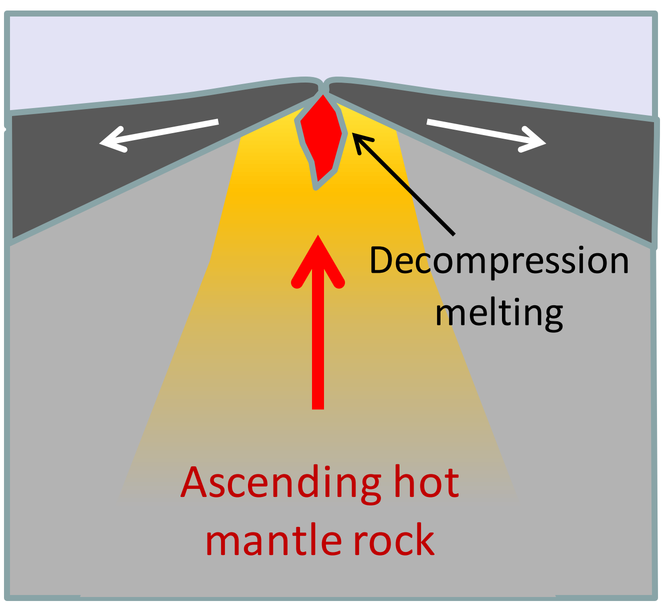
2. Role of pressure

- **High pressures** deep in the Earth's interior prevent rocks from melting

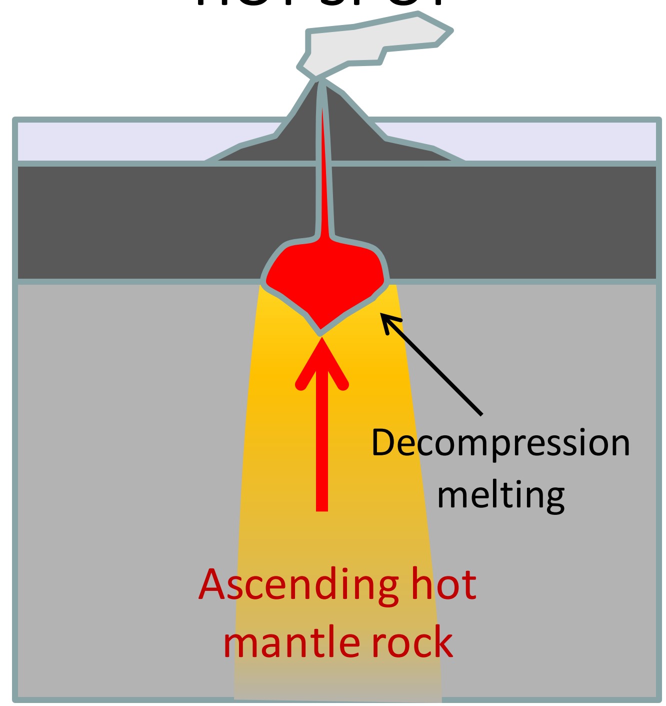
- Hot mantle rock begins to melt when it rises beneath mid-ocean ridges and hotspots when the pressure drops =

Decompression melting

Mid Ocean Ridge (MOR)



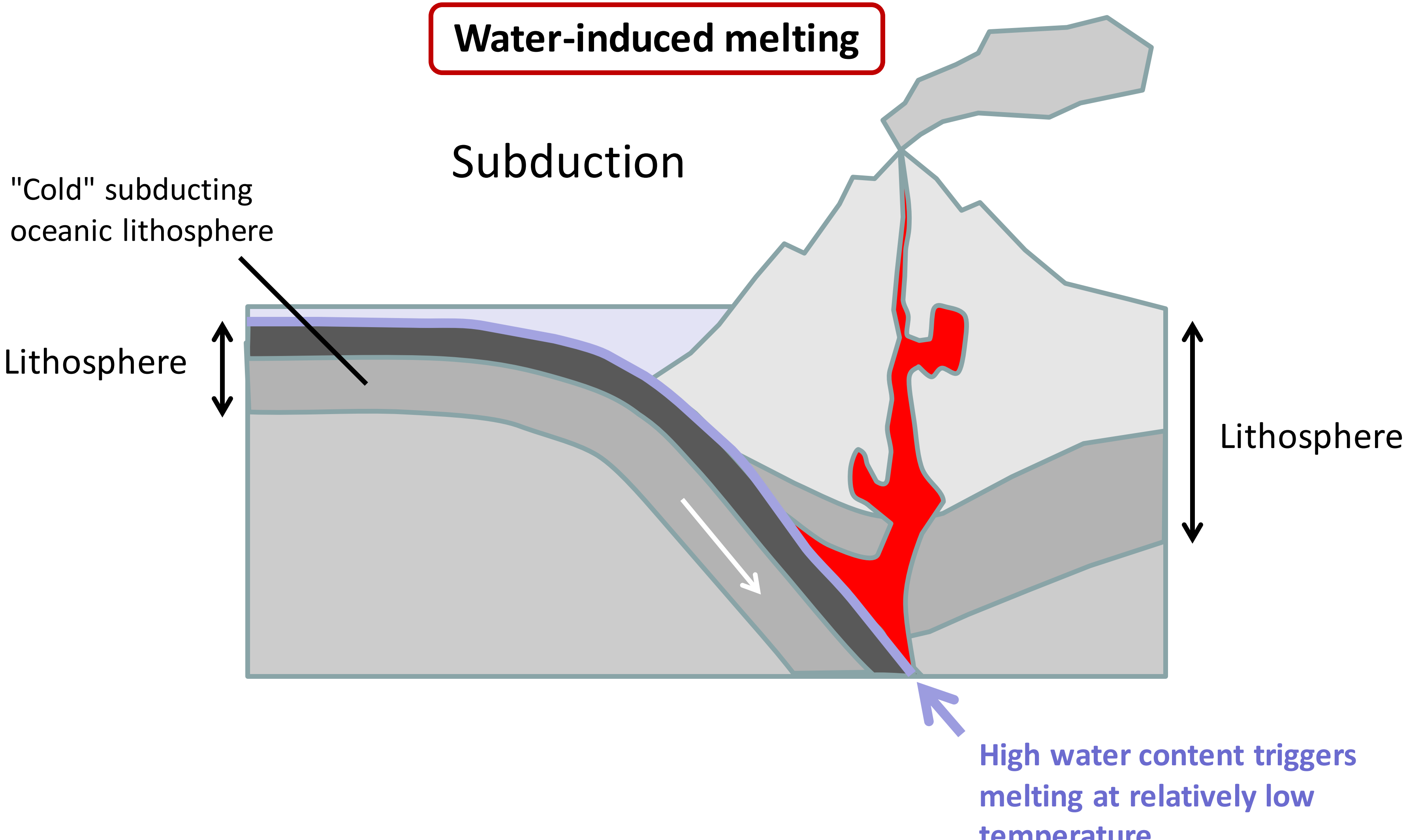
HOT SPOT



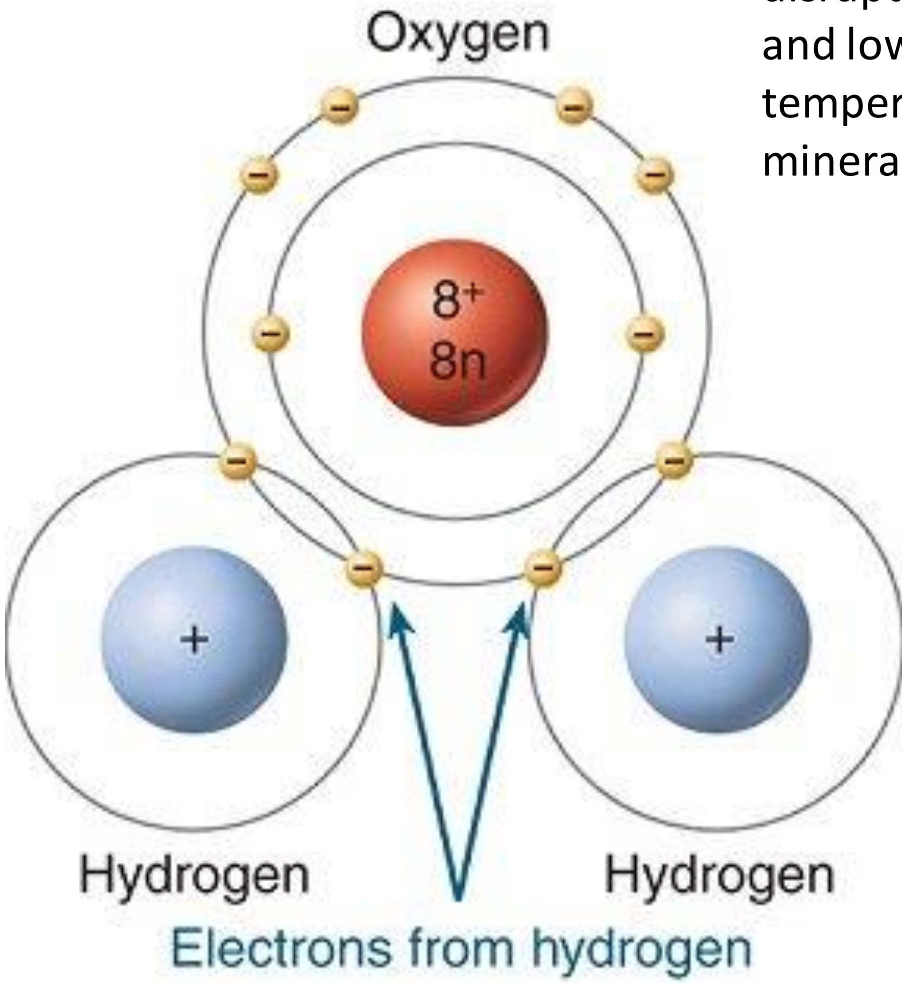
3. Role of water

Sedimentary rocks carried by the subducting plate have a **high water content** in the **open space** between grains (pores) and in **clay minerals**.

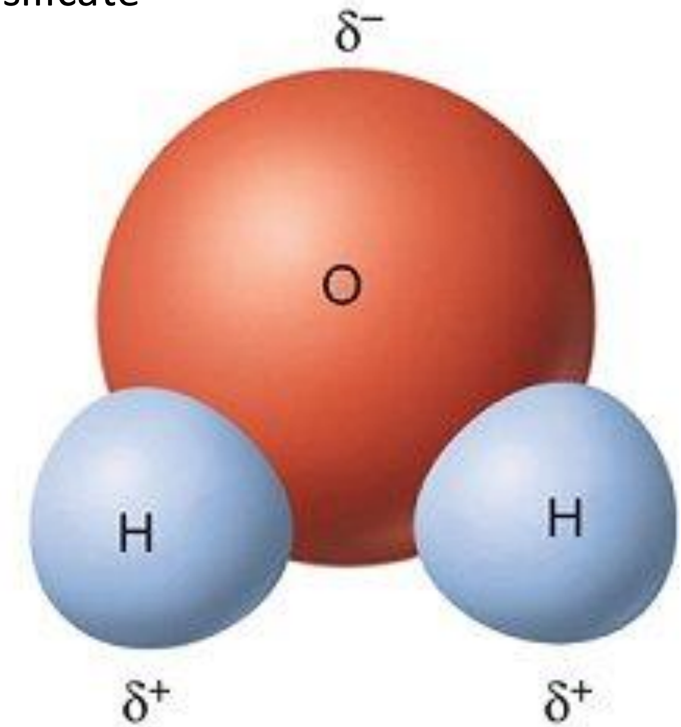
Water-induced melting



Water molecules disrupt chemical bonds and lower the melting temperature of silicate minerals.



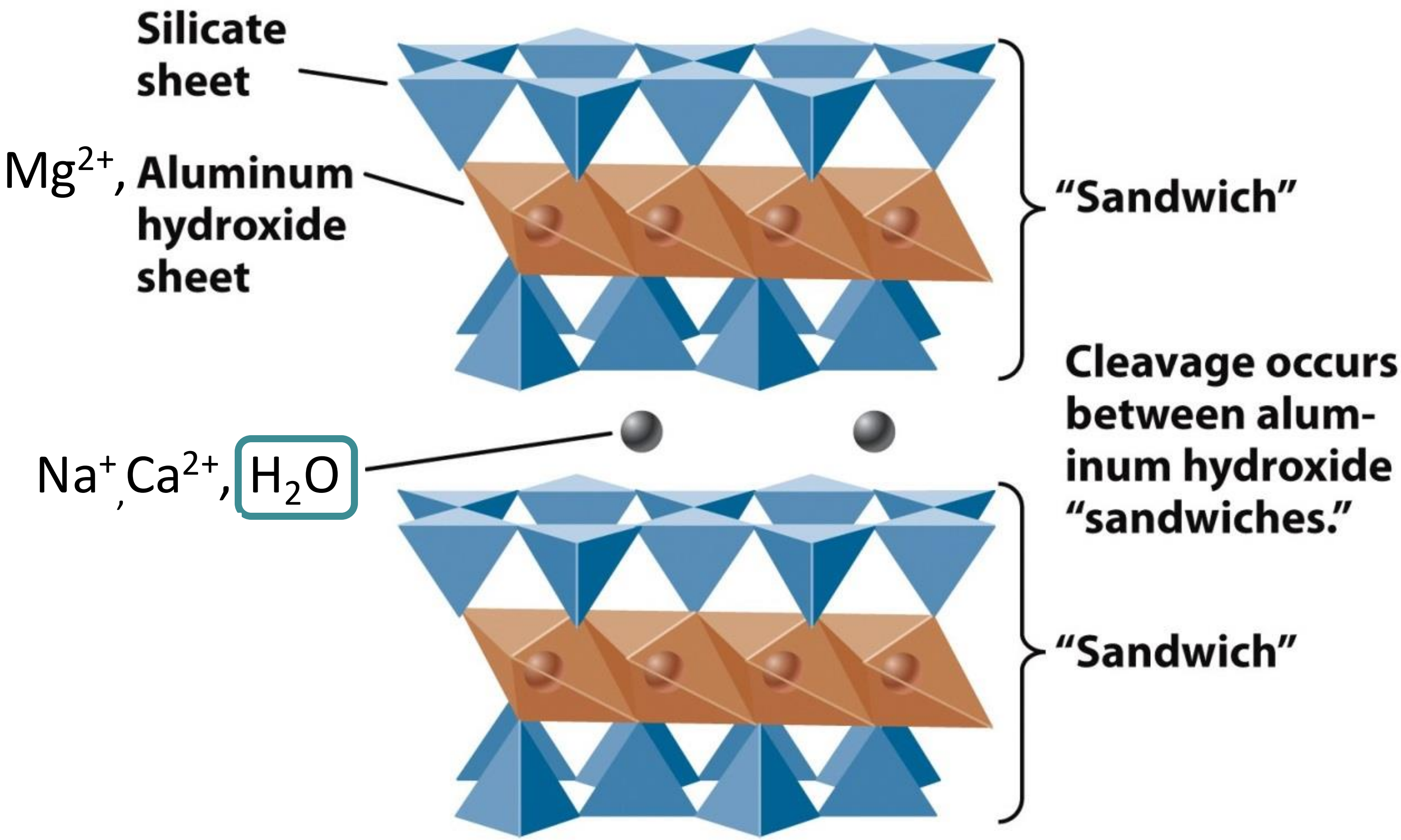
(a) Electron shells in a water molecule



(b) Distribution of partial charges in a water molecule

Hydrous Aluminium Phylosilicates (smectite group)

e.g. montmorillonite → $(Na, Ca)_{0.33}(Al, Mg)_2Si_4O_{10}(HO)_2.nH_2O$



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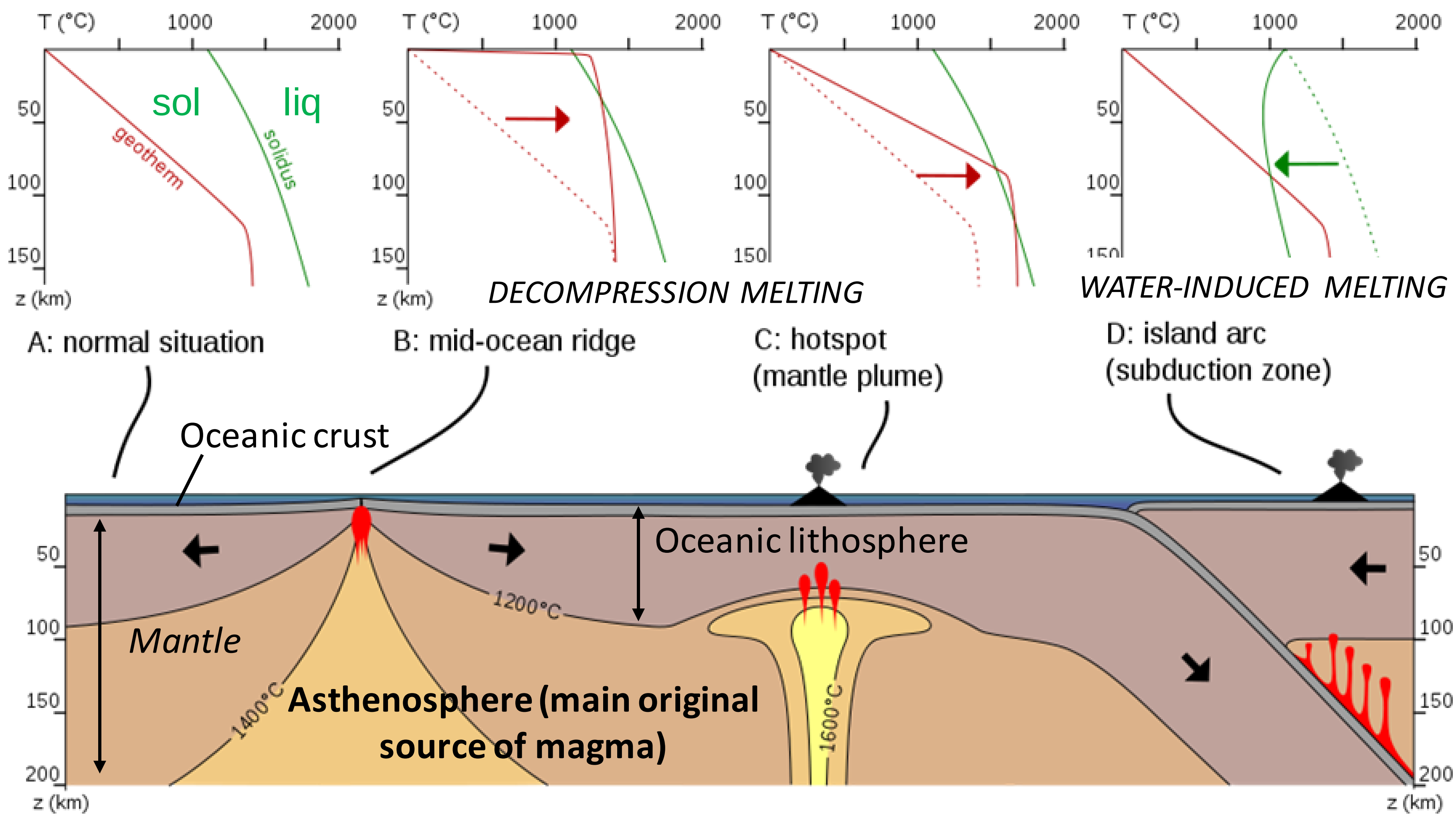
How magma forms: Geothermal gradient & rock solidus

Red line (geotherm): Rock temperature vs. depth (T increases with depth)

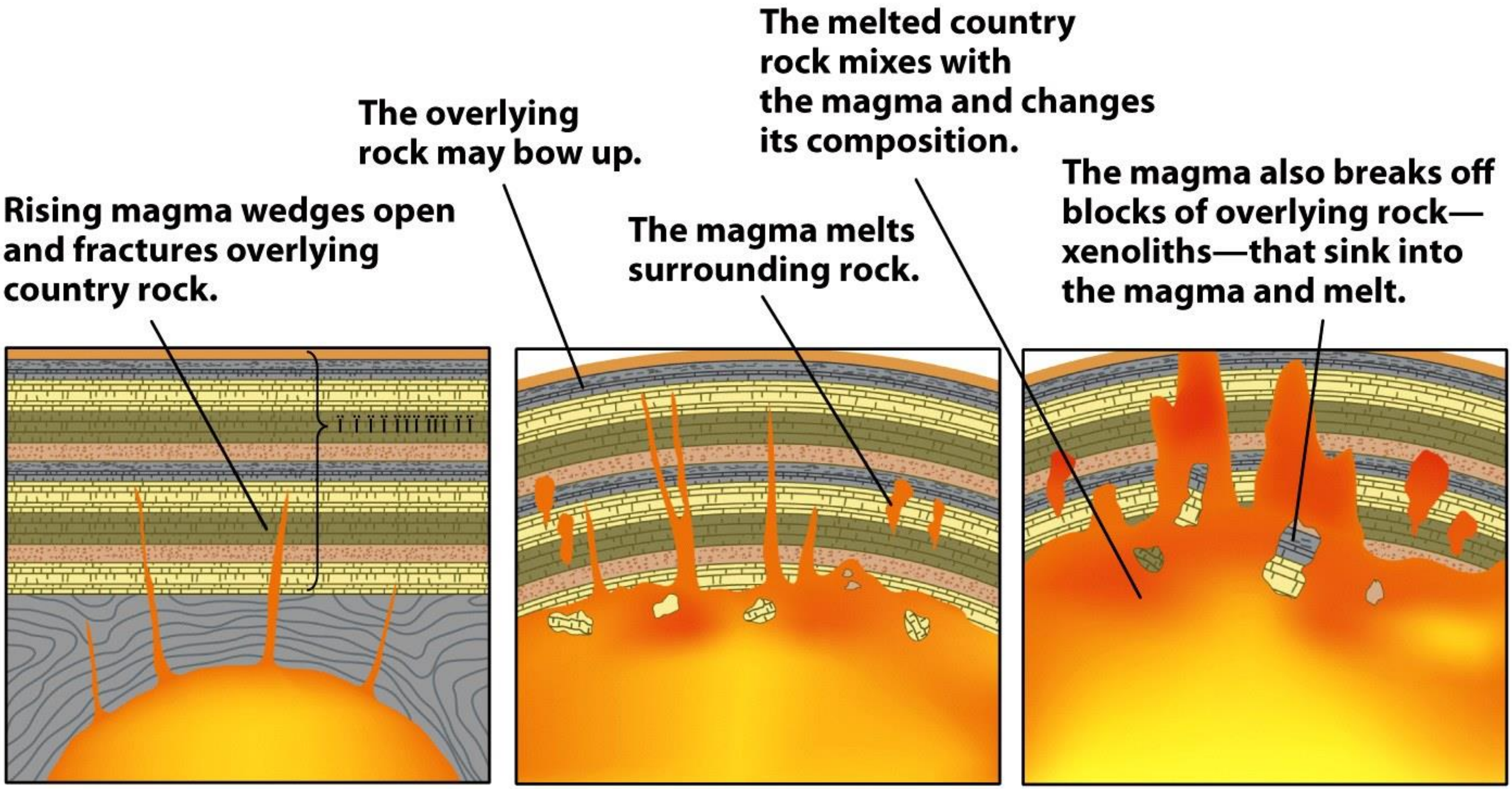
Green line (solidus): Temperature at which the rock starts to melt



http://www.ei.lehigh.edu/learners/tectonics/heatflow/heatflow2.html

Magma is less dense than surrounding solid rocks and rises through fissures in the rock or by melting its way up.

Magma accumulates in large **magma chambers** in the crust.



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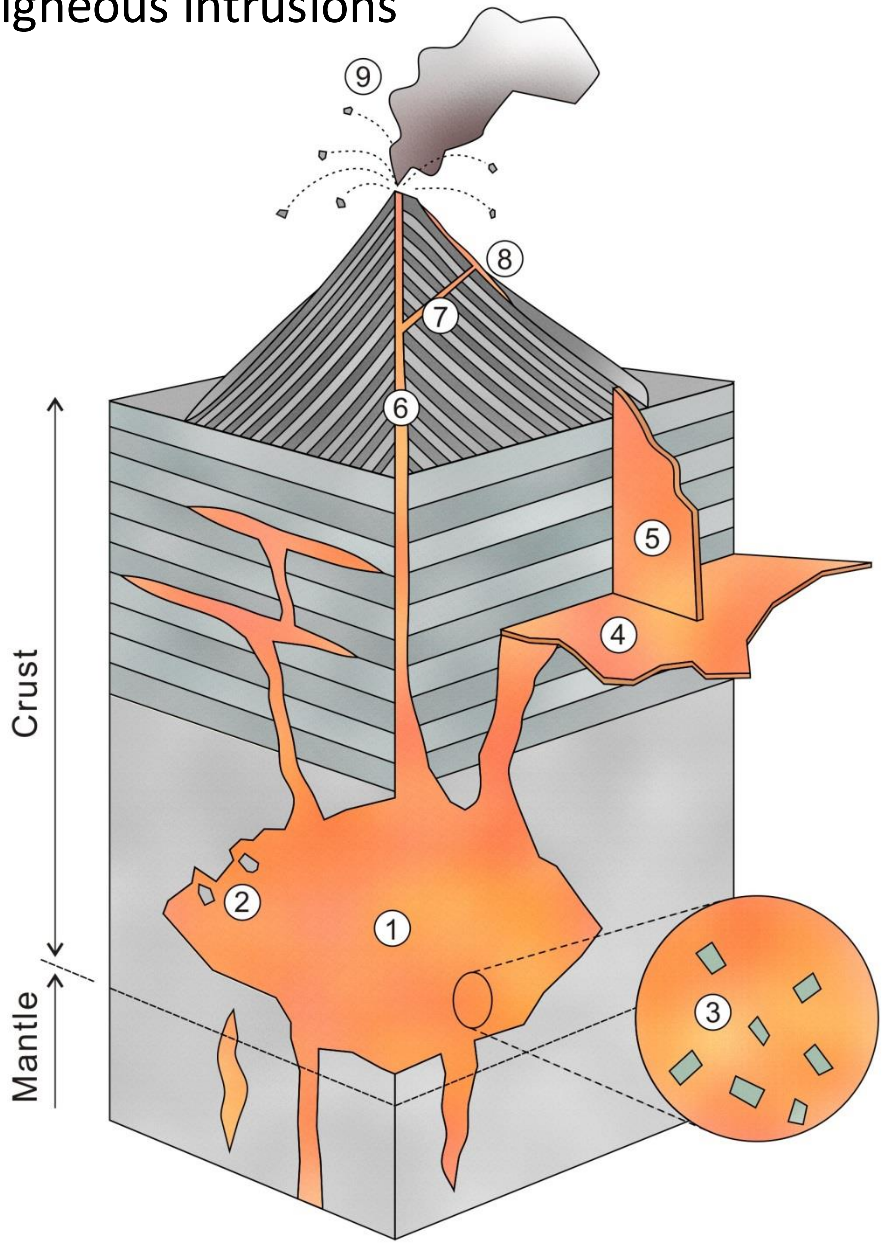
Forms of igneous intrusions



1. **Magma chamber (pluton)**
2. **Surrounding rocks melt and influence magma composition**
3. **Different minerals crystallize at different temperatures which influence the composition of the remaining melt**
4. **Sill (horizontal sheet-like intrusion)**
5. **Dyke (vertical sheet-like intrusion)**
6. **Central vent**
7. **Side dent**
8. **Lava flow**
9. **Pyroclasts**

✶ Magma crystallization and formation of igneous rocks

How can we explain the diversity of igneous rocks?

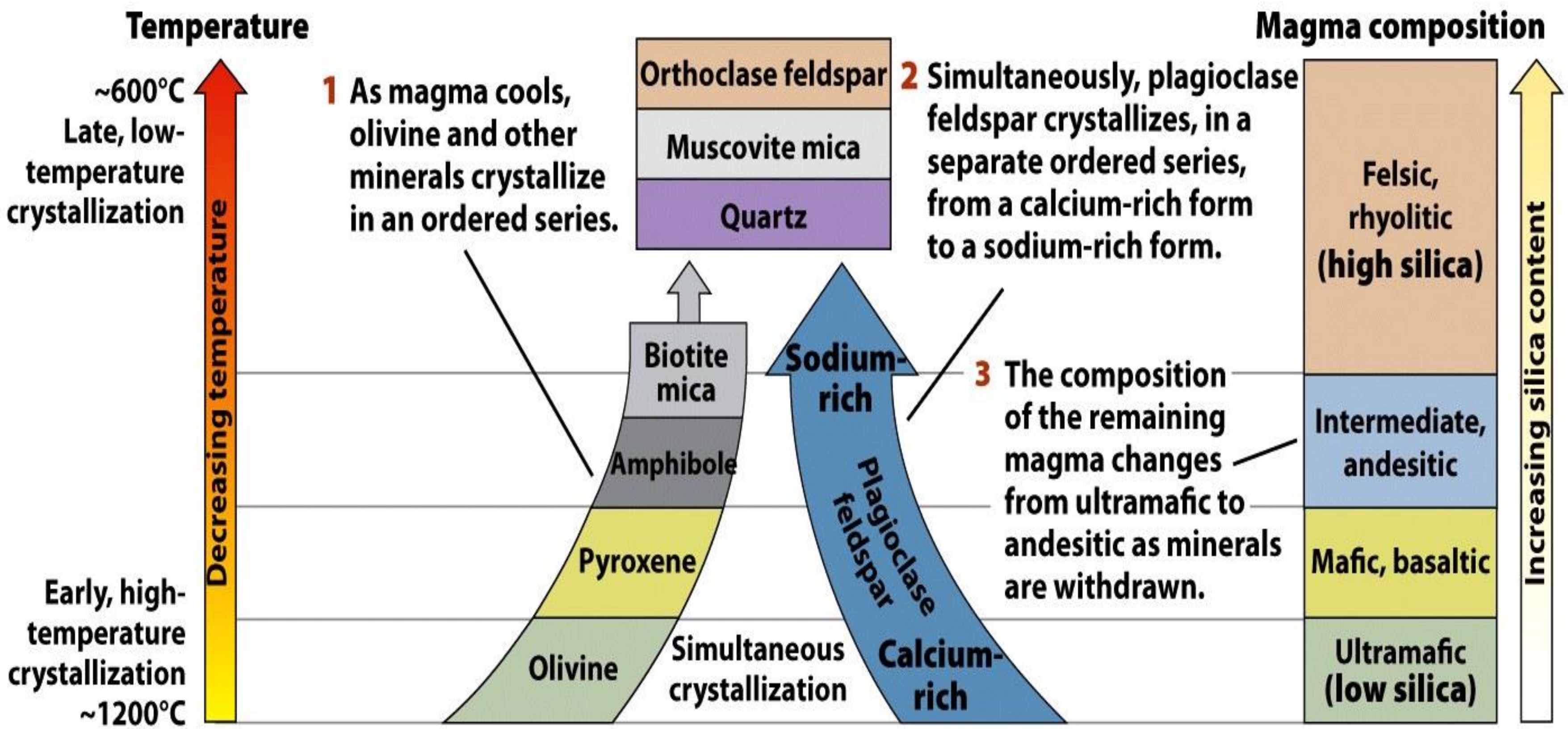
1. **Crystal fractionation**
   - Minerals crystallize at different temperatures. Minerals that crystallize first in the magma chamber tend to settle down first. This is called **crystal fractionation**. This process results in the formation of igneous rocks of different compositions. One single parent magma can therefore produce different igneous rocks. Change in magma composition during crystallization is called **magmatic differentiation**.

2. **Crustal contamination**
   - Changes in magma composition as the magma travels in the crust and incorporate pieces of the surrounding crustal rocks.

3. **Magma mixing**
   - The mixing of magmas with different chemical compositions may lead to the formation of igneous rocks whose compositions differ from the rocks that would have been produced if the two magmas had crystallized separately without mixing.

1. Crystal fractionation

The **Bowen's reaction series** (established experimentally)



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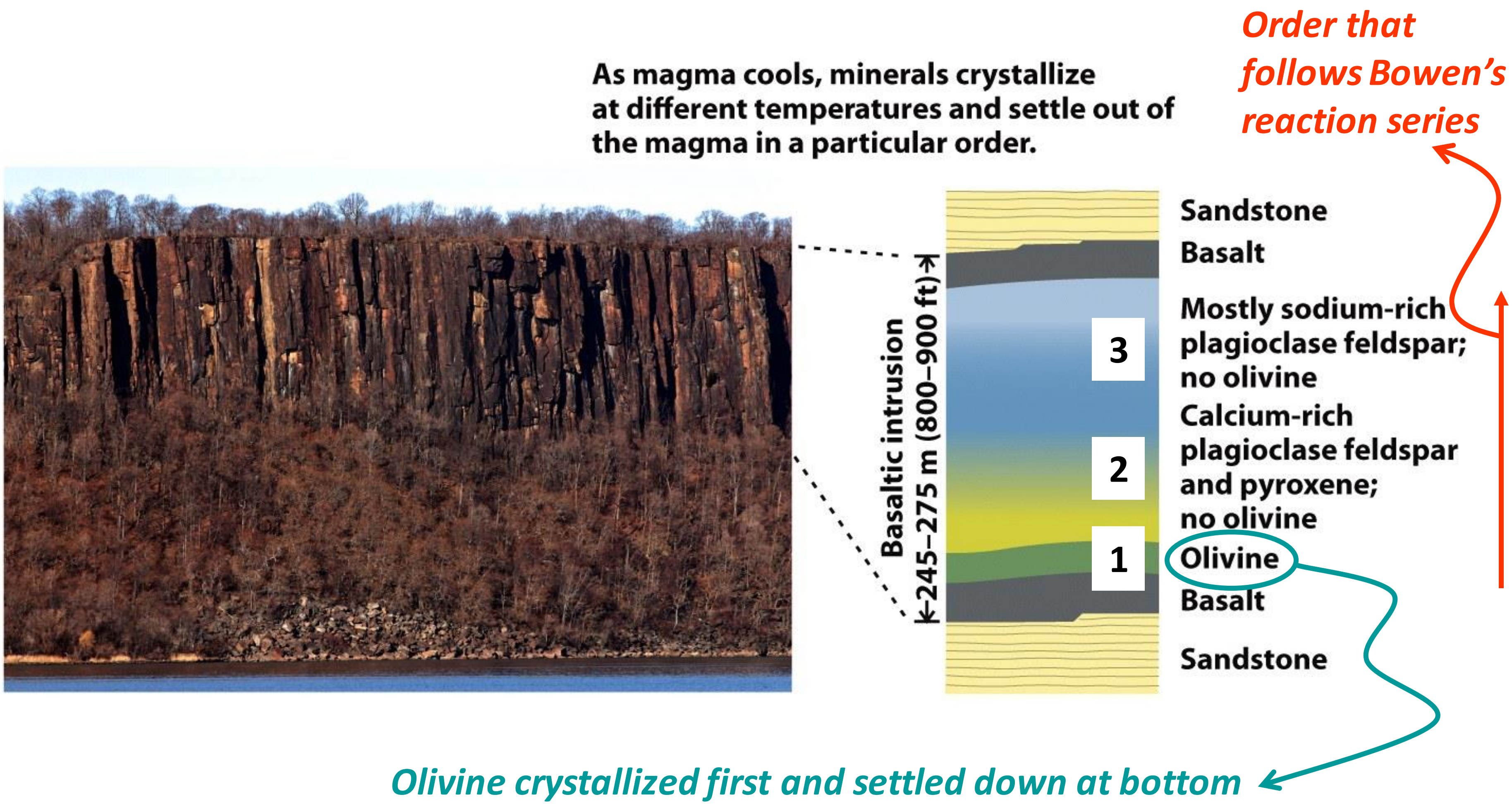
Minerals crystallizing first tend to settle down first in magmatic intrusions which means that layers of igneous rocks of different compositions can form.

Crystal settling rate also depends on density and size of crystals and the viscosity of the remaining magma (+ turbulences in magma chamber)



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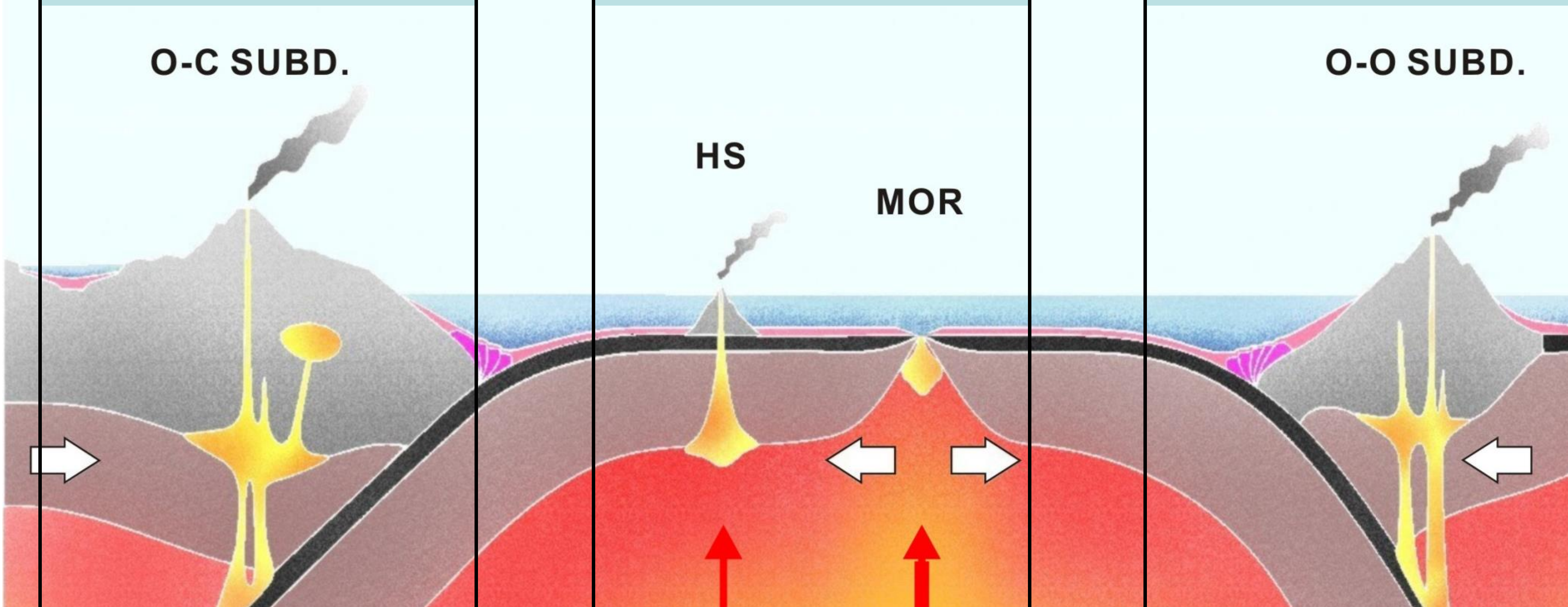
2. Crustal contamination

Mafic to felsic

Mafic

Mafic to intermediate



Contamination by sedimentary rocks and continental crustal rocks

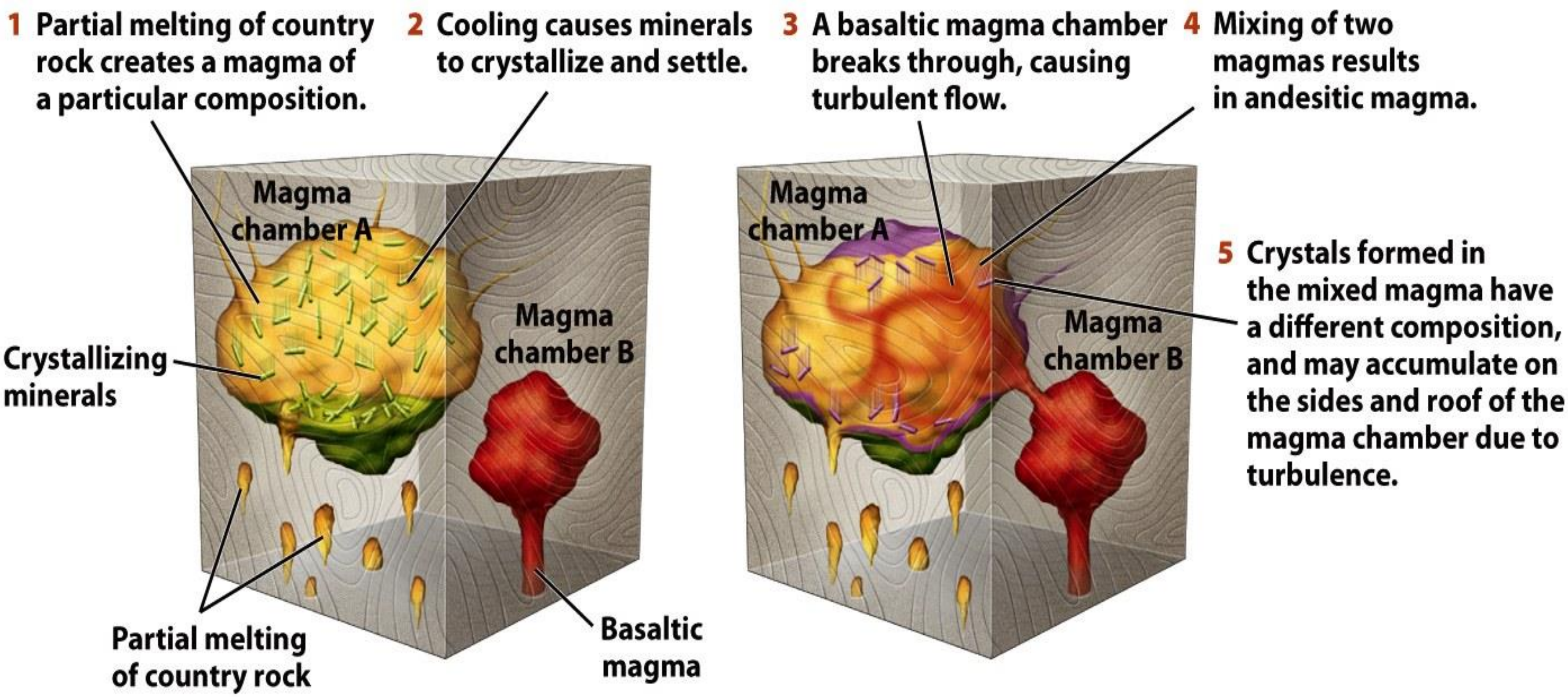
Magma derived from mantle rocks

Contamination by oceanic crustal rocks (including sediments)

Original magma derived mostly from mantle rocks

ULTRAMAFIC

3. Magma mixing



NB: Some magmas are immiscible, which means they cannot mix (like oil and water)

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Igneous differentiation can lead to the segregation of valuable minerals in layered intrusions.

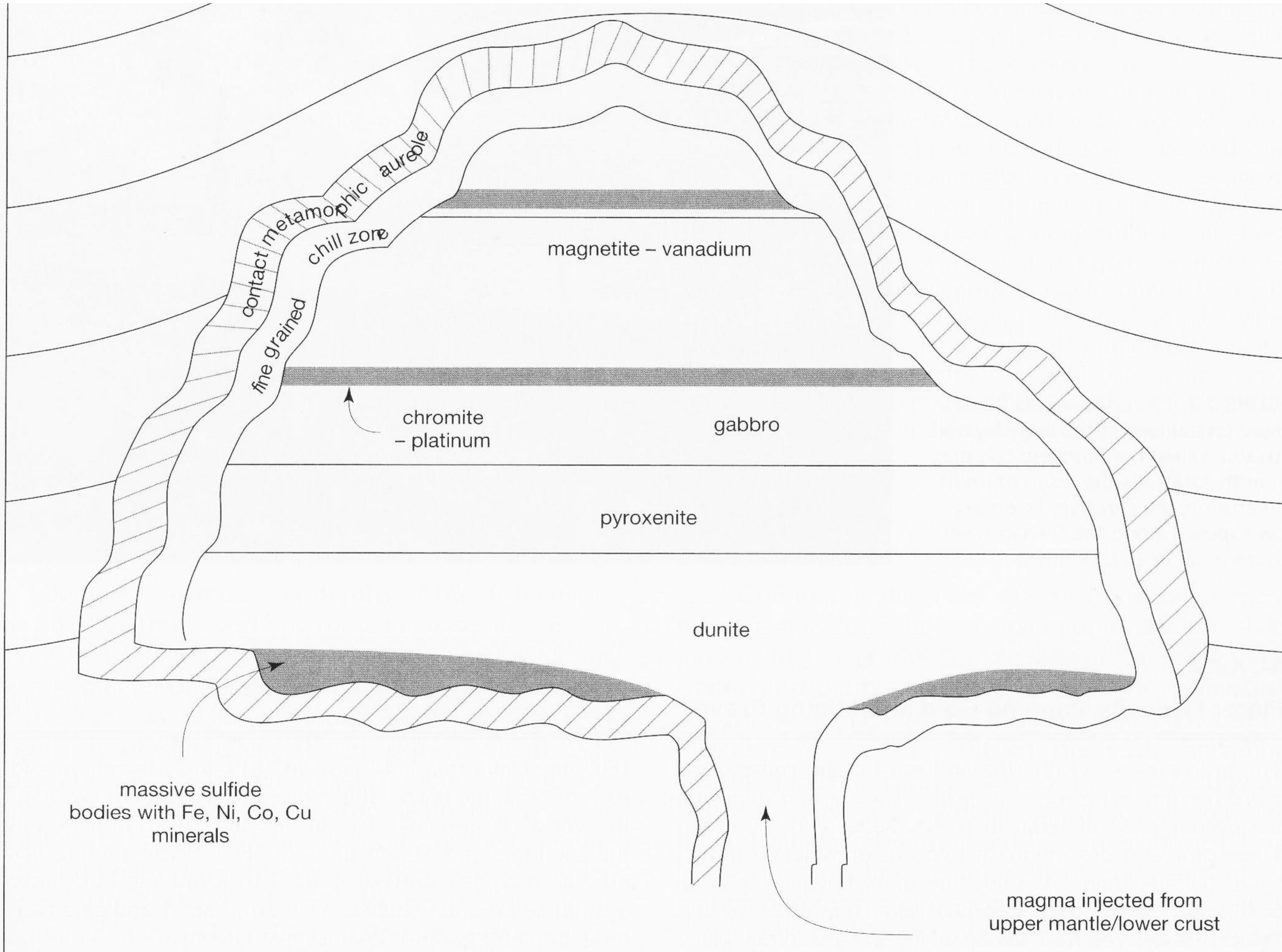


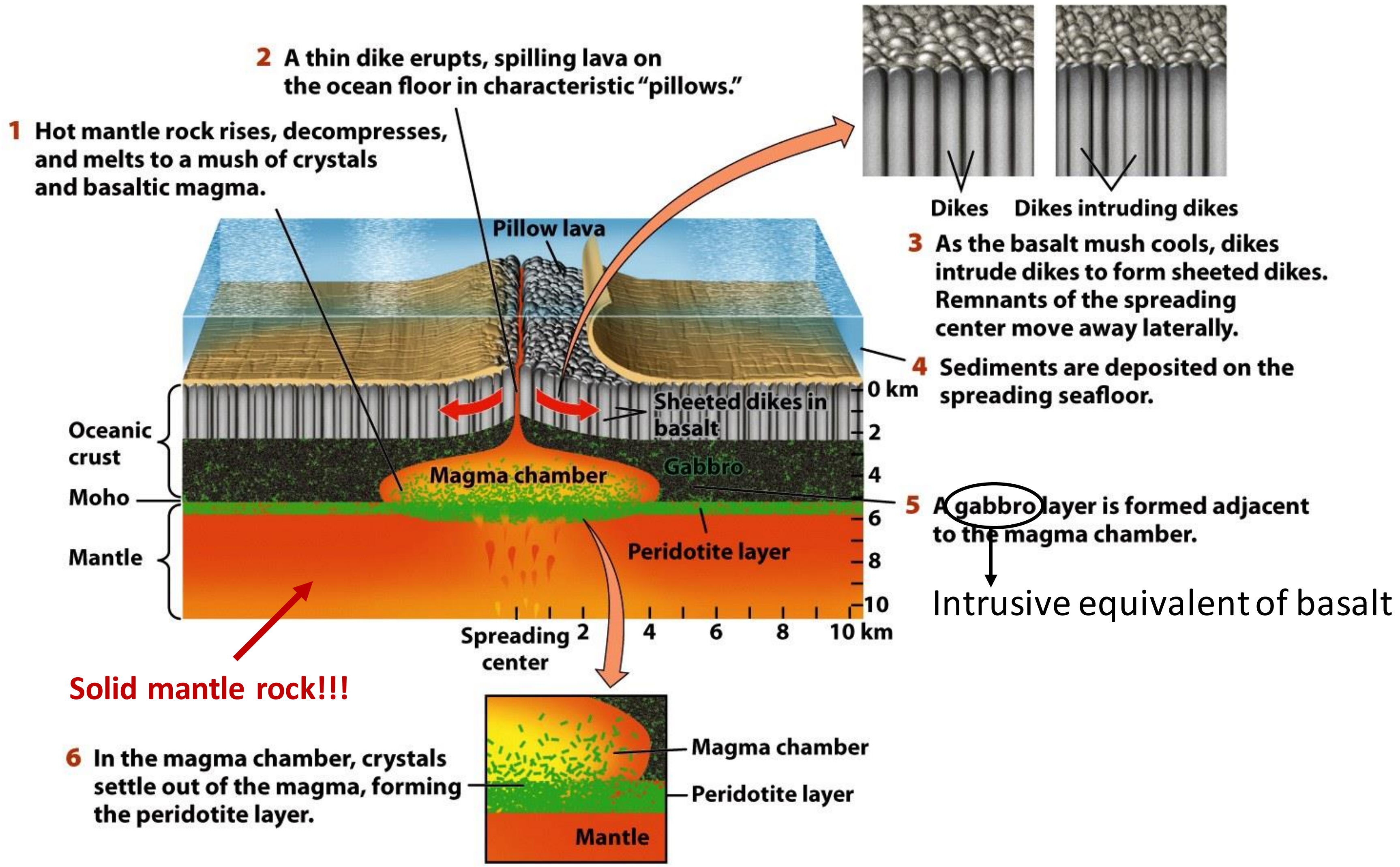
FIGURE 2.6 After large masses of silica-poor magmas are emplaced or melt their way into Earth's crust, they may take tens of thousands to millions of years to crystallize. During crystallization, these intrusions acquire a distinctly layered structure, with some zones being rich in minerals useful as mineral resources.

Craig et al. (2011)

Layers of chromite (black), Bushveld *(photo: Jackie Gauntlett, blogs.agu.org)*

Iron-titanium oxide (ilmenite) mining in Norway *(wikipedia)*

✶ Formation of oceanic crust at mid-ocean ridges



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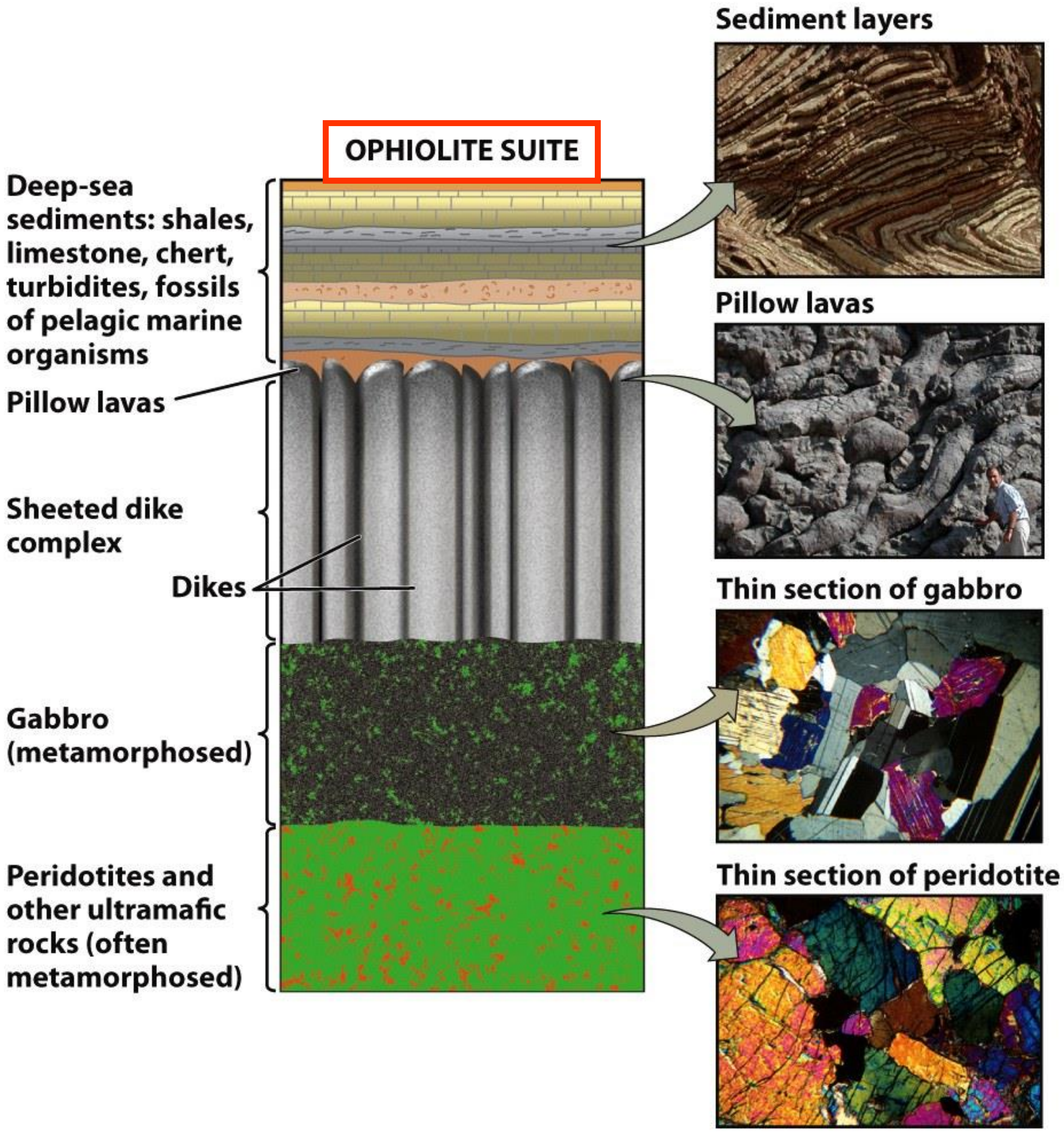

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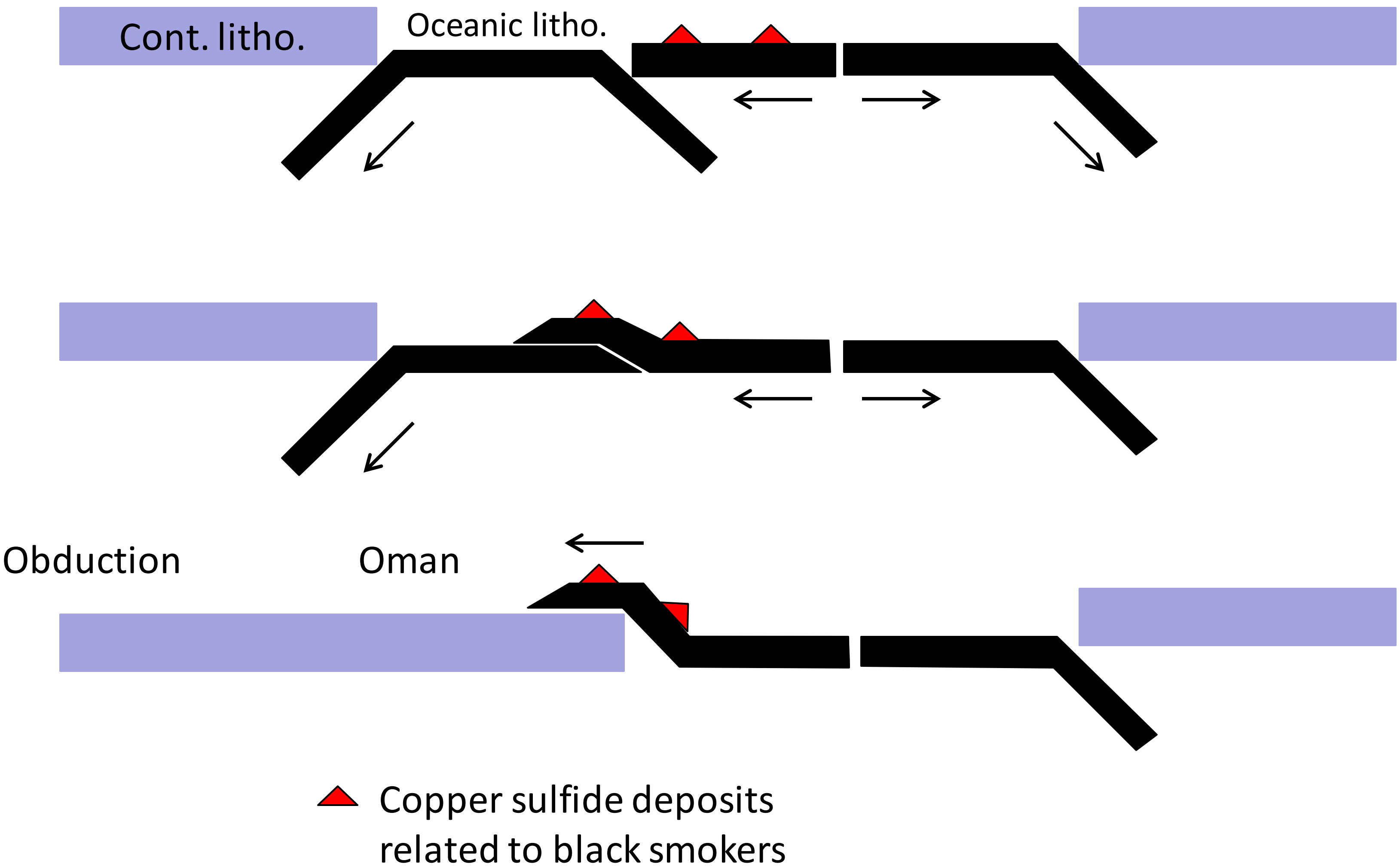
Large ophiolite outcrops occur in Oman

www.omantourism.gov.om

100-80 x 10^6 yr ago

Subduction



Modified from Schreurs and Milson (2006)