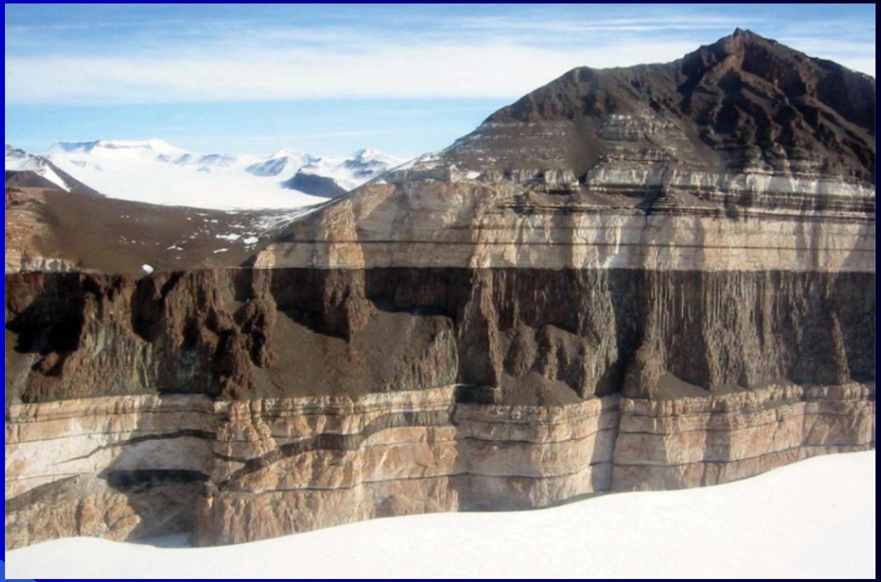
Igneous Rocks - Occurrence and Classification

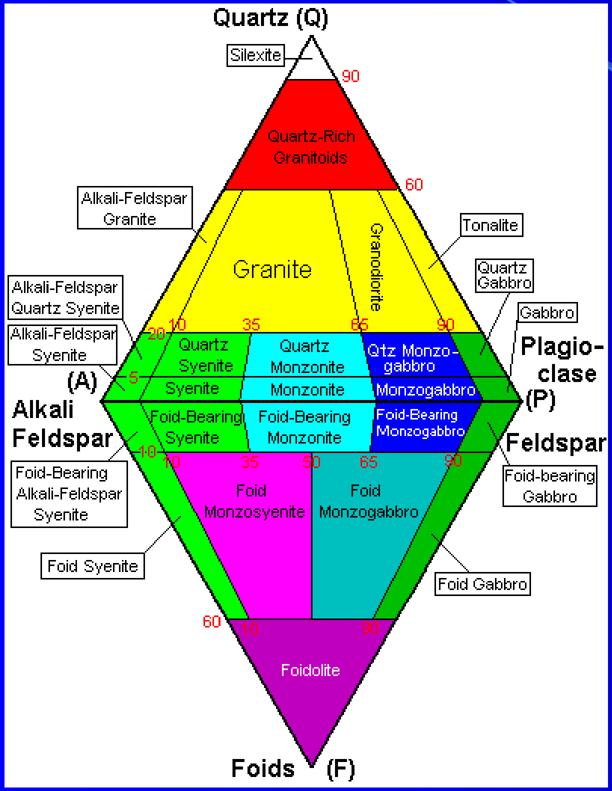


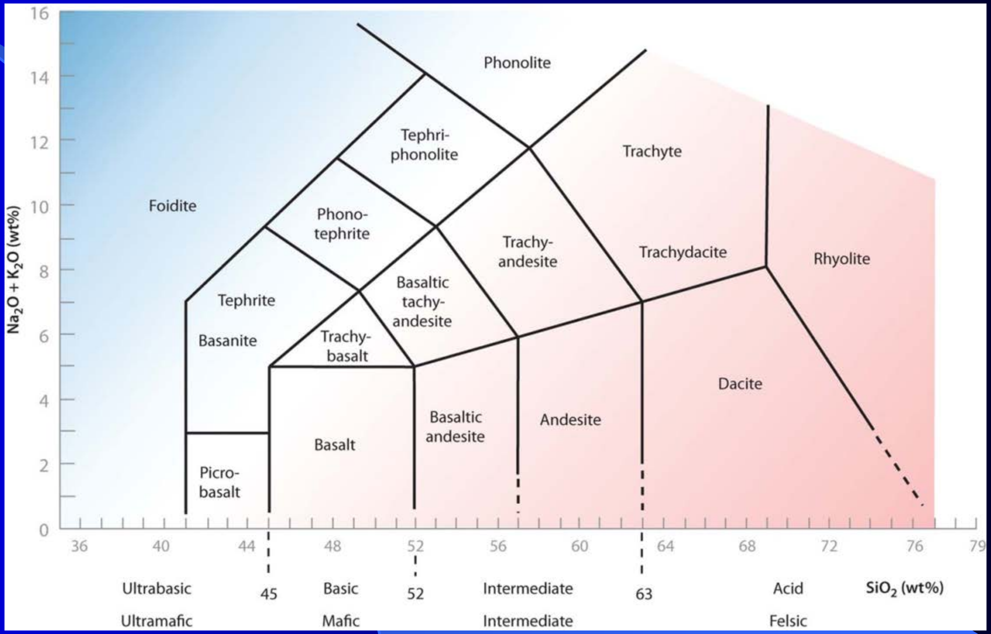
Classification of Igneous Rocks

Rocks are classified on the basis of

- Texture
- Mineralogy

Very fine-grained or glassy rocks are classified on the basis of chemistry



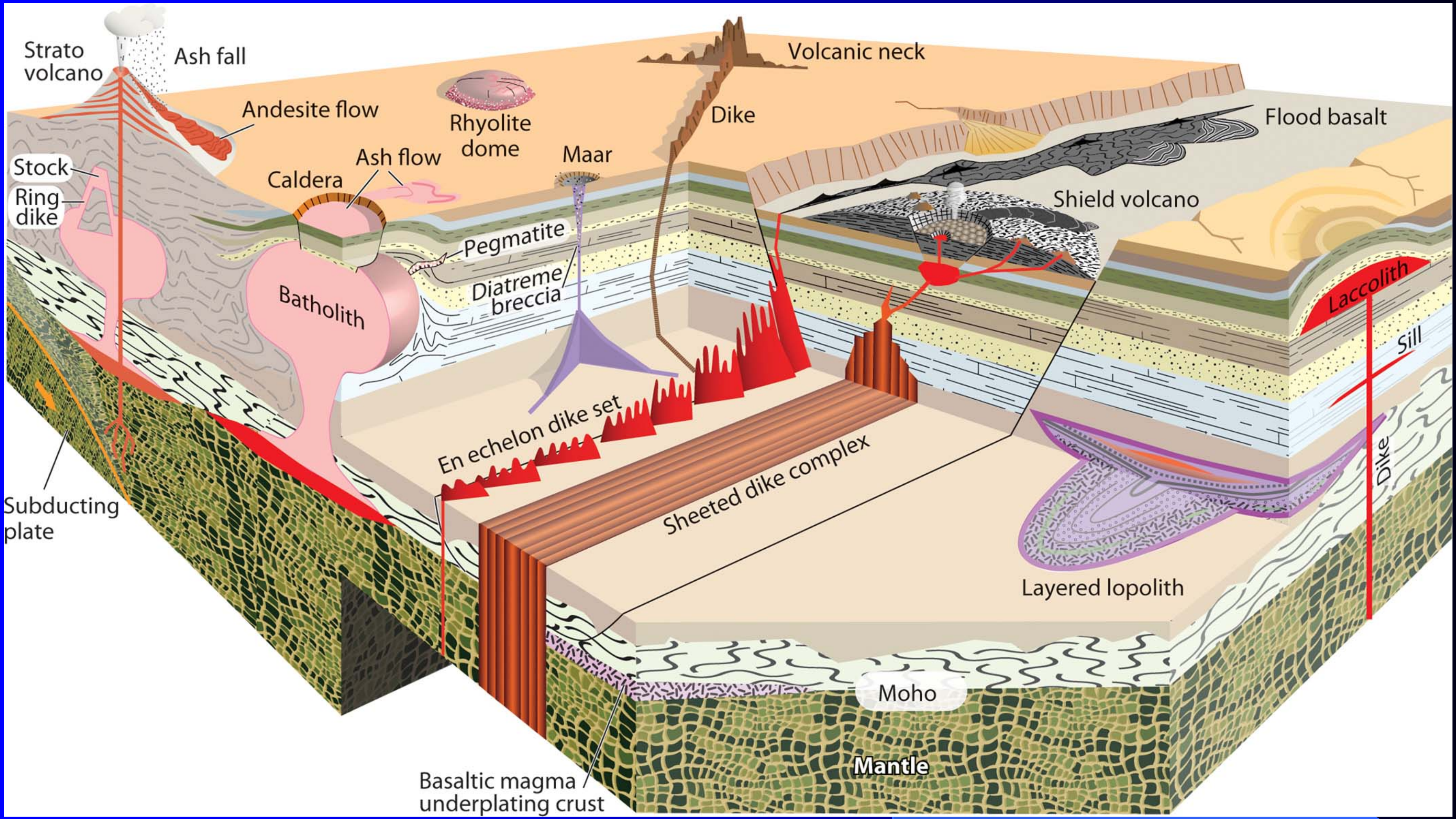


Grain Size →

Silica Content of Magma	*Resulting Volcanic Rocks*	*Resulting Plutonic Rocks*
High (≈ 70%–75%)	**Rhyolite** lies at the felsic, high-silica end of the scale and consists largely of quartz and feldspars. It is usually pale, ranging from nearly white to shades of gray, yellow, red, or lavender. 	**Granite**, the plutonic equivalent of rhyolite, is common because felsic magmas usually crystallize before they reach the surface. It is found most often in continental crust, especially in the cores of mountain ranges. 
Intermediate (≈ 60%)	**Andesite** is an intermediate-silica rocks, with lots of feldspar mixed with darker mafic minerals, such as amphibole or pyroxene. It is usually light to dark gray, purple, or green. 	**Diorite** is the plutonic equivalent of andesite, an intermediate-silica rock. 
Low (≈ 45%–50%)	**Basalt,** a mafic rock, is dominant in oceanic crust and the most common igneous rock on Earth. Large, low-viscosity lava flows from shield volcanoes and fissures are usually basaltic. Dark-colored pyroxene and olivine give it a dark gray, dark green, or black color. 	**Gabbro** is the plutonic equivalent of basalt, a low-silica rock. 

Silica Content ↑

Mode of Occurrence of Igneous Rocks



Extrusive igneous rocks – fine-grained or glassy

- Lava flows
- Volcanoes

Intrusive igneous rocks – medium to coarse-grained

- Hypabyssal – transitional between fine- and coarse-grained. Often porphyritic.
- Plutonic – coarse-grained

Physical Properties and Behavior of Various Types of Magmas

Magma type	Basaltic	Andesitic	Dacitic	Rhyolitic
SiO_2 (wt. %)	50.83	54.20	63.58	73.66
Eruptive T (^oC)	1150	1000	900	800
Viscosity (Pa s)	50	1×10^3	4×10^3	4×10^8

Eruptive behavior   Fluid → Explosive

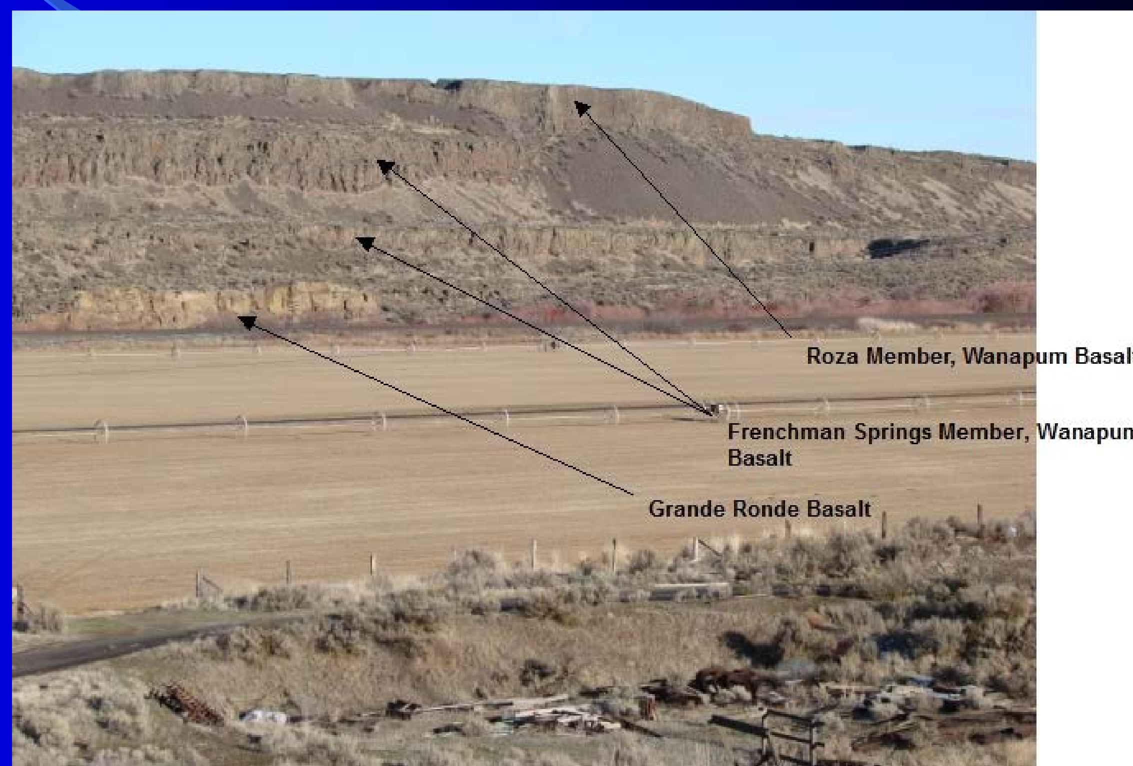
Magma Viscosity

Table 8.1 Viscosities of magmas and common substances.

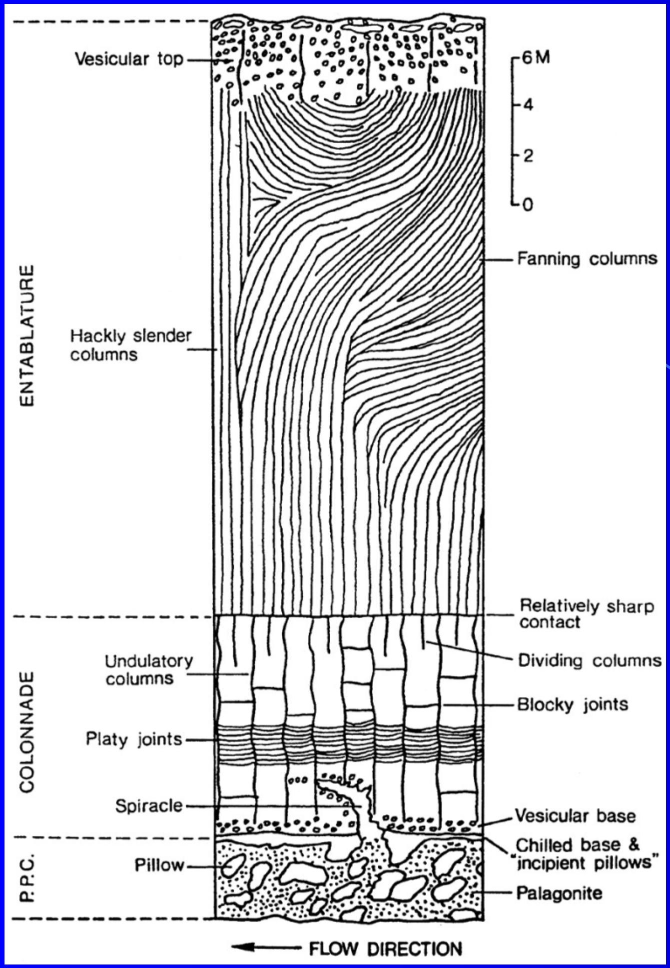
Material	Viscosity (Pa·s)	Weight % SiO_2	Temp. (°C)
Water	1.002×10^{-3}	–	20
ASE 30 motor oil	2×10^{-1}	–	20
Kimberlite	$10^{-1} - 1$	30–35	~1000
Komatiite	$10^{-1} - 10$	40–45	1400
Ketchup	~5 × 10	–	20
Basalt	$10 - 10^{2}$	45–52	1200
Peanut butter	$\sim 2.5 \times 10^{2}$	–	20
Crisco shortening	2×10^{3}	–	20
Andesite	$\sim 3.5 \times 10^{3}$	~58–62	1200
Silly Putty	$\sim 10^{4}$		
Tonalite 6% H_2O	$\sim 10^{4}$	65	950
Rhyolite	$\sim 10^{5}$	~73–77	1200
Granite 6% H_2O	$\sim 10^{5}$	75	750
Rhyolite	$\sim 10^{8}$	~73–77	800
Average mantle	10^{21}	–	–

Note: Magma viscosities from Dingwell (1995) and references therein. Granite and Tonalite viscosities from Petford (2003). Mantle viscosity is from King (1995).

Flood Basalts

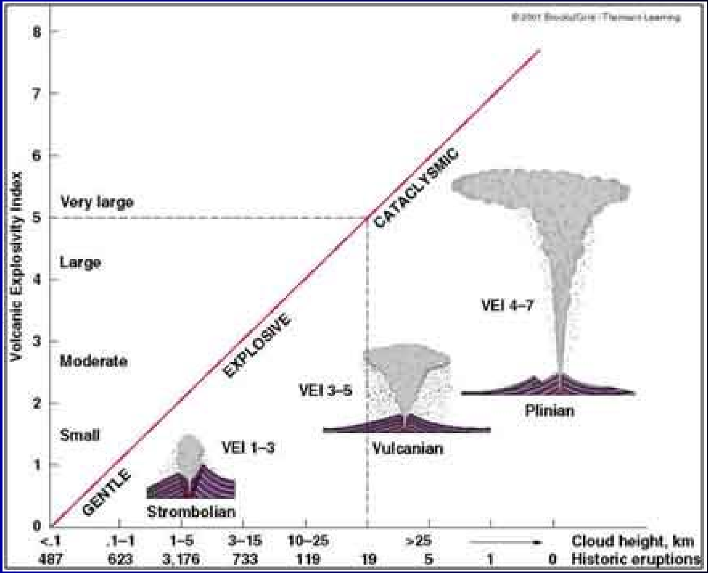


Lava Flows and Columnar Joints



Types of volcanic eruptions

- Hawaiian – fluid basaltic lava is thrown into the air in jets from a vent or line of vents (a fissure) at the summit or on the flank of a volcano.
- Strombolian – distinct bursts of fluid lava (usually basalt or basaltic andesite) from the mouth of a magma-filled summit conduit.
- Vulcanian - short, violent, relatively small explosion of viscous magma (usually andesite, dacite, or rhyolite).
- Pelean - explosive outbursts that generate pyroclastic flows, dense mixtures of hot volcanic fragments and gas.
- Plinian - caused by the fragmentation of gassy magma, and are usually associated with very viscous magmas (dacite and rhyolite).



Tephra – volcanic ash (< 2mm)

Lapilli – 2 to 64 mm

Bombs - >64 mm. Bombs form a cow pancake on landing

VEI	Ejecta volume	Classification	Description	Plume	Frequency	Examples	Occurrences in last 10,000 years*
0	< 10,000 m³	Hawaiian	effusive	< 100 m	constant	Kilauea, Piton de la Fournaise	many
1	> 10,000 m³	Hawaiian/Strombolian	gentle	100–1000 m	daily	Stromboli, Nyiragongo (2002)	many
2	> 1,000,000 m³	Strombolian/Vulcanian	explosive	1–5 km	weekly	Galeras (1993), Mount Sinabung (2010)	3477*
3	> 10,000,000 m³	Vulcanian/Peléan	severe	3–15 km	few months	Nevado del Ruiz (1985), Soufrière Hills (1995)	868
4	> 0.1 km³	Peléan/Plinian	cataclysmic	10–25 km	≥ 1 yr	Mount Pelée (1902), Eyjafjallajökull (2010)	421
5	> 1 km³	Plinian	paroxysmal	20–35 km	≥ 10 yrs	Mount Vesuvius (79 CE), Mount St. Helens (1980)	166
6	> 10 km³	Plinian/Ultra-Plinian	colossal	> 30 km	≥ 100 yrs	Krakatoa (1883), Mount Pinatubo (1991)	51
7	> 100 km³	Ultra-Plinian	super-colossal	> 40 km	≥ 1,000 yrs	Thera (Minoan Eruption), Tambora (1815)	5 (+2 suspected)
8	> 1,000 km³	Supervolcanic	mega-colossal	> 50 km	≥ 10,000 yrs	Yellowstone (640,000 BP), Toba (74,000 BP)	0

Shield Volcanoes

Mauna Kea

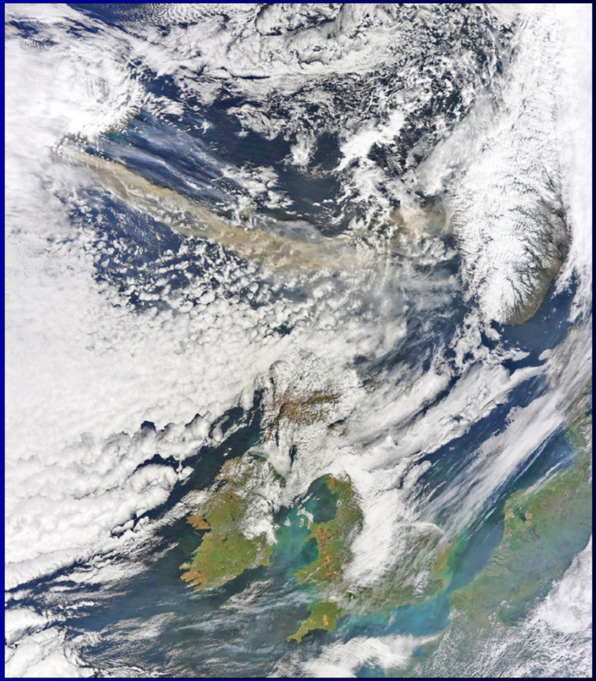
Mauna Loa

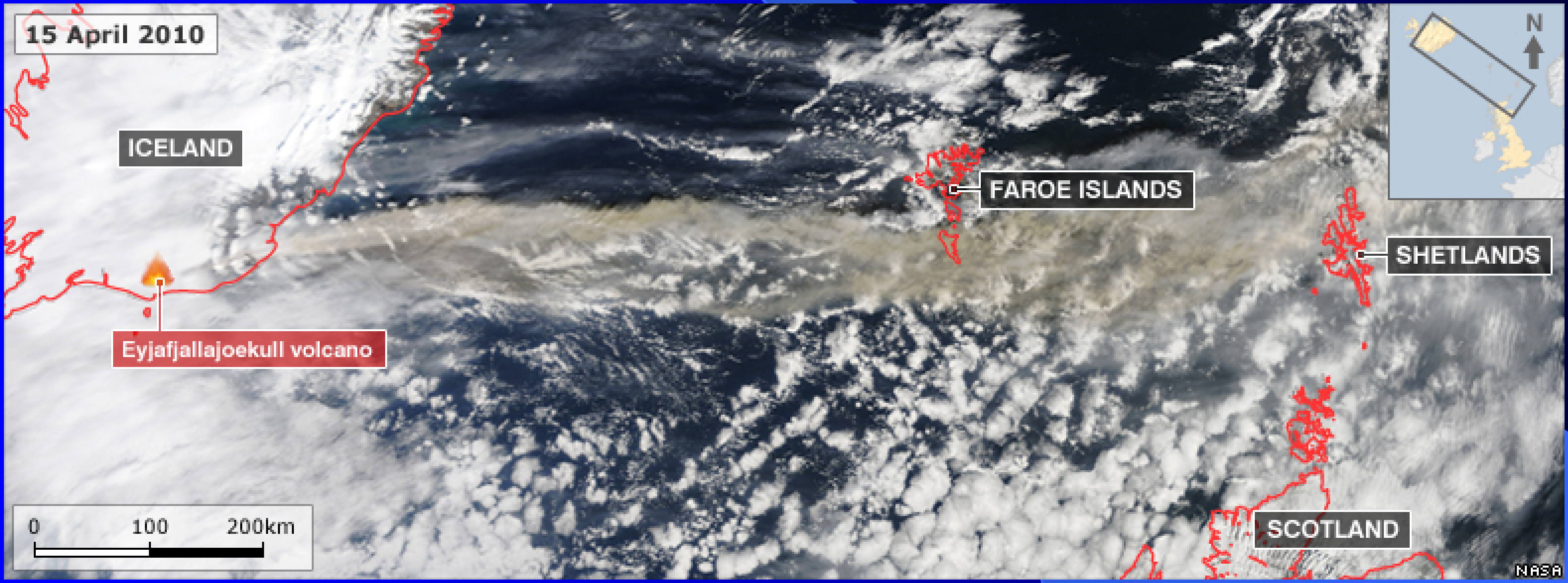






16 April 0000GMT
Scope of ash
ICELAND
Eyjafjallajoekull
Glacier
NORWAY
FINLAND
RUSSIA
SWEDEN
UNITED
KINGDOM
SOURCE: Met Office




15 April 2010
ICELAND
FAROE ISLANDS
SHETLANDS
Eyjafjallajoekull volcano
SCOTLAND
0
100
200km
N
NASA

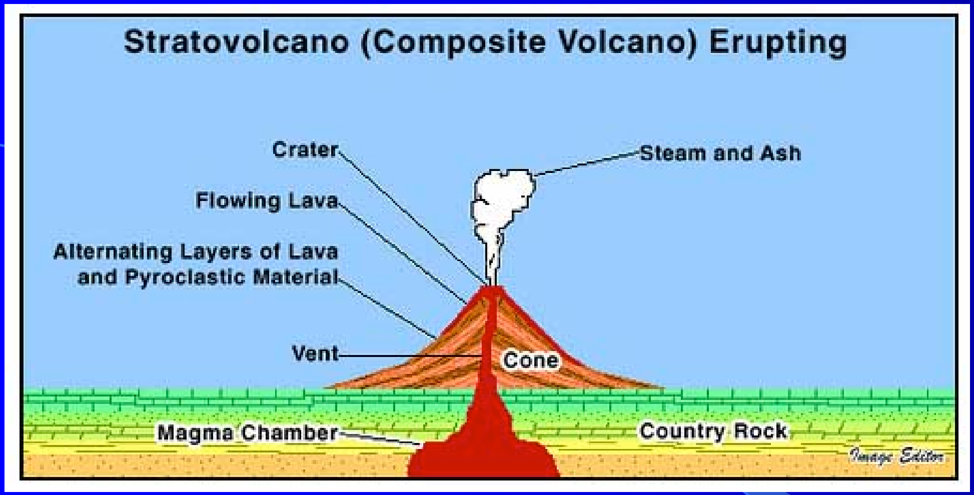






Jökulhlaup - glacial outburst flood. Generally, large and abrupt release of water from a subglacial or proglacial lake/reservoir.

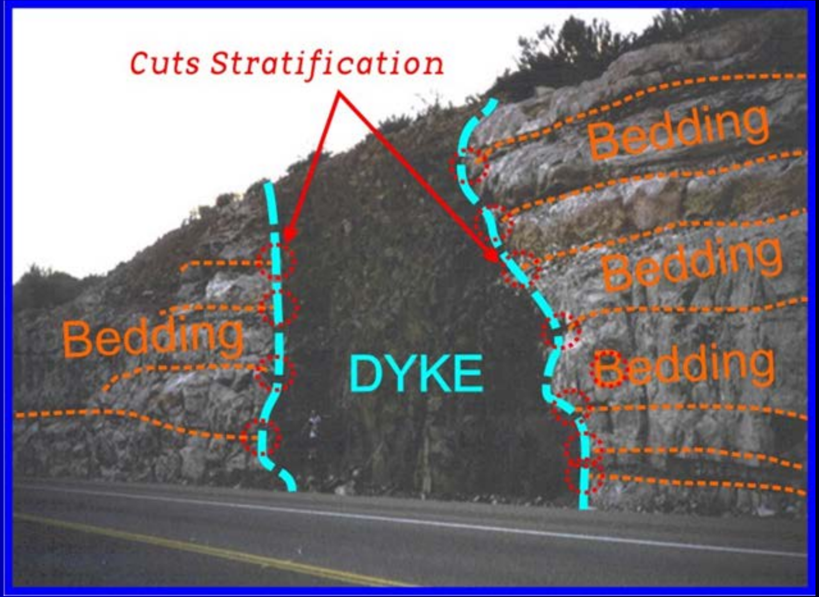
Composite Volcano (Strato-volcano)



Shallow intrusive igneous bodies

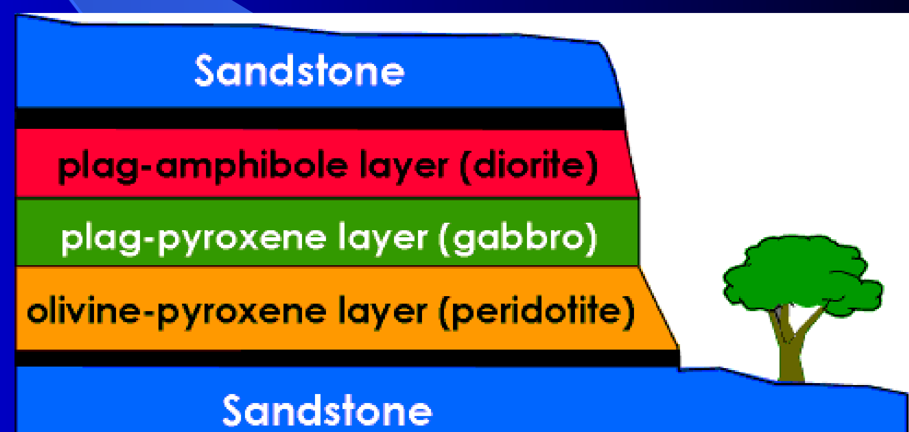
Dikes – tabular intrusions that cross-cut existing layering (discordant)

Sills – tablular intrusions that are parallel to existing layering (concordant)

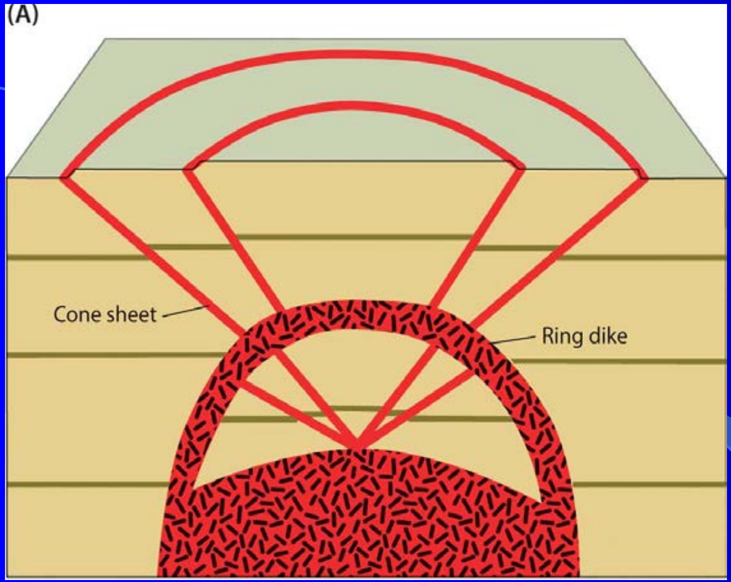


Salisbury Crags – Arthur’s Seat

Palisades Sill

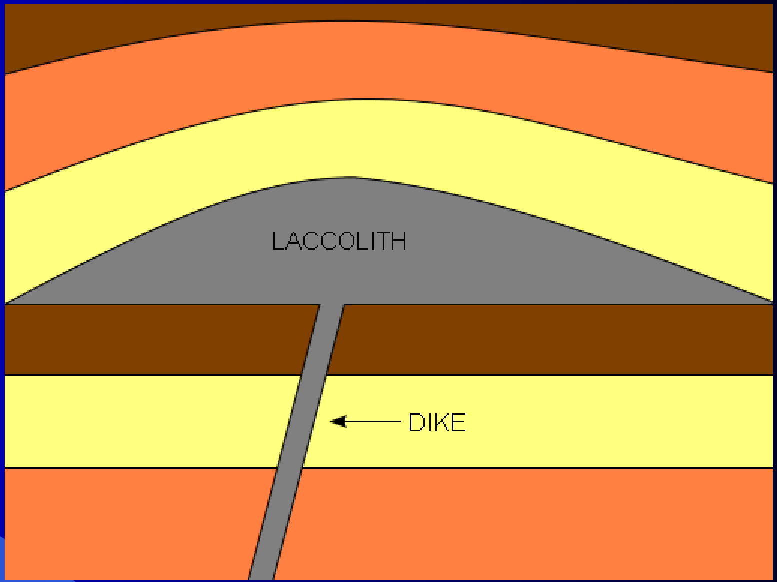


Ring dikes and cone sheets



Dikes are intruded by magma fracturing and sills involve lifting of the overlying rock (bouyancy). These are hypabyssal intrusions and imply that the crust showed brittle behavior.

Laccolith – domes up overlying strata – concordant intrusion

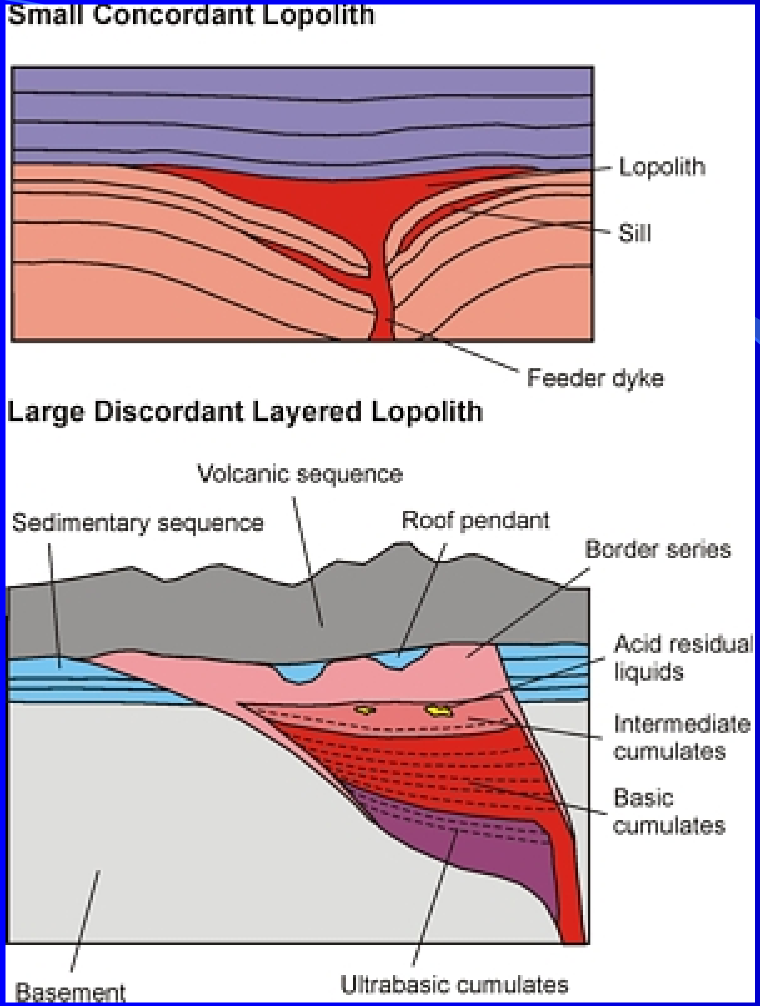


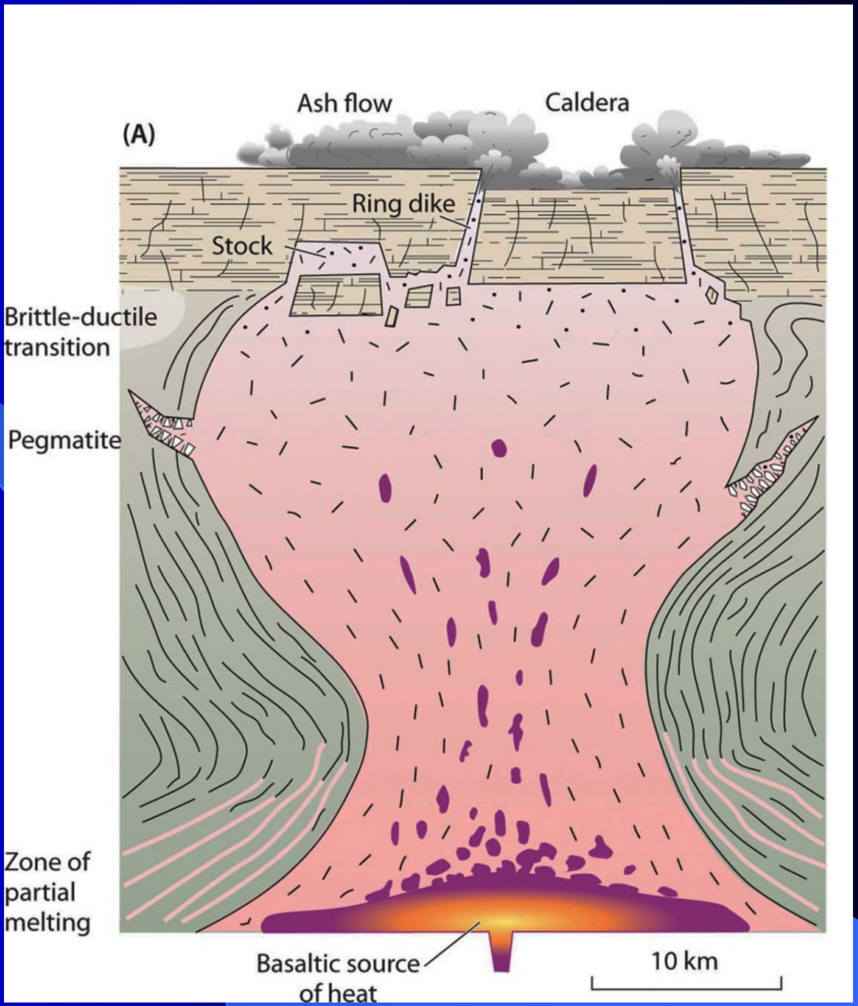
Lopolith

Batholith > 100 km^2

Stock < 100 km^2

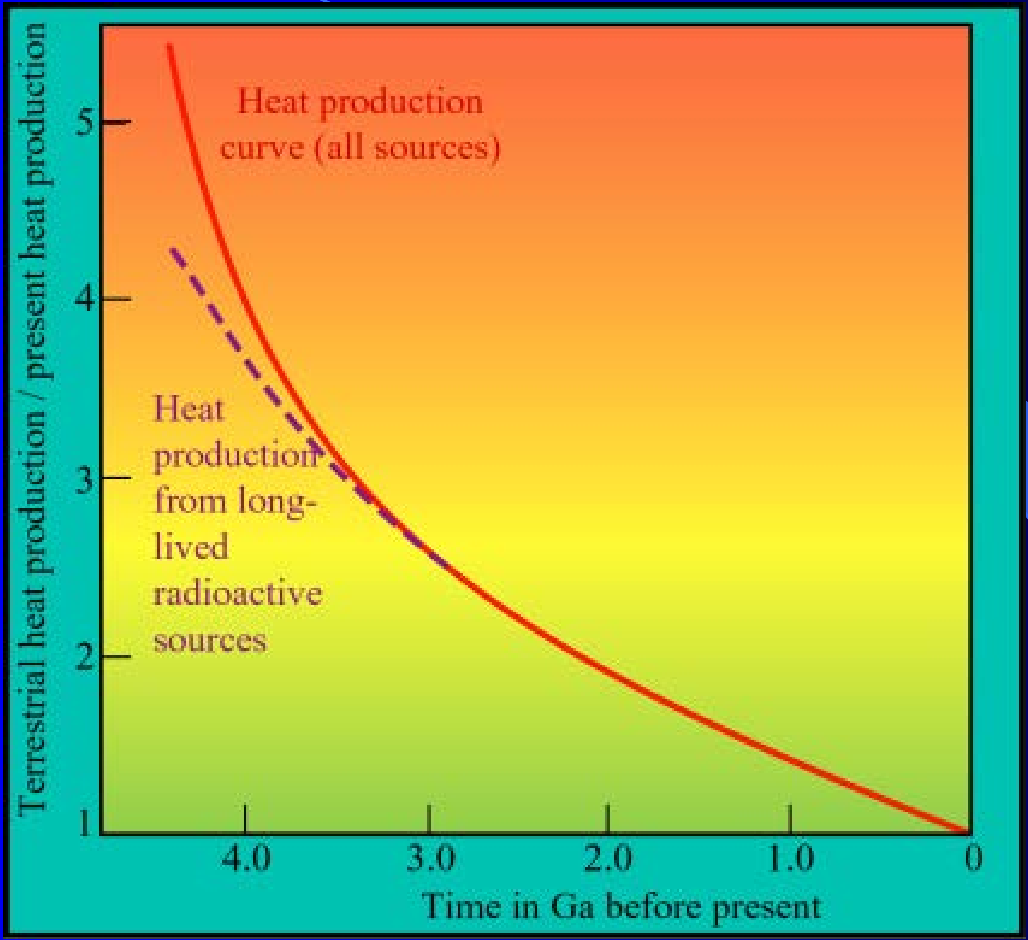
Batholiths are everywhere



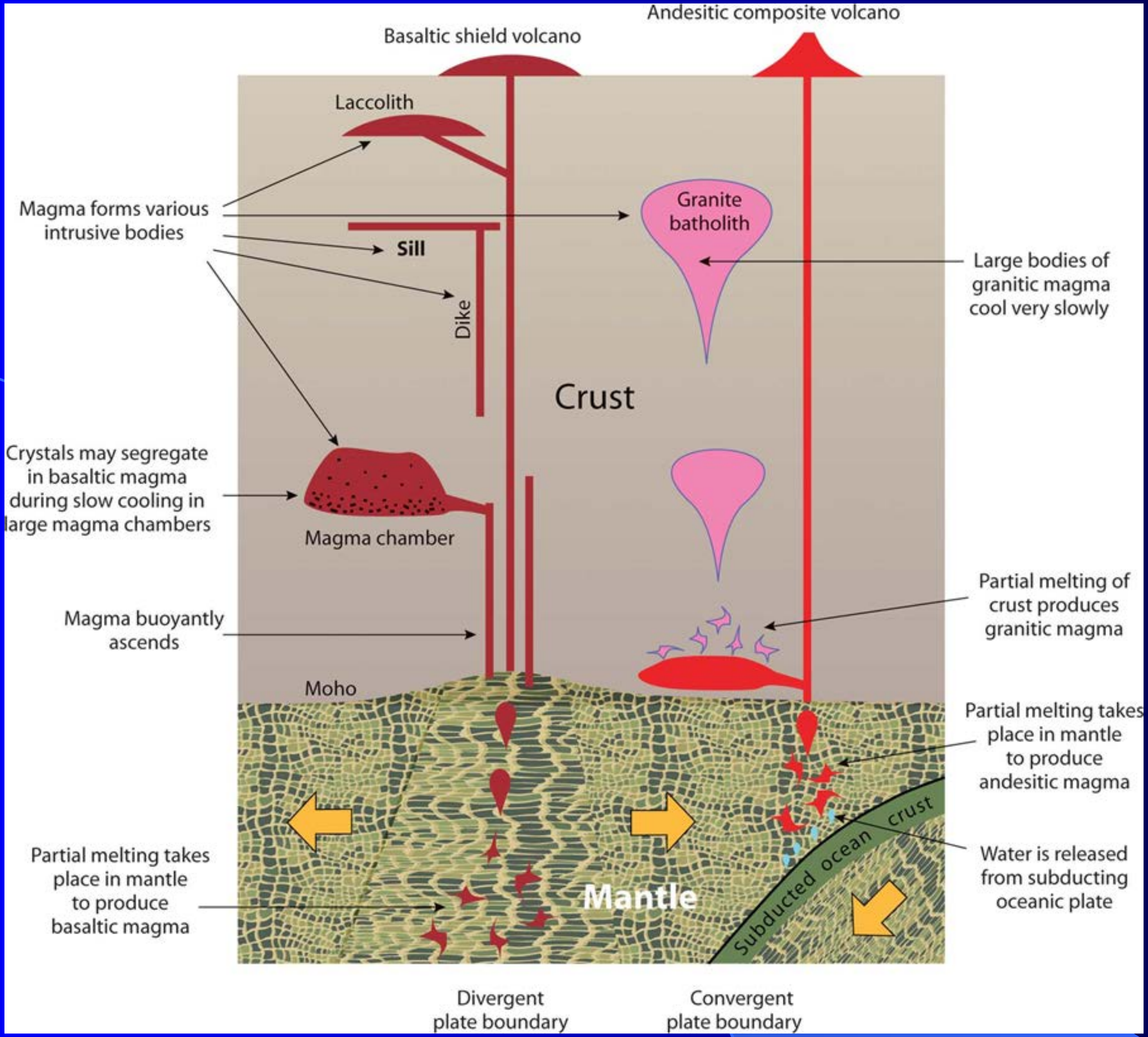


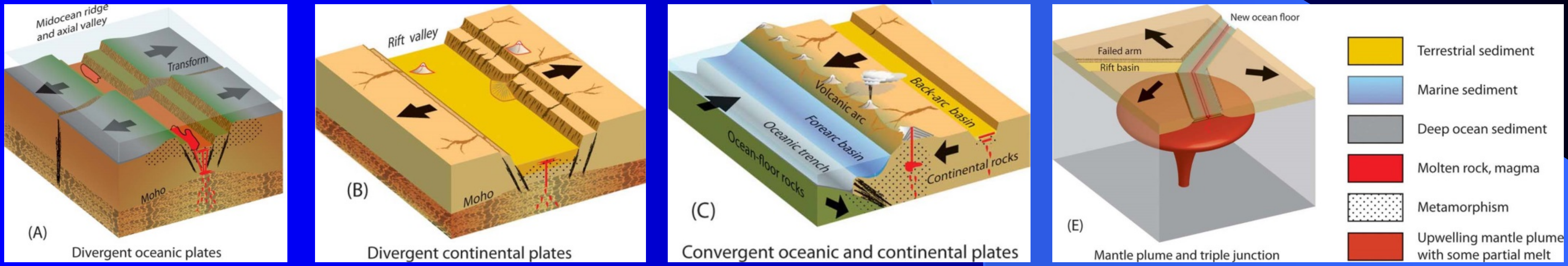
Formation of Igneous Rocks

Earth's heat production

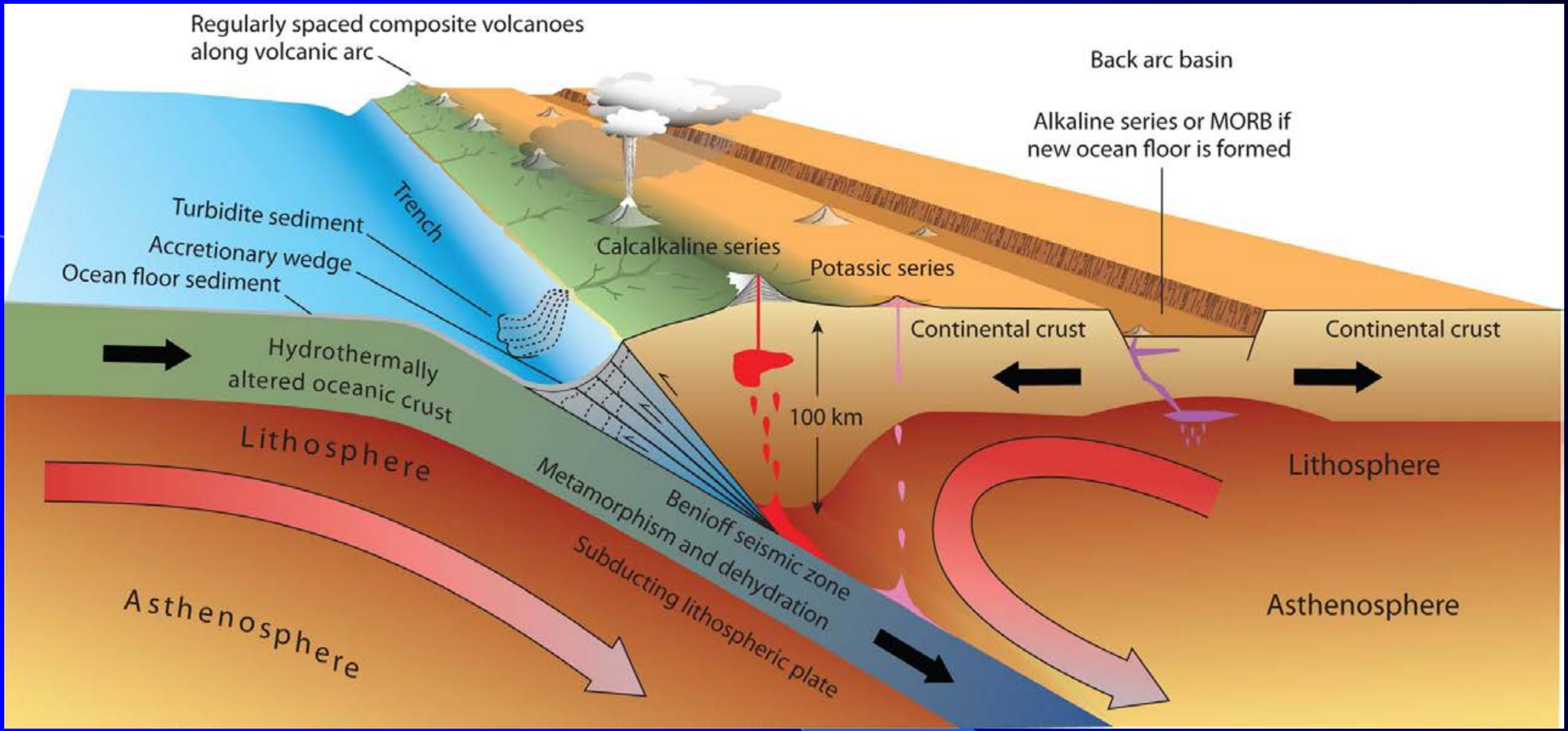


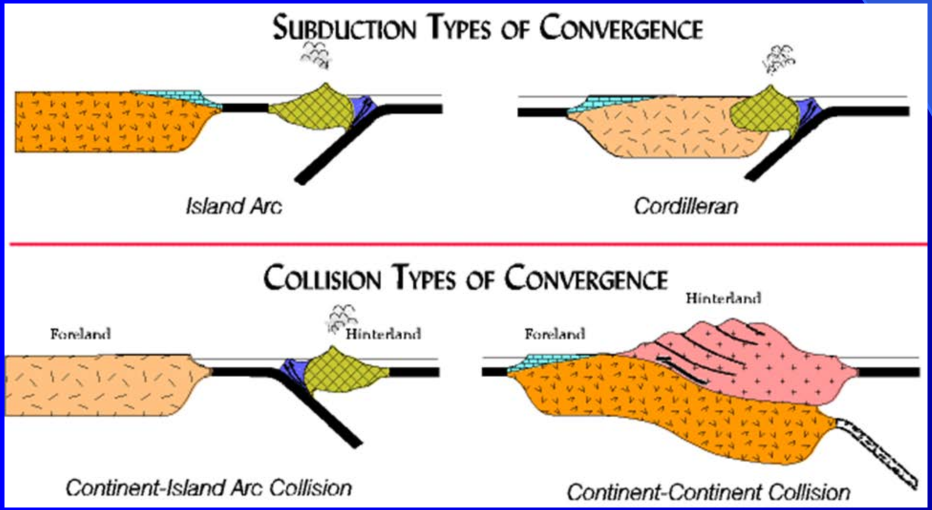
A 2- to 4-fold decrease from the Archean to now

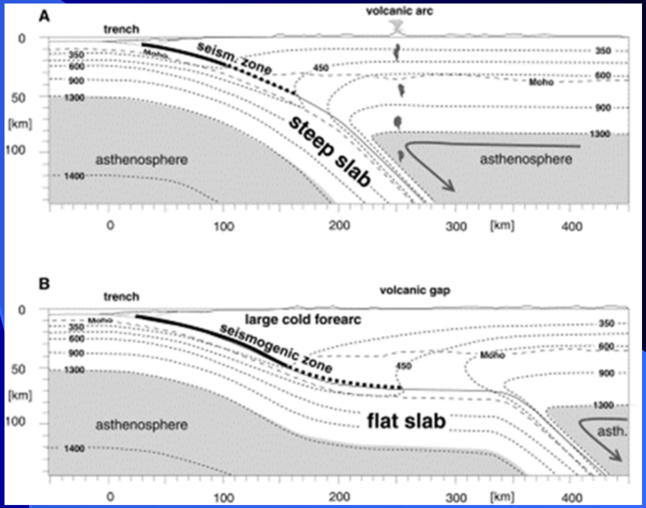

Andesitic composite volcano
Basaltic shield volcano
Laccolith
Magma forms various intrusive bodies
Granite batholith
Sill
Dike
Large bodies of granitic magma cool very slowly
Crust
Crystals may segregate in basaltic magma during slow cooling in large magma chambers
Magma chamber
Partial melting of crust produces granitic magma
Magma buoyantly ascends
Moho
Partial melting takes place in mantle to produce andesitic magma
Subducted ocean crust
Water is released from subducting oceanic plate
Partial melting takes place in mantle to produce basaltic magma
Mantle
Divergent plate boundary
Convergent plate boundary


Midocean ridge and axial valley
Transform
Moho
(A)
Divergent oceanic plates
Rift valley
(B)
Moho
Divergent continental plates
Volcanic arc
Back-arc basin
Forearc basin
Oceanic trench
Ocean-floor rocks
Continental rocks
(C)
Convergent oceanic and continental plates
New ocean floor
Failed arm
Rift basin
(E)
Mantle plume and triple junction
Terrestrial sediment
Marine sediment
Deep ocean sediment
Molten rock, magma
Metamorphism
Upwelling mantle plume with some partial melt

The Subduction Zone Factory





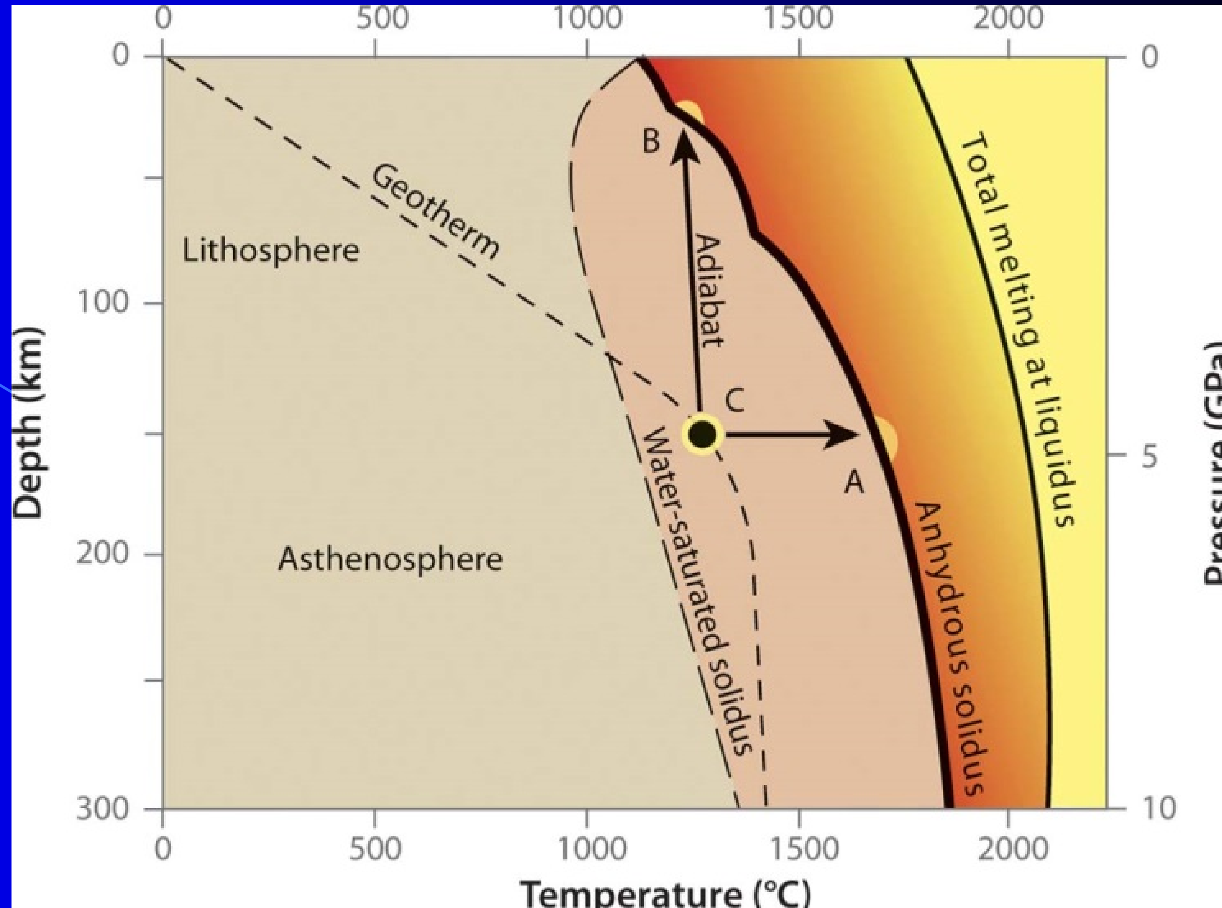


Why do rocks melt?

- Increasing temperature
- Decreasing pressure
- Adding water

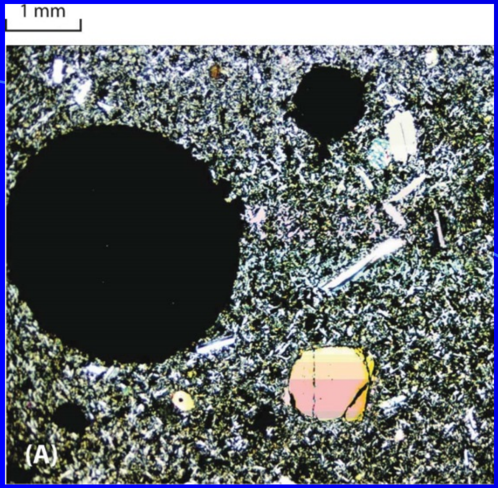
Types of Mantle rocks

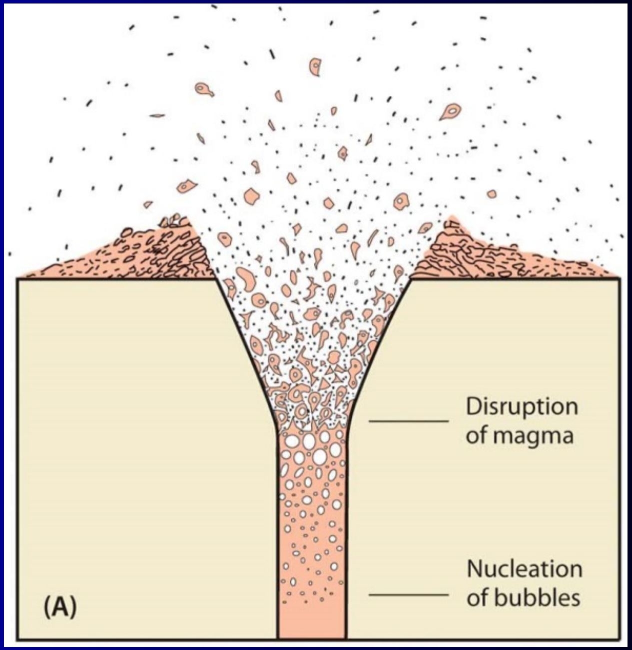
- Plagioclase lherzolite
- Spinel lherzolite
- Garnet lherzolite

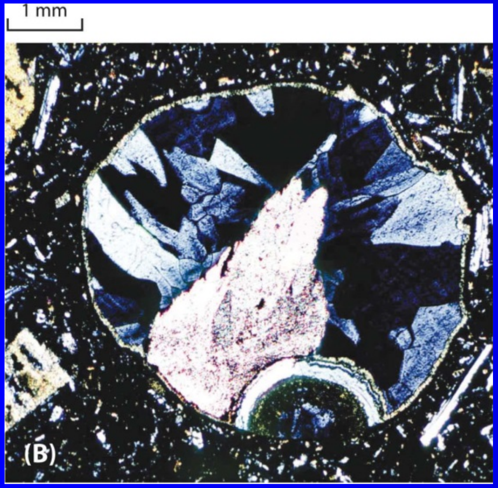


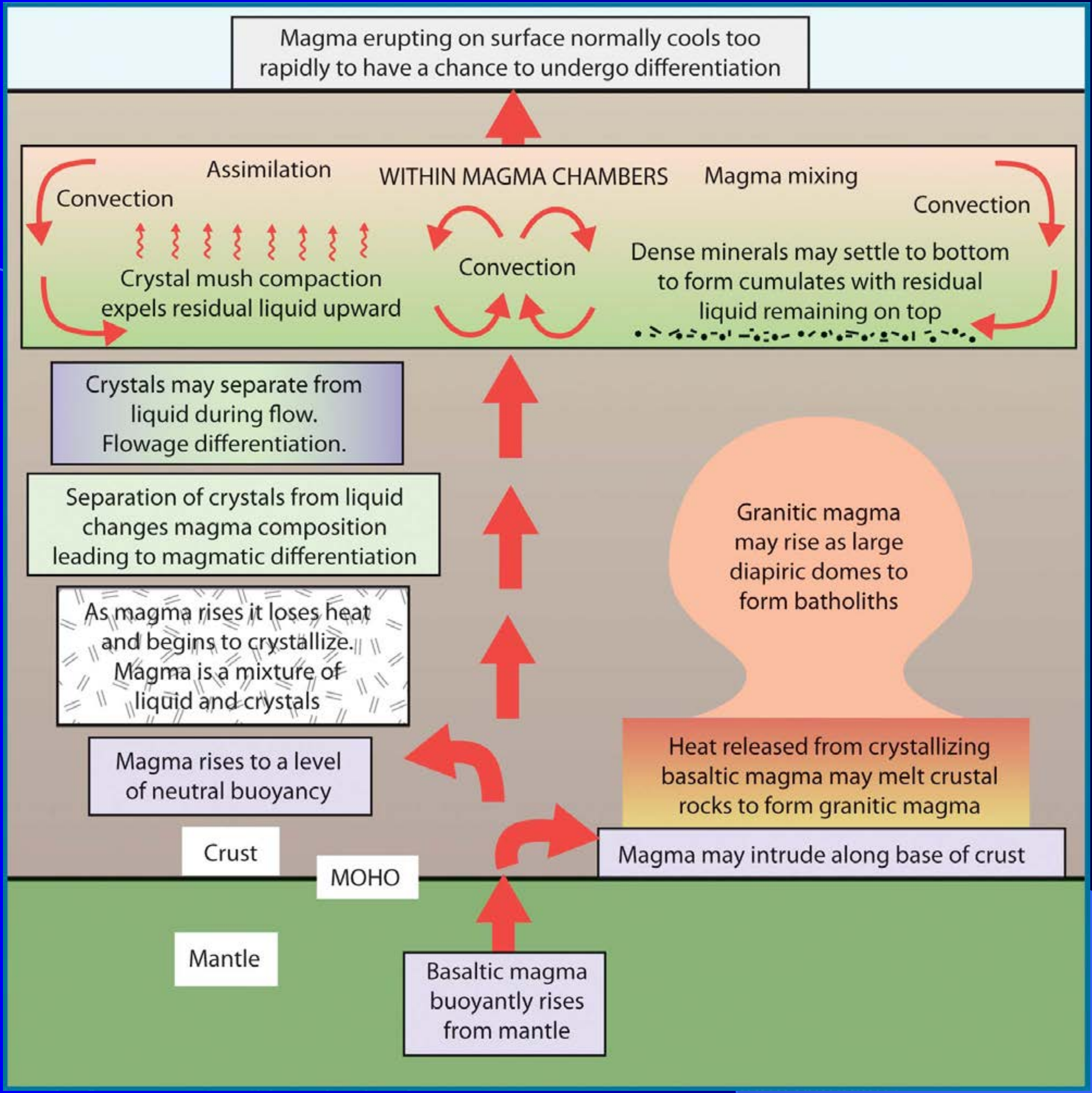
Lherzolite ⟹ olivine > orthopyroxene > Ca-pyroxene > aluminous phase

Exsolution of magmatic gases and explosive volcanism








Magma erupting on surface normally cools too rapidly to have a chance to undergo differentiation
WITHIN MAGMA CHAMBERS
Assimilation
Magma mixing
Convection
Convection
Convection
Crystal mush compaction expels residual liquid upward
Dense minerals may settle to bottom to form cumulates with residual liquid remaining on top
Crystals may separate from liquid during flow. Flowage differentiation.
Separation of crystals from liquid changes magma composition leading to magmatic differentiation
As magma rises it loses heat and begins to crystallize. Magma is a mixture of liquid and crystals
Magma rises to a level of neutral buoyancy
Granitic magma may rise as large diapiric domes to form batholiths
Heat released from crystallizing basaltic magma may melt crustal rocks to form granitic magma
Magma may intrude along base of crust
Crust
MOHO
Mantle
Basaltic magma buoyantly rises from mantle