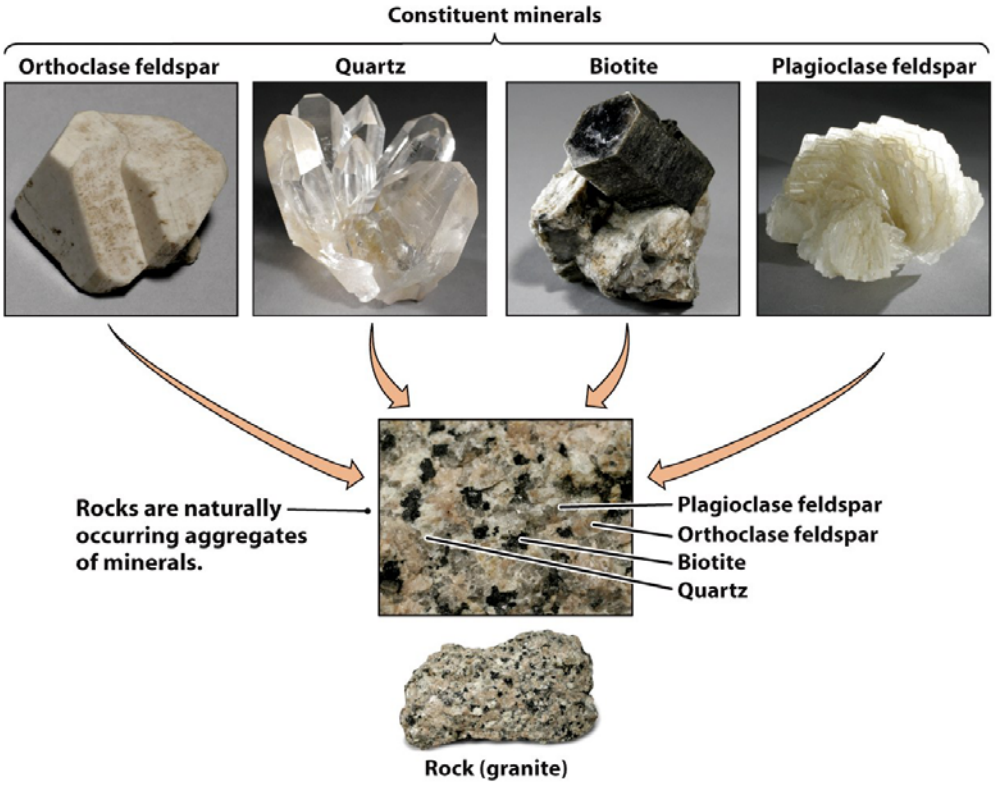
G-100 Lectures 6 & 7
Introduction to Rocks
Focus on: Igneous Rocks

What are rocks?



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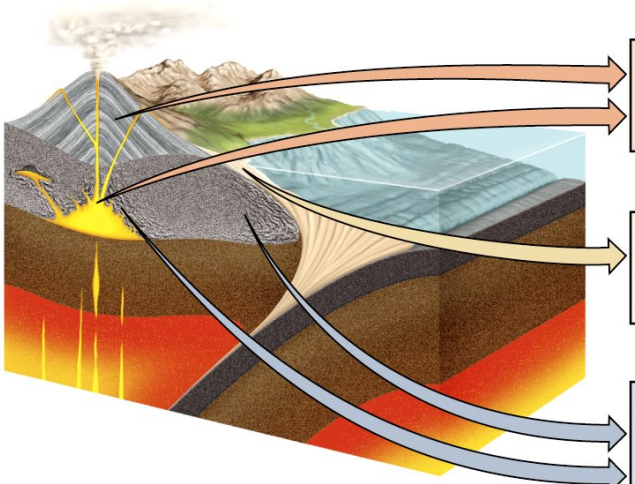
Three Rock Types



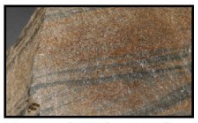
Type of rock and source material	Rock-forming process	Example
IGNEOUS Melting of rocks in hot, deep crust and upper mantle	Crystallization (solidification of magma or lava)	 Coarsely crystallized granite
SEDIMENTARY Weathering and erosion of rocks exposed at surface	Deposition, burial, and lithification	 Cross-laminated sandstone
METAMORPHIC Rocks under high temperatures and pressures in deep crust and upper mantle	Recrystallization in solid state of new minerals	 Gneiss

Figure 3-22
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Table 3.5 Some Common Minerals of Igneous, Sedimentary, and Metamorphic Rocks

Igneous Rocks	Sedimentary Rocks	Metamorphic Rocks
*Quartz	*Quartz	*Quartz
*Feldspar	*Clay minerals	*Feldspar
*Mica	*Feldspar	*Mica
*Pyroxene	Calcite	*Garnet
*Amphibole	Dolomite	*Pyroxene
*Olivine	Gypsum	*Staurolite
	Halite	*Kyanite

Note: Asterisk indicates that the mineral is a silicate.

Table 3-5
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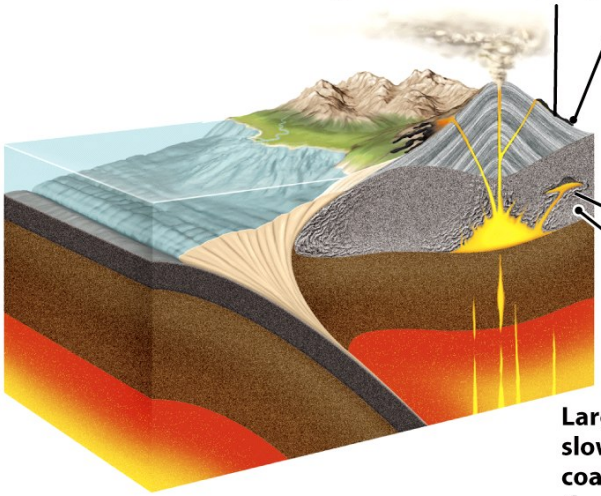
Igneous rocks



Extrusive igneous rocks form when magma erupts at the surface, rapidly cooling to fine ash or lava and developing tiny crystals.

The resulting rock, such as the basalt sample here, is fine-grained or has a glassy texture.

Intrusive igneous rocks crystallize when molten rock intrudes into unmelted rock masses in Earth's crust.

Large crystals grow during the slow cooling process, producing coarsely grained rocks such as the granite sample shown here.

Figure 3-23
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Sedimentary rocks

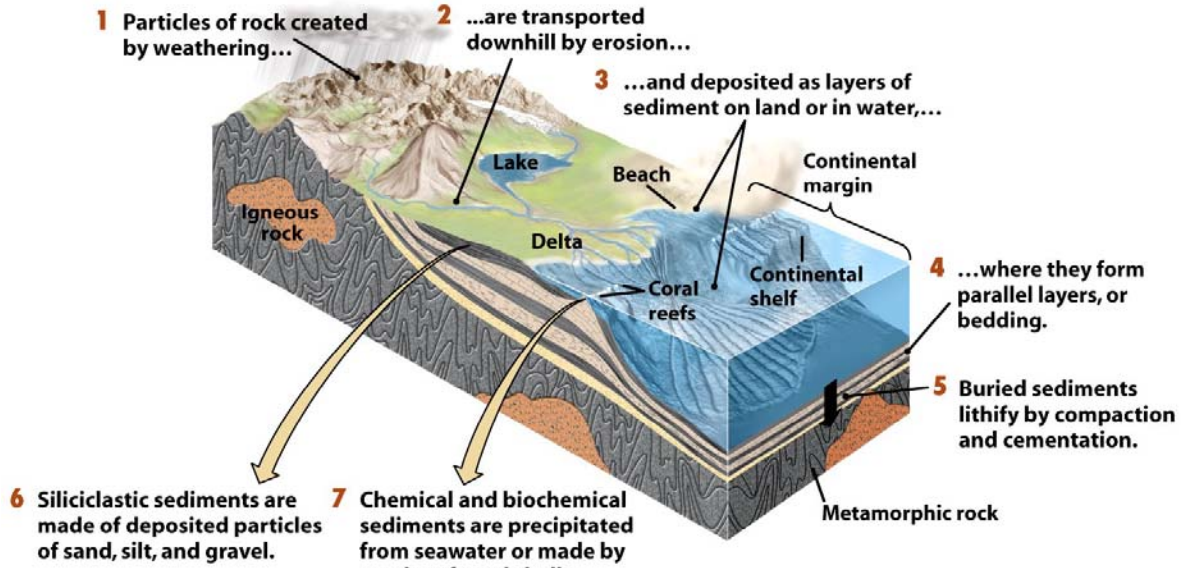

Figure 3-24
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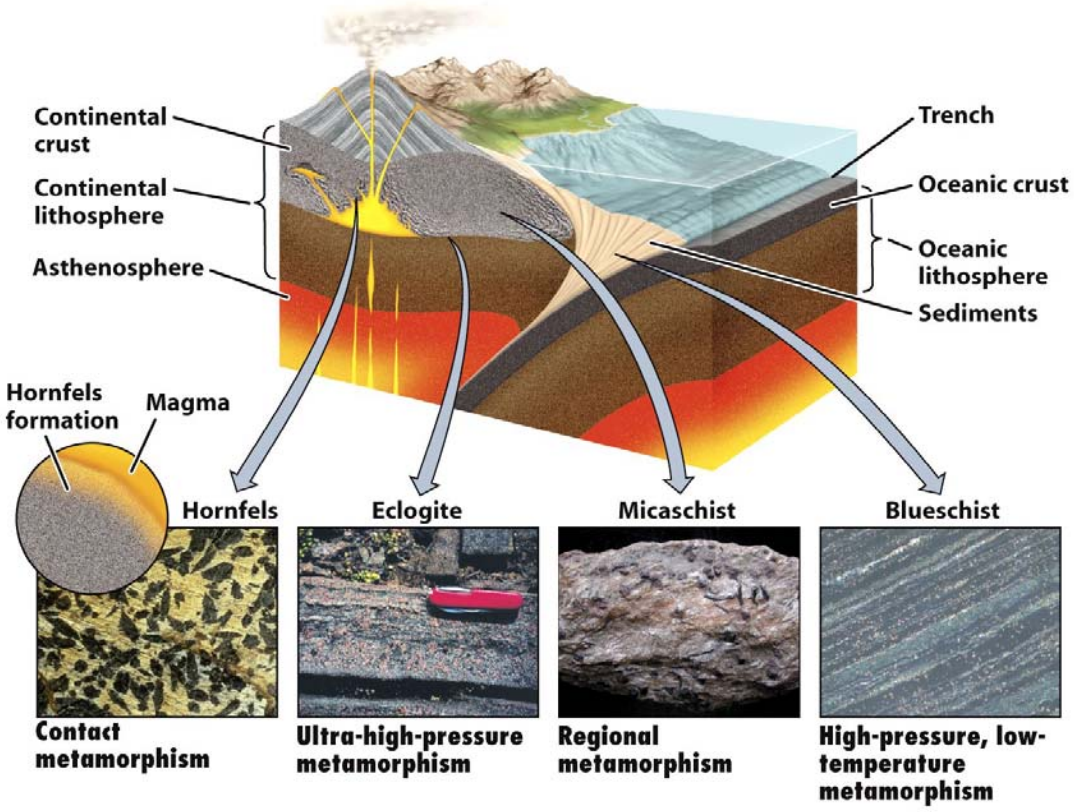
Metamorphic rocks



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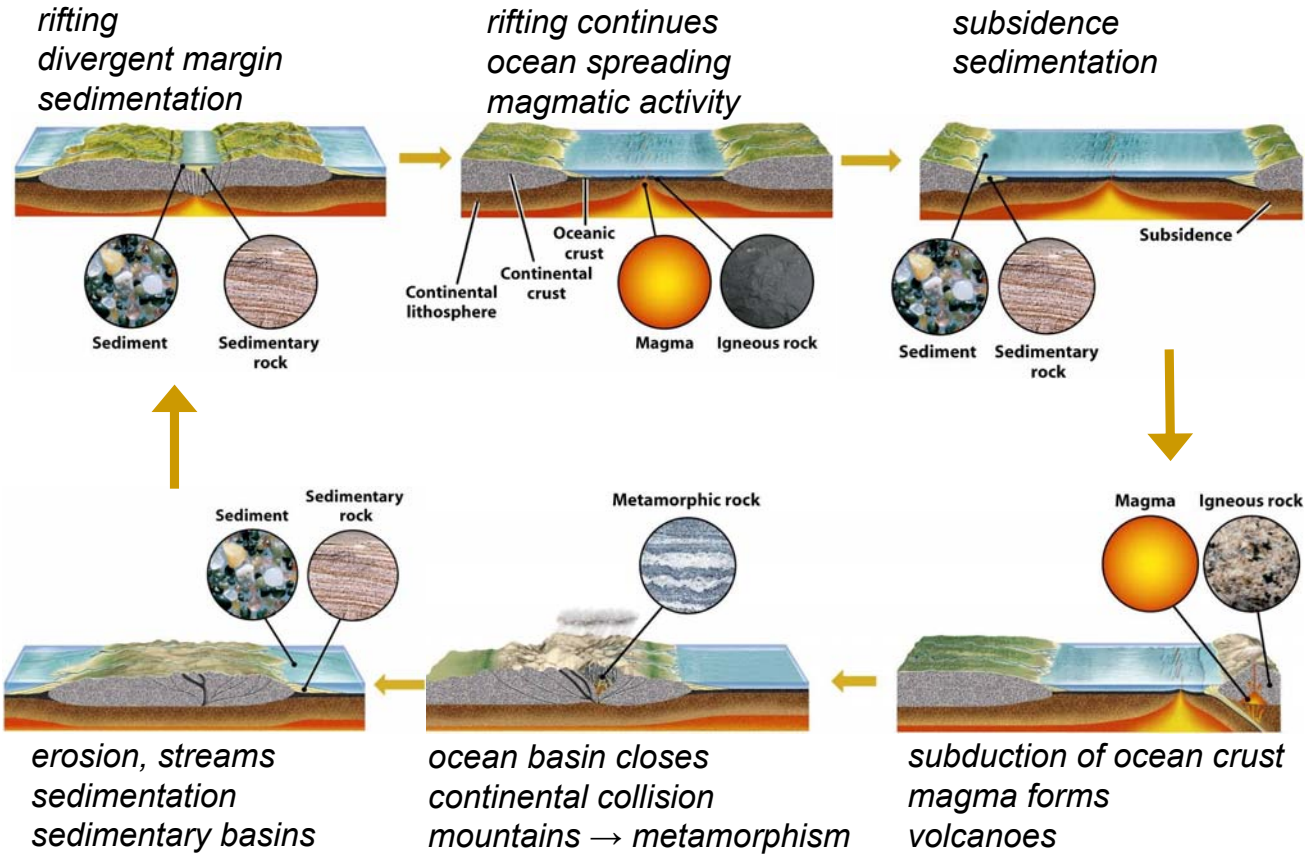
The Rock Cycle



- Classification of Igneous Rocks
  - Texture
  - Mineral & Chemical Composition

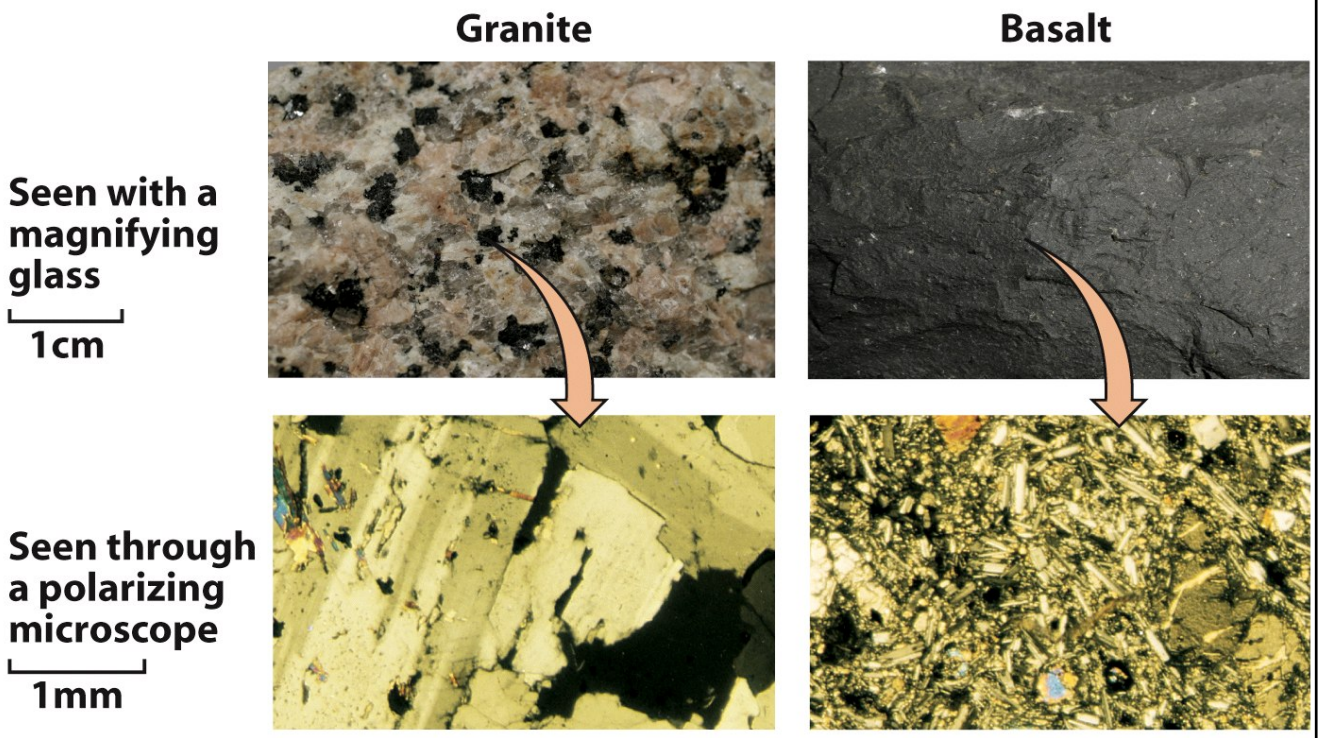


Figure 4-1
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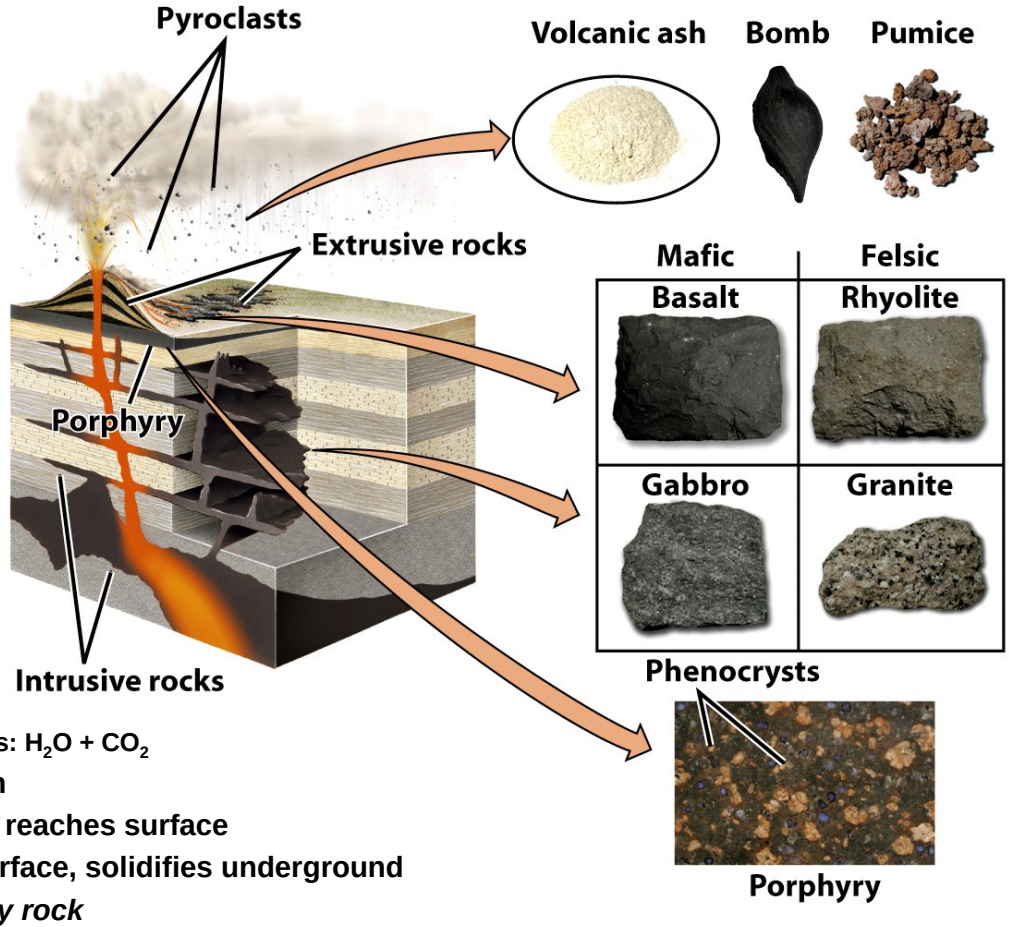

MAGMA

- Molten Rock
  - with dissolved gas: $H_2O + CO_2$
- Generated at depth
- Eruption if magma reaches surface
- If doesn't reach surface, solidifies underground
  - Intrudes *country rock*
  - Intrusive *contact*

Table 4.1 Common Minerals of Igneous Rocks

Compositional Group	Mineral	Chemical Composition	Silicate Structure
FELSIC	Quartz	SiO_2	Frameworks
	Potassium feldspar	$KAlSi_3O_8$	
	Plagioclase feldspar	$NaAlSi_3O_8$; $CaAl_2Si_2O_8$	
	Muscovite (mica)	$KAl_3Si_3O_{10}(OH)_2$	Sheets
MAFIC	Biotite (mica)	K, Mg, Fe, Al } $Si_3O_{10}(OH)_2$	
	Amphibole group	Mg, Fe, Ca, Na } $Si_8O_{22}(OH)_2$	Double chains
	Pyroxene group	Mg, Fe, Ca, Al } SiO_3	Single chains
	Olivine	$(Mg,Fe)_2SiO_4$	Isolated tetrahedra

Table 4-1
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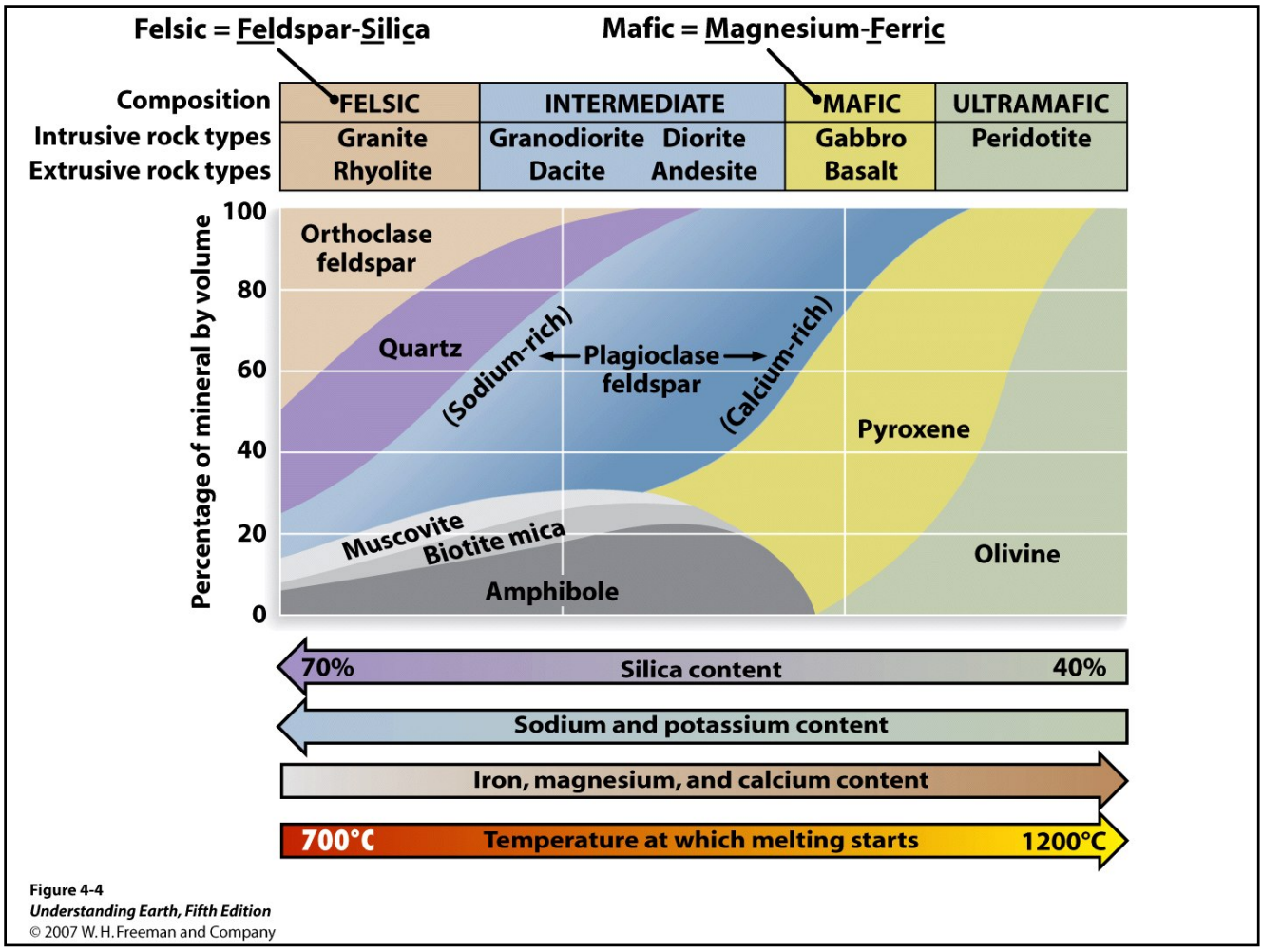

Figure 4-4
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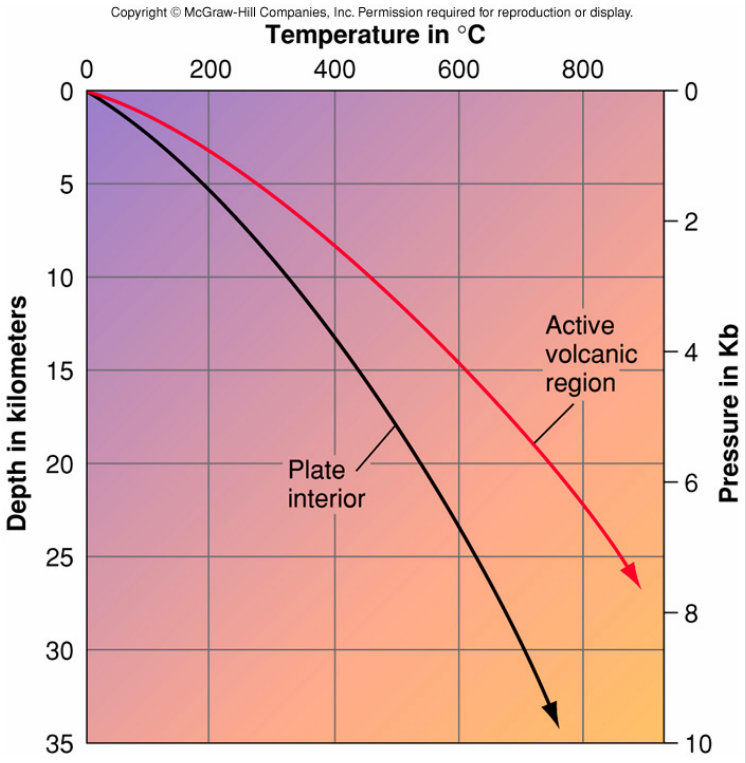
How does magma form?

- *Partial melting* of rock at depth

- Source of heat?
  - **Geothermal gradient**
    - *Rate of Temperature increase with depth*
    - *Average 30 °C/km depth*
    - *Not same everywhere*

    - *Tells us that heat is being conducted to the surface of the earth from the interior*



How does magma form?

- Factors that control melting temperatures
  - **Pressure**
    - *melting points of minerals increase with pressure*
      - This is why increasing temperature along the geotherm alone fails to melt crustal rocks
    - *reduction in pressure can therefore induce melting*
  - **Water** added under pressure
    - *lowers melting point of minerals*

Where does all that basalt come from, *dad?*

How does magma evolve?

- Magmatic differentiation
  - **Mirror image of partial melting**
    - *Crystal formation over a range in temperature*
      - *First to melt are also first to crystallize*
    - ***Fractional crystallization***
      - *As crystallization proceeds, crystals are separated from the melt, thus the melt evolves away from the composition of the crystals removed*
    - *Bowen's reaction series, a model of crystallization:*

How does magma evolve?

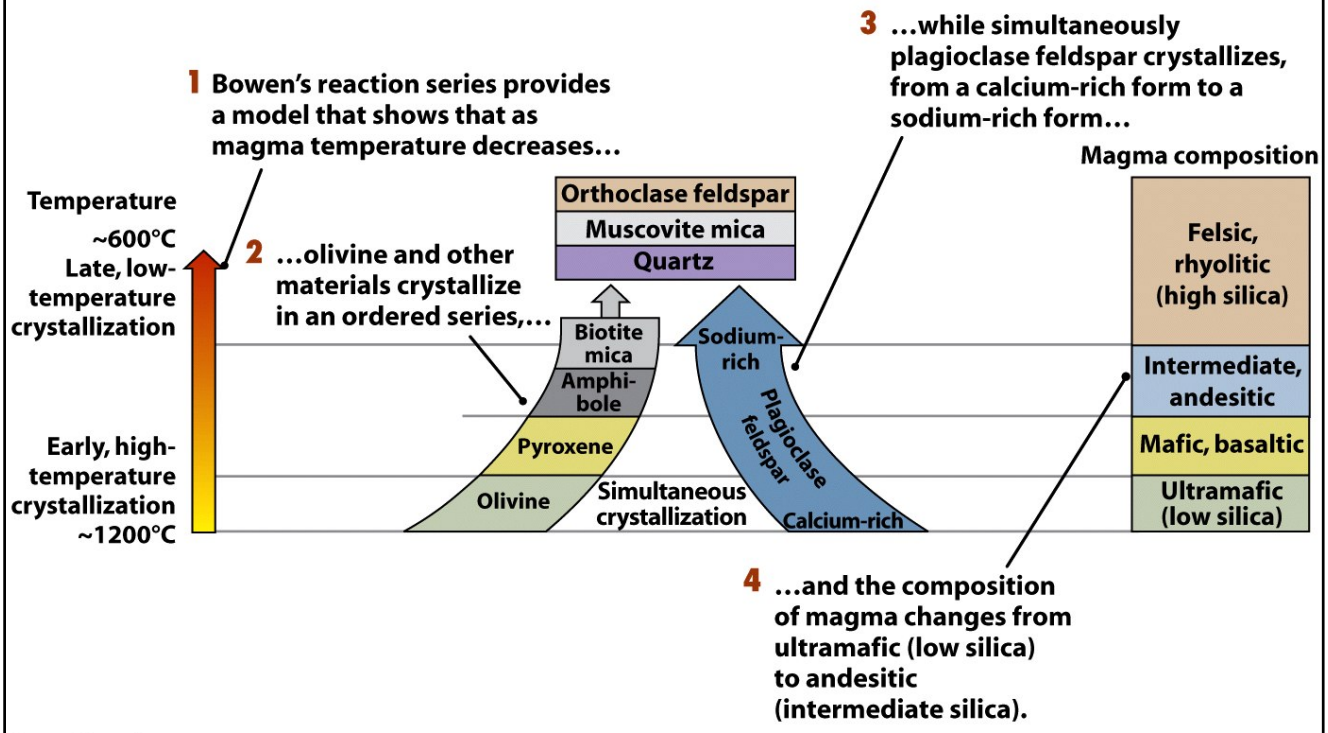


Figure 4-5 part 1
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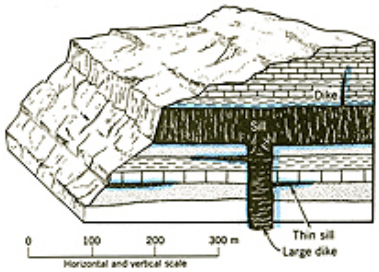
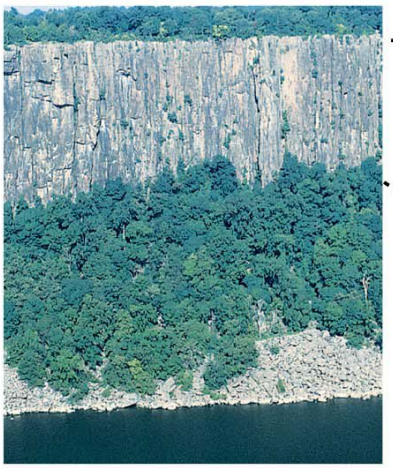
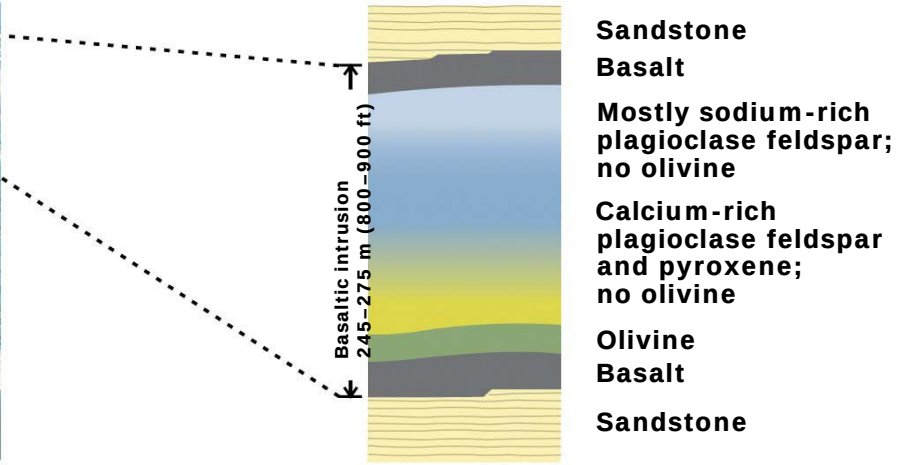
Palisades Sill, New Jersey
nature, matched by experiments

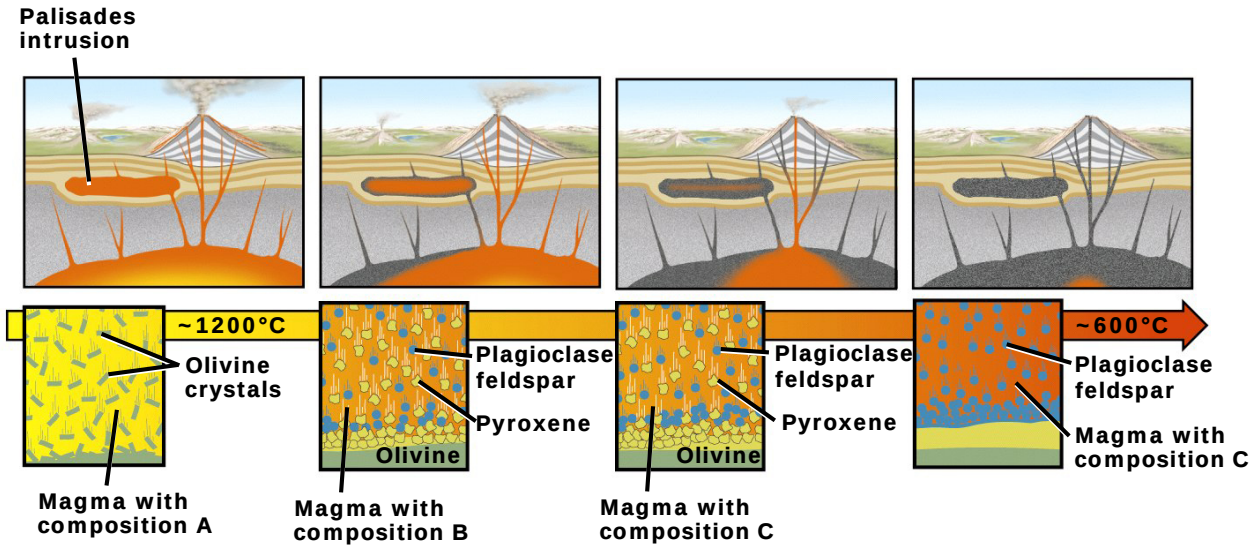


From: Paul Olsen web pages LDEO





Palisades Sill, New Jersey
nature, matched by experiments



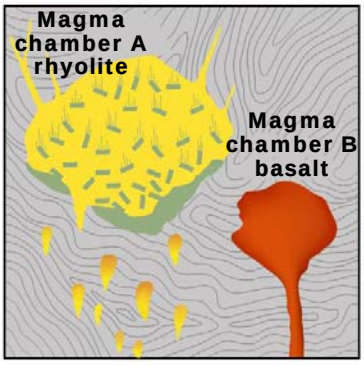
Olivine crystallizes first.

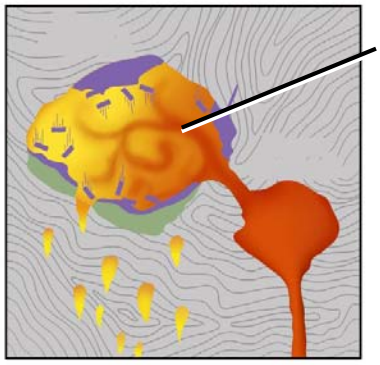
Pyroxene and plagioclase feldspar crystallize.

A gradient of pyroxene and feldspar is established.

Plagioclase feldspar continues to crystallize.

How does magma evolve?

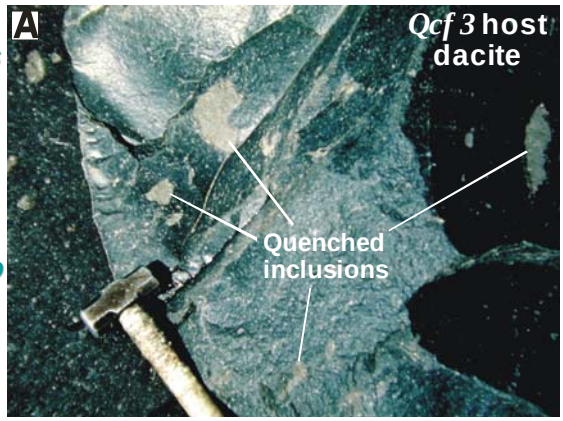


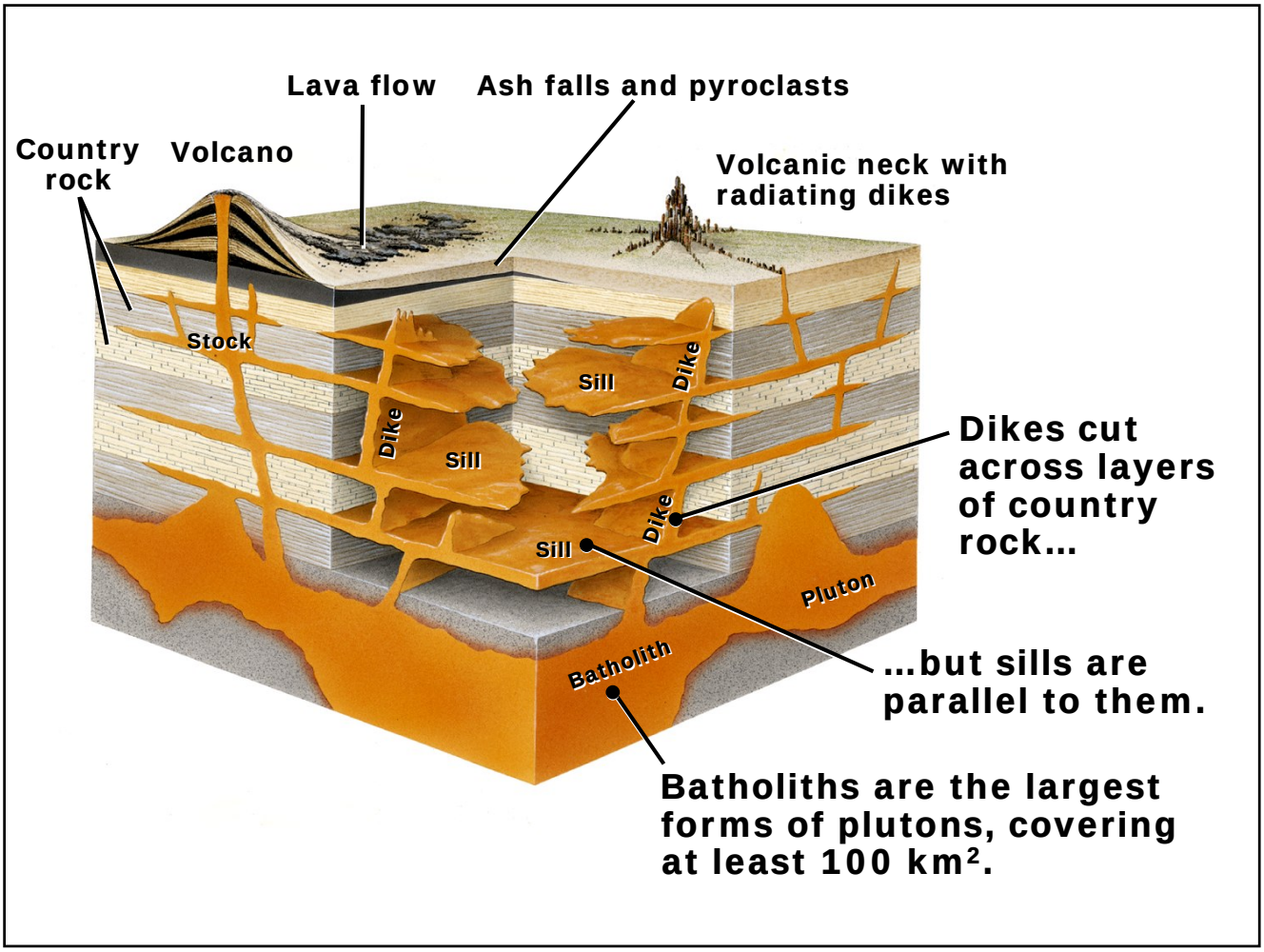


Mixing **of the basaltic and rhyolitic magmas results in andesitic magma.**

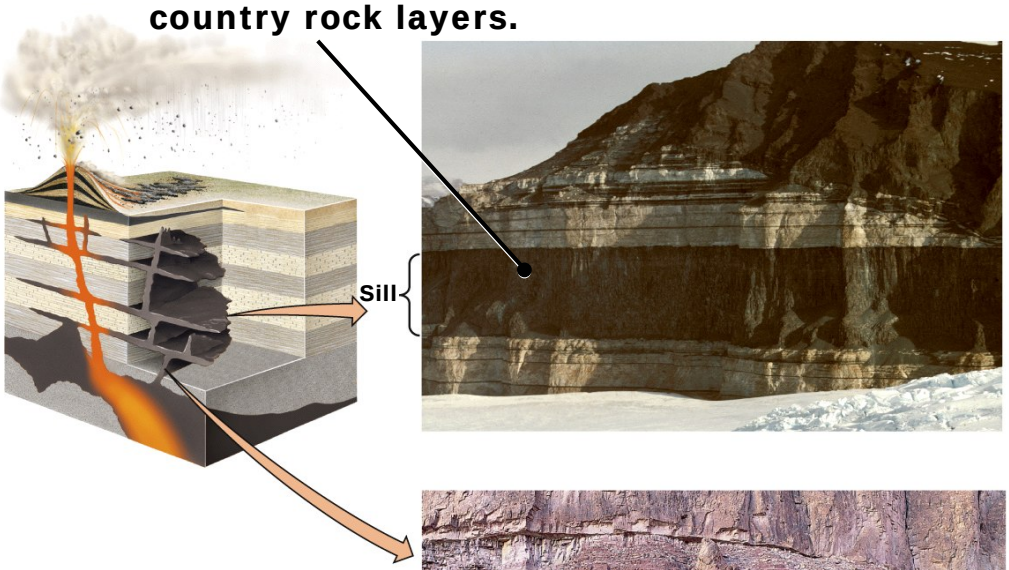
Basaltic inclusions in granite, Adamello batholith, Italy

Basaltic inclusions (grey) in glassy dacite lava flow (black), San Pedro Volcano, Chilean Andes

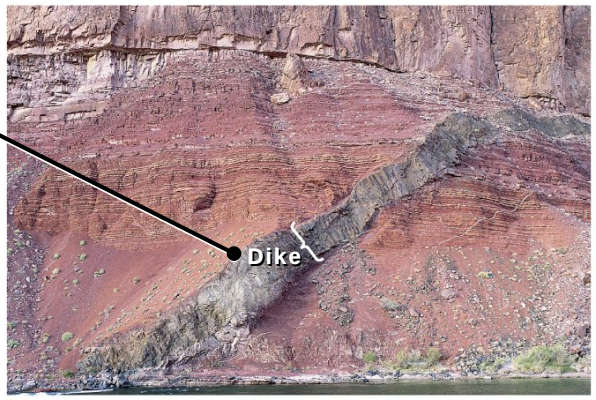


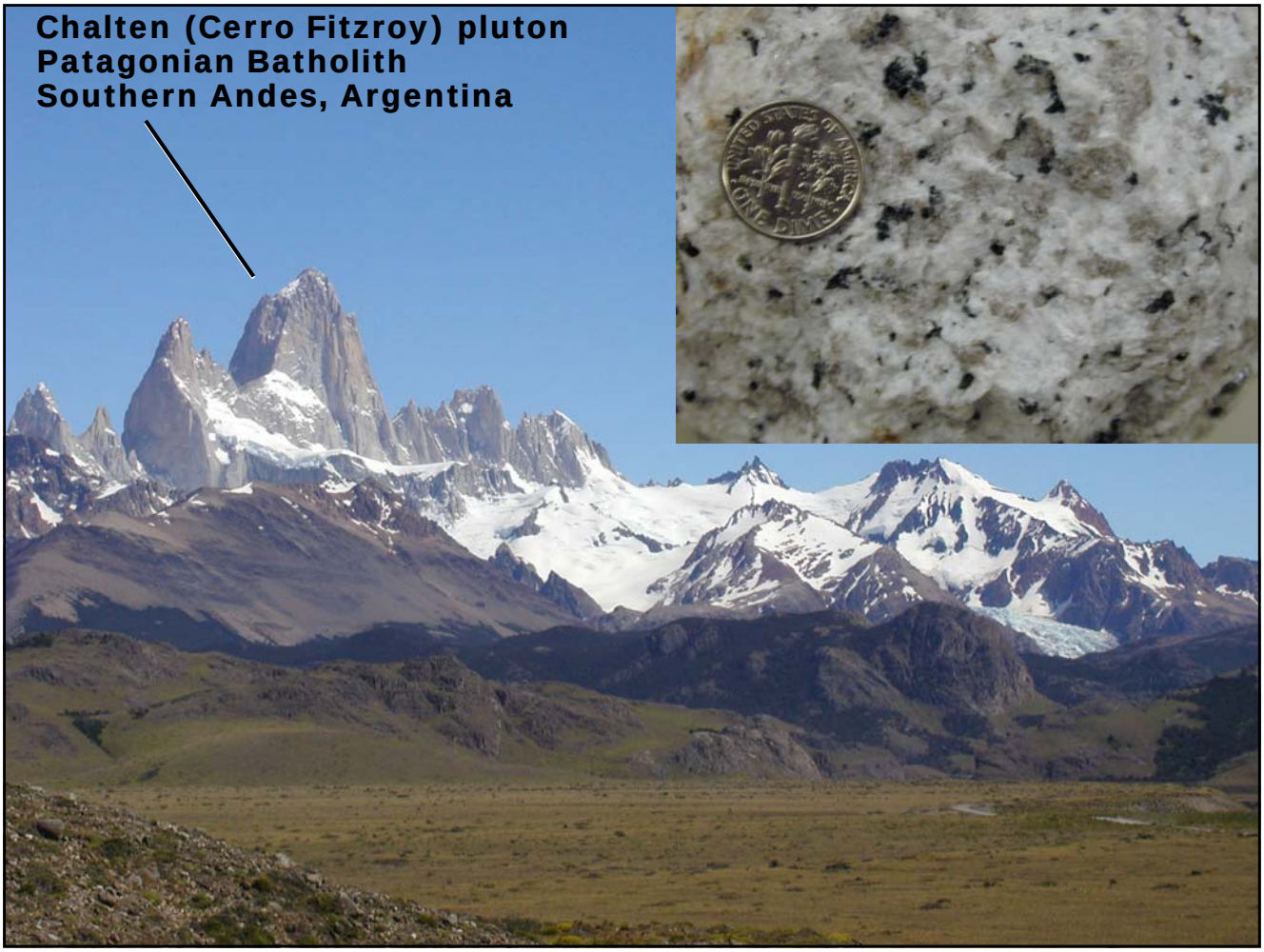

Lava flow
Ash falls and pyroclasts
Country rock
Volcano
Volcanic neck with radiating dikes
Stock
Sill
Dike
Dike
Sill
Dike
Sill
Pluton
Batholith
Dikes cut across layers of country rock…
…but sills are parallel to them.
Batholiths are the largest forms of plutons, covering at least 100 km².

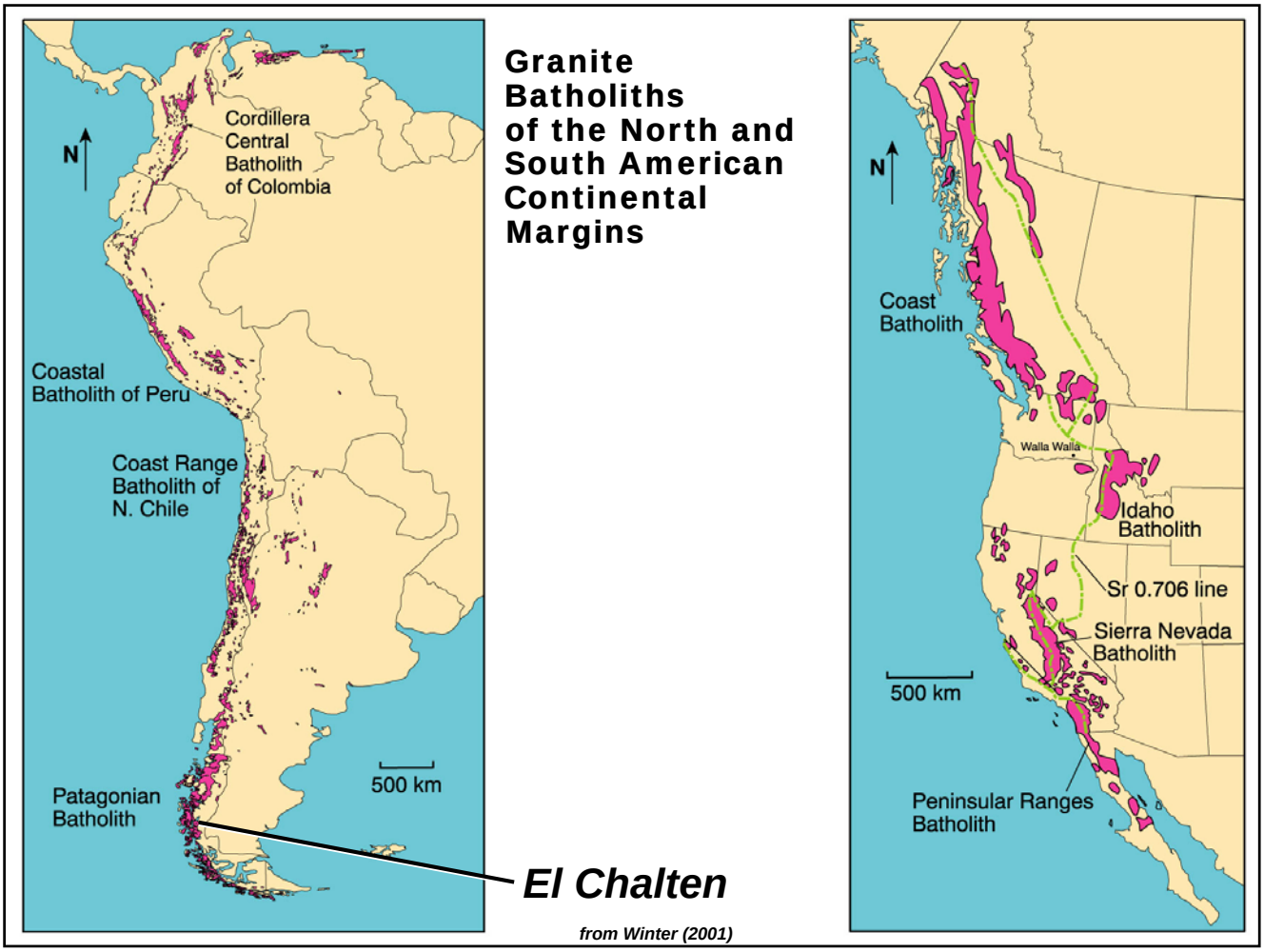
A sill parallels country rock layers.



A dike cuts across layers.




Chalten (Cerro Fitzroy) pluton
Patagonian Batholith
Southern Andes, Argentina


Granite Batholiths of the North and South American Continental Margins
N
Cordillera Central Batholith of Colombia
Coastal Batholith of Peru
Coast Range Batholith of N. Chile
Patagonian Batholith
500 km
El Chalten
from Winter (2001)
N
Coast Batholith
Walla Walla
Idaho Batholith
Sr 0.706 line
Sierra Nevada Batholith
500 km
Peninsular Ranges Batholith

Tectonic/Dynamic setting of magmatism

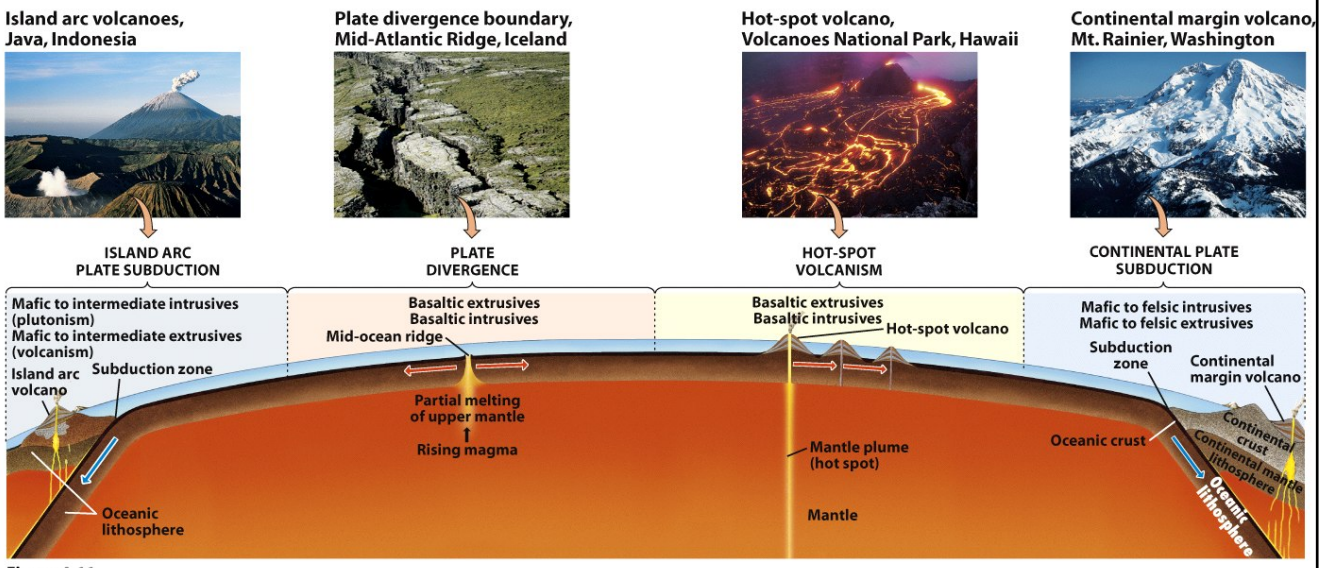


Figure 4-11
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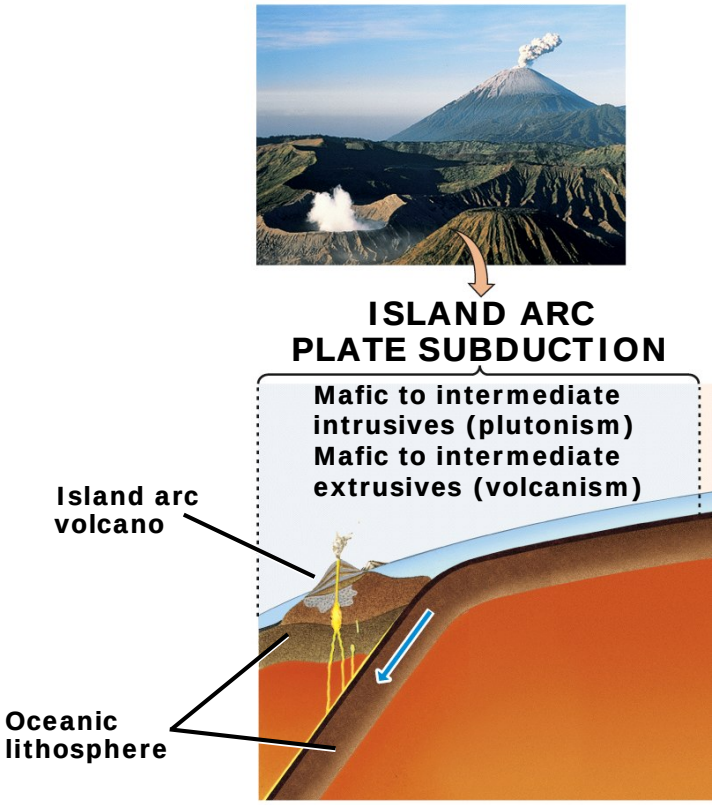
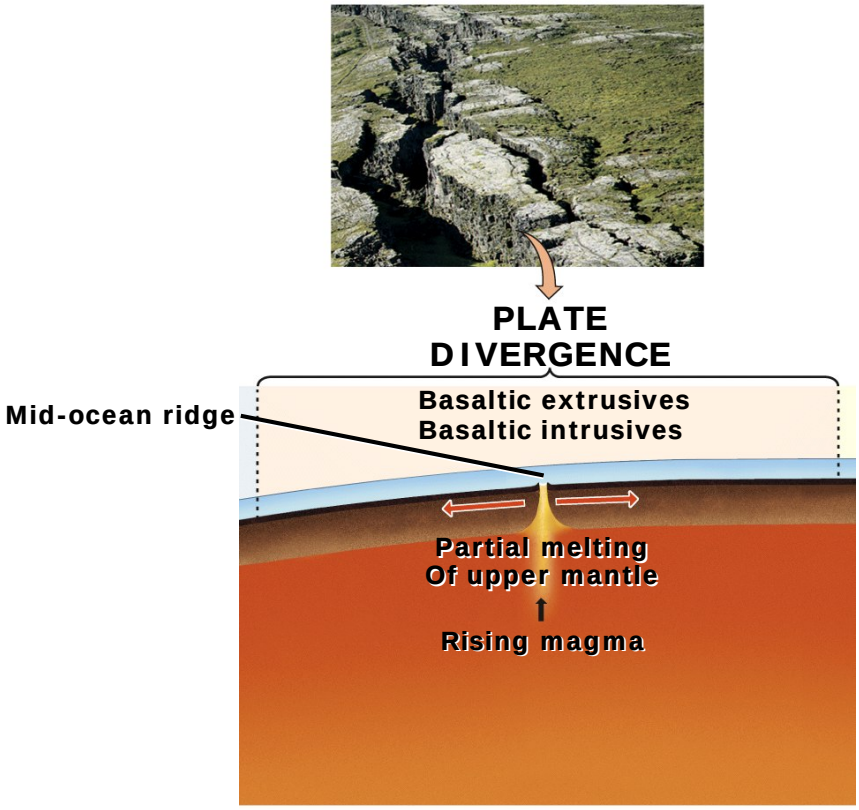
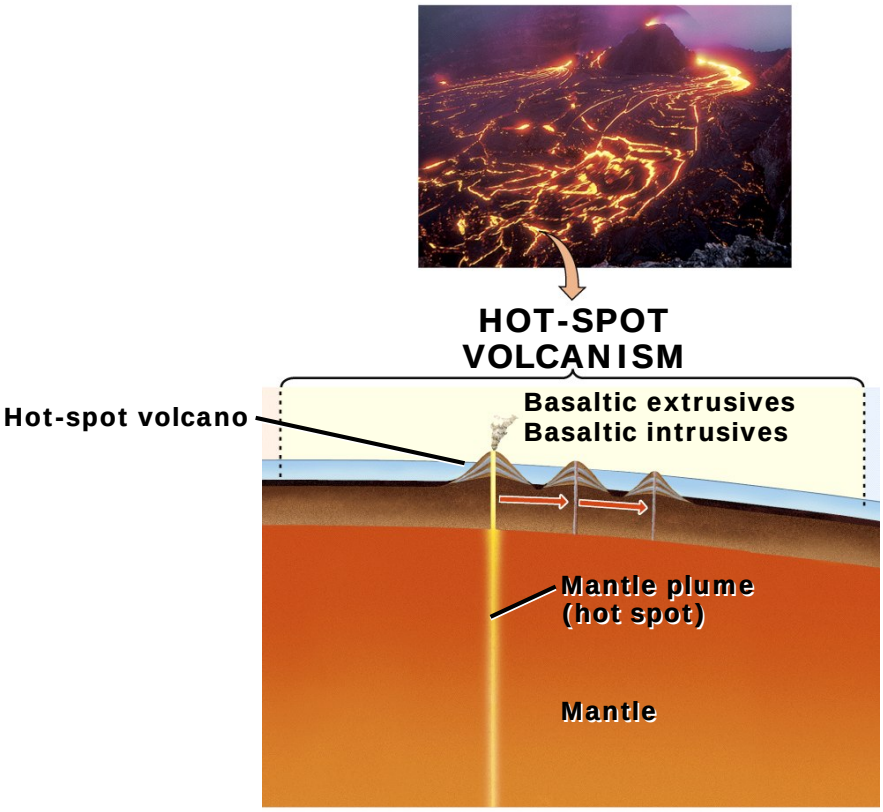
Island arc subduction zone



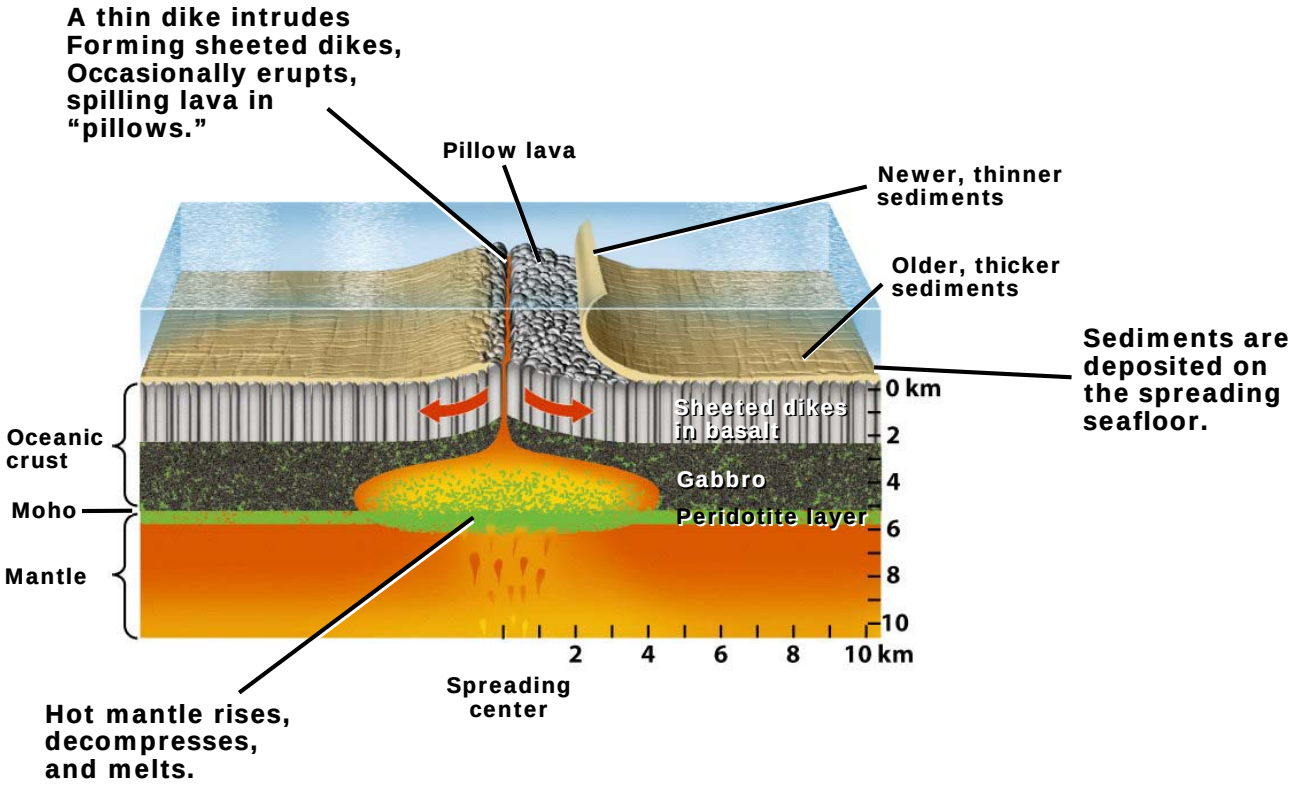
Divergent plate boundary-spreading center



Hot-spot volcanism-upwelling mantle plume



Decompression melting at mid ocean ridge



Fluid induced melting in subduction zone