

Igneous Rocks and Their Origin

Chapter 5



Three Types of Rocks

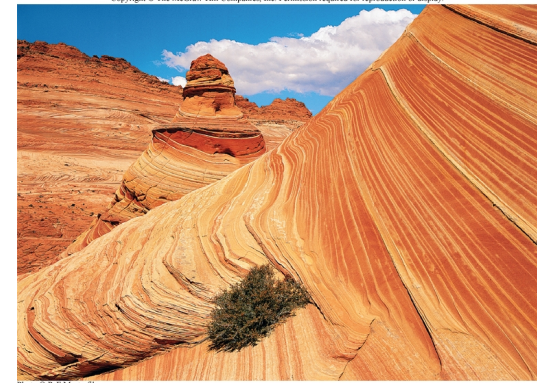
- **Igneous rocks**

- Formed from volcanic eruptions
- either external or internal



- **Sedimentary rocks**

- Formed from erosional processes



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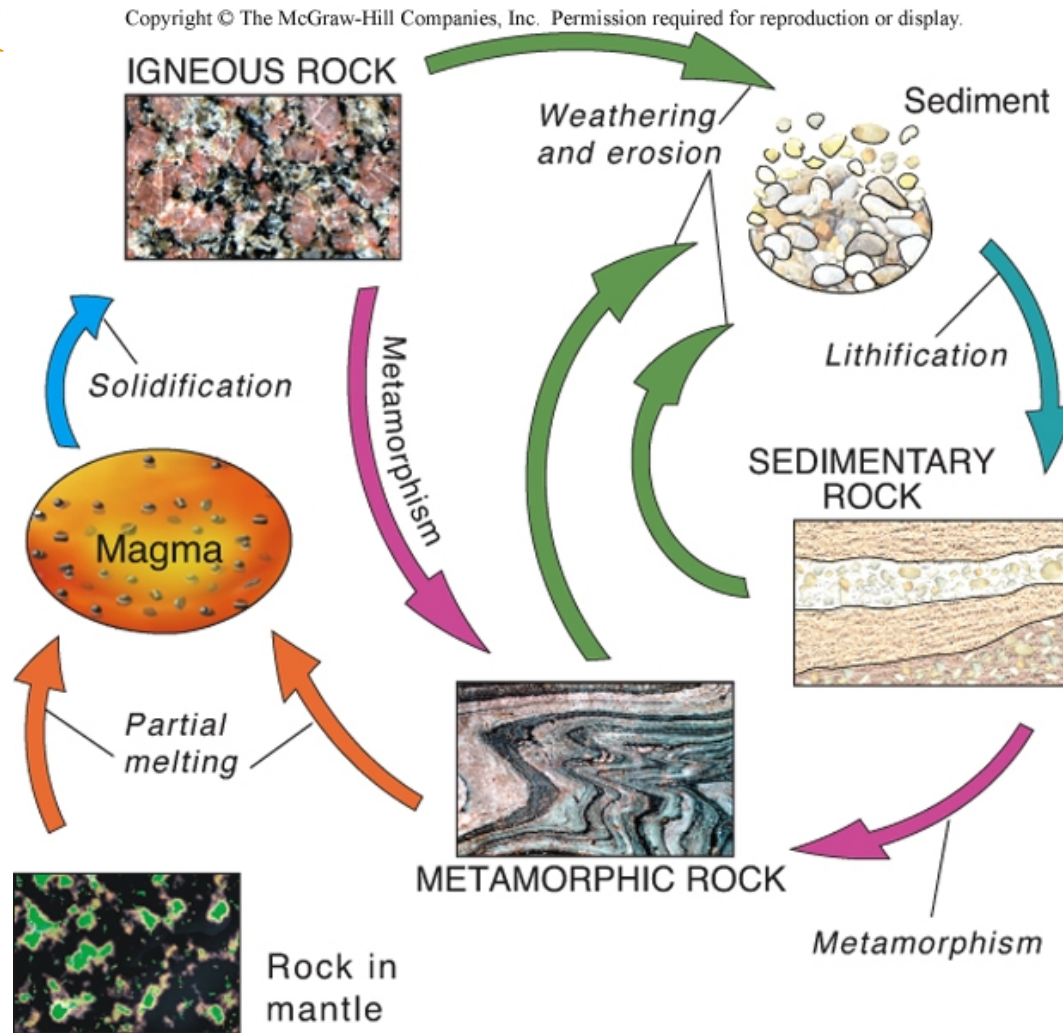
Photo © R-F Masterfile

- **Metamorphic rocks**

- Deforming of rocks above from exposure to high pressure and temperature



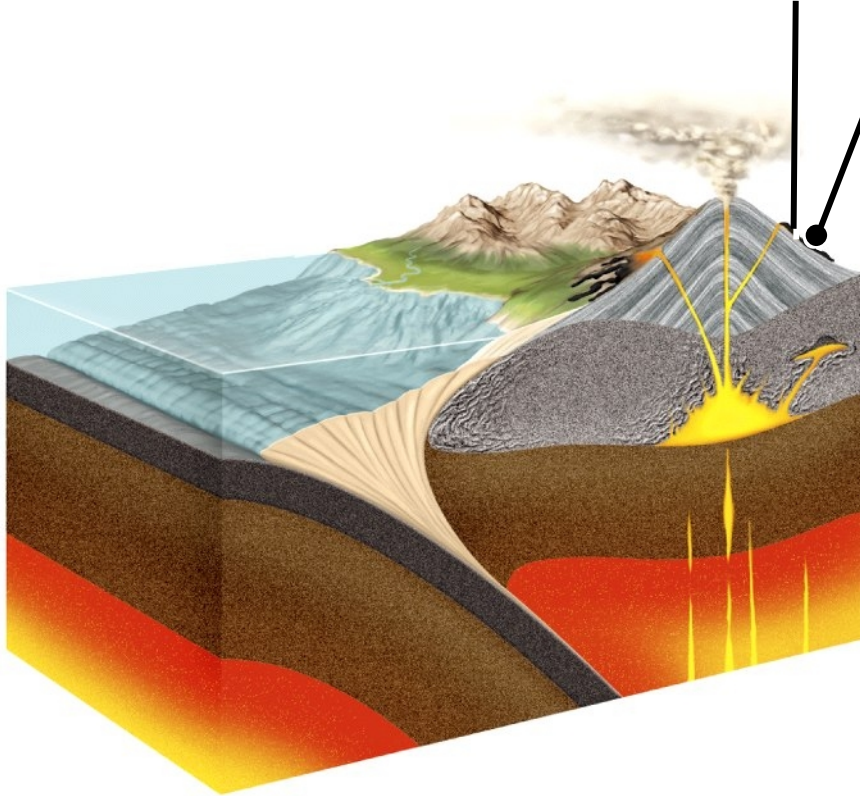
The Rock Cycle



- A *rock* is composed of grains of one or more minerals
- The *rock cycle* shows how one type of rocky material is transformed into another

Igneous Rocks

Igneous extrusion (lava)



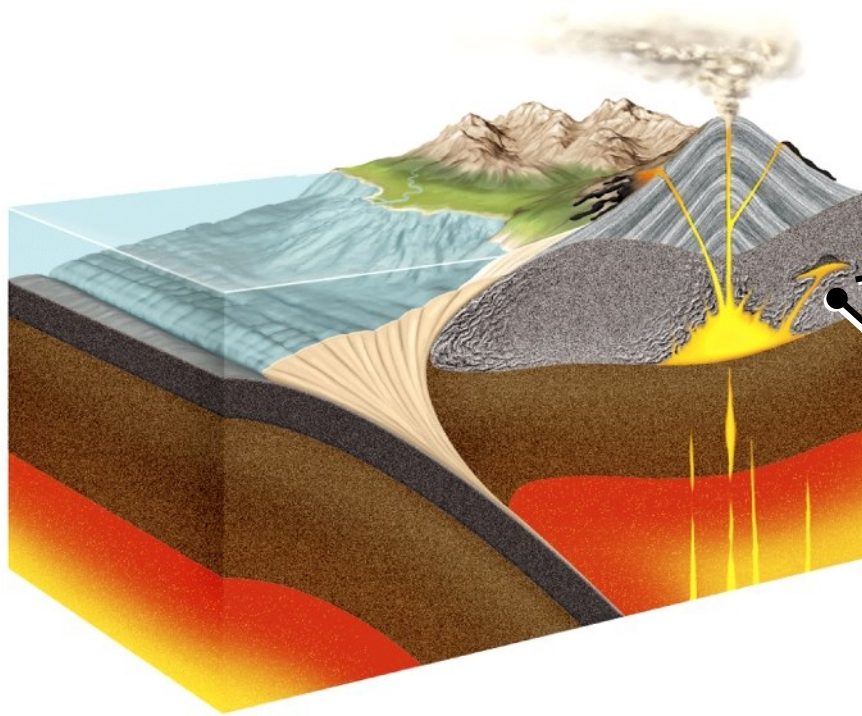
Extrusive igneous rocks form when *lava* erupts at the surface.

The resulting rock is fine-grained or has a glassy texture.



Basalt

Igneous Rocks



Igneous
intrusion

Intrusive igneous
rocks form
when *magma*
intrudes into
unmelted rock
masses.



Granite

The slow cooling process
produces coarsely grained
rocks.

How do we Know Igneous Rocks Formed at Depth?

Torres del Paine,
Chile

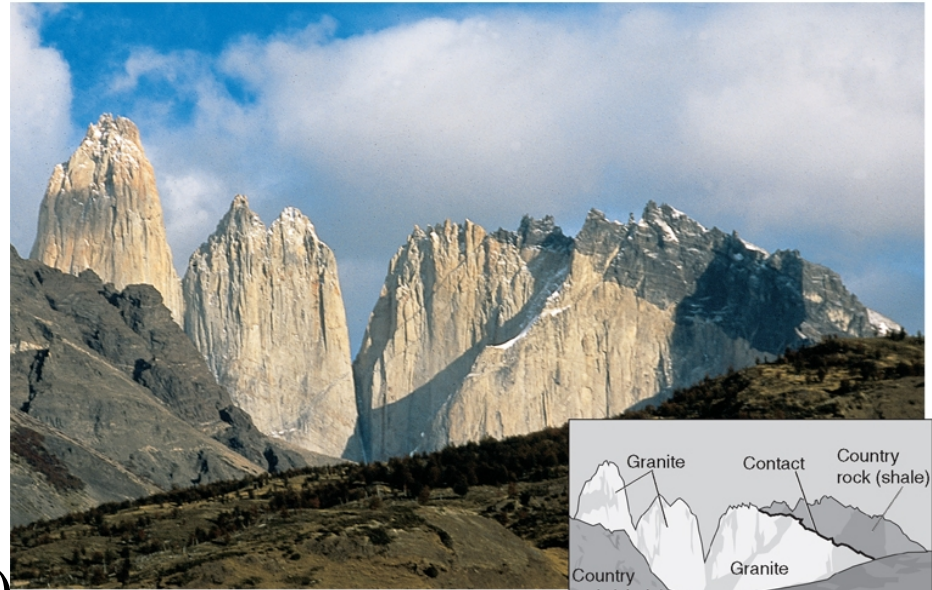


Photo by Kay Kepler

- Mineralogy / Chemistry ?
- Grain size (coarse vs fine grained)
- Lab expmts require high P & T to form large grains
- Outcrops: See intrusions into *country rock*
 - Contact/chill zones, baked and metamorphosed
- Xenoliths of country rock found in igneous intrusions

Igneous Rock Identification

- Igneous rock names are based on *texture* (grain size) and *composition*
- ***Textural classification***
 - **Coarse-grained:** *Plutonic* rocks (gabbro-diorite-granite) cooled slowly at depth
 - **Fine-Grained:** *Volcanic* rocks (basalt-andesite-rhyolite) cooled rapidly at the Earth's surface
- ***Compositional classification***
 - **Mafic** rocks (gabbro-basalt) contain dark-colored ferromagnesian minerals, iron rich (50% silica)
 - **Intermediate** rocks (diorite-andesite) contain roughly equal amounts of dark- and light-colored minerals
 - **Felsic** rocks (granite-rhyolite) light-colored minerals, silica rich (65%)

Igneous Rock Textures

- *Texture* refers to the size, shape and arrangement of grains
- Texture of igneous rocks is controlled by *cooling rate*
- Extrusive rocks cool quickly at the Earth's surface and are *fine-grained* (small <1 mm)
- Intrusive rocks cool slowly deep beneath Earth's surface and are *coarse-grained* (large >1 mm)



Fine-grained igneous rock



Coarse-grained igneous rock

Igneous Rock Identification

Igneous names are based on

- 1) *texture* and
- 2) mineralogic *composition*

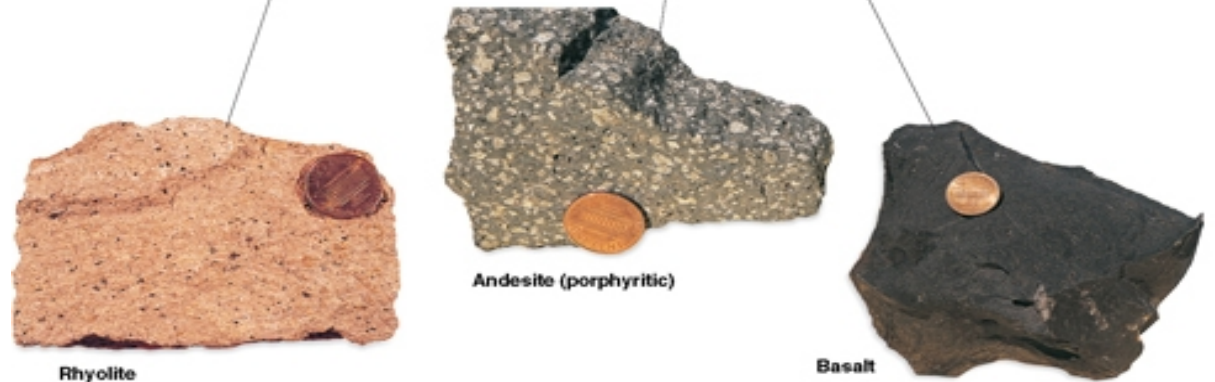
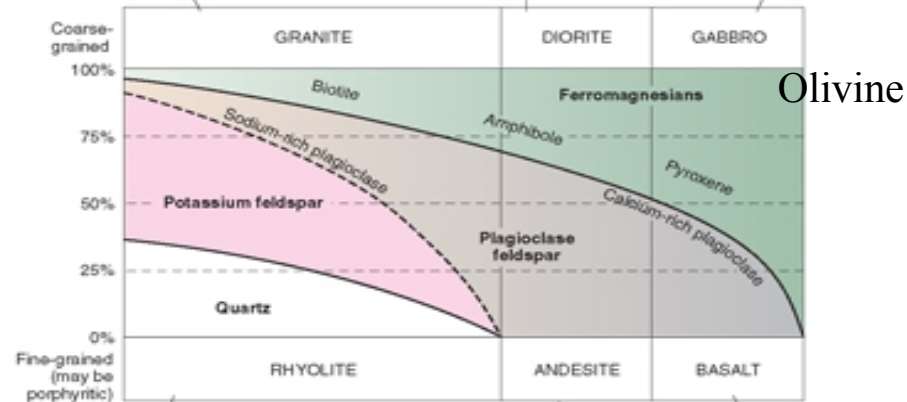
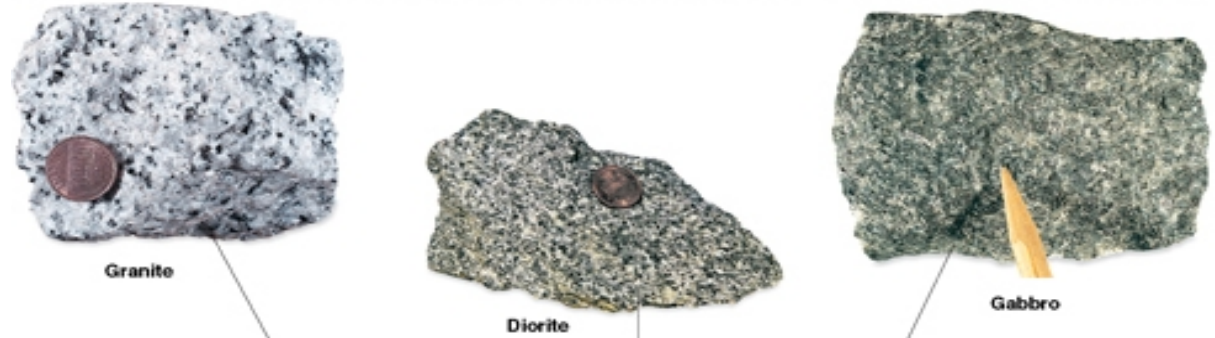
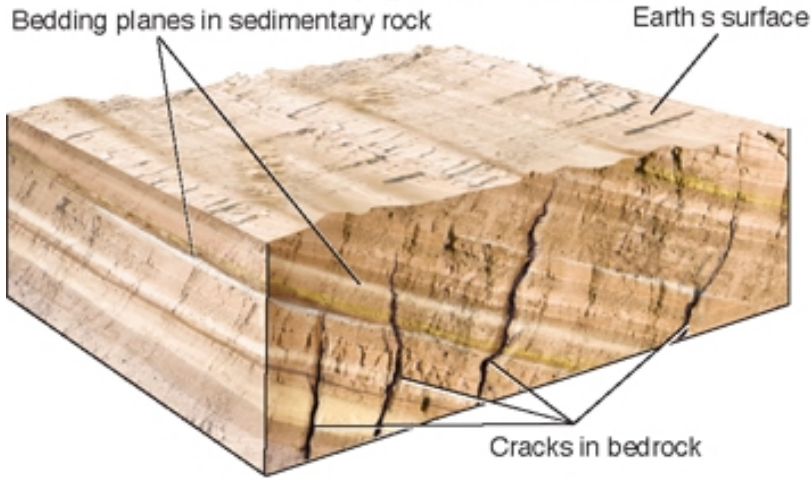


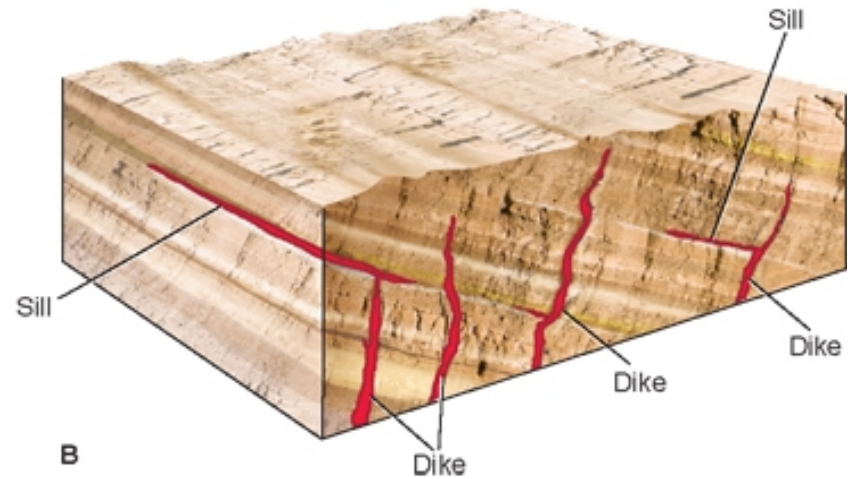
Photo of gabbro by Larry Davis; all others by C. C. Plummer

Intrusive Rock Bodies

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A



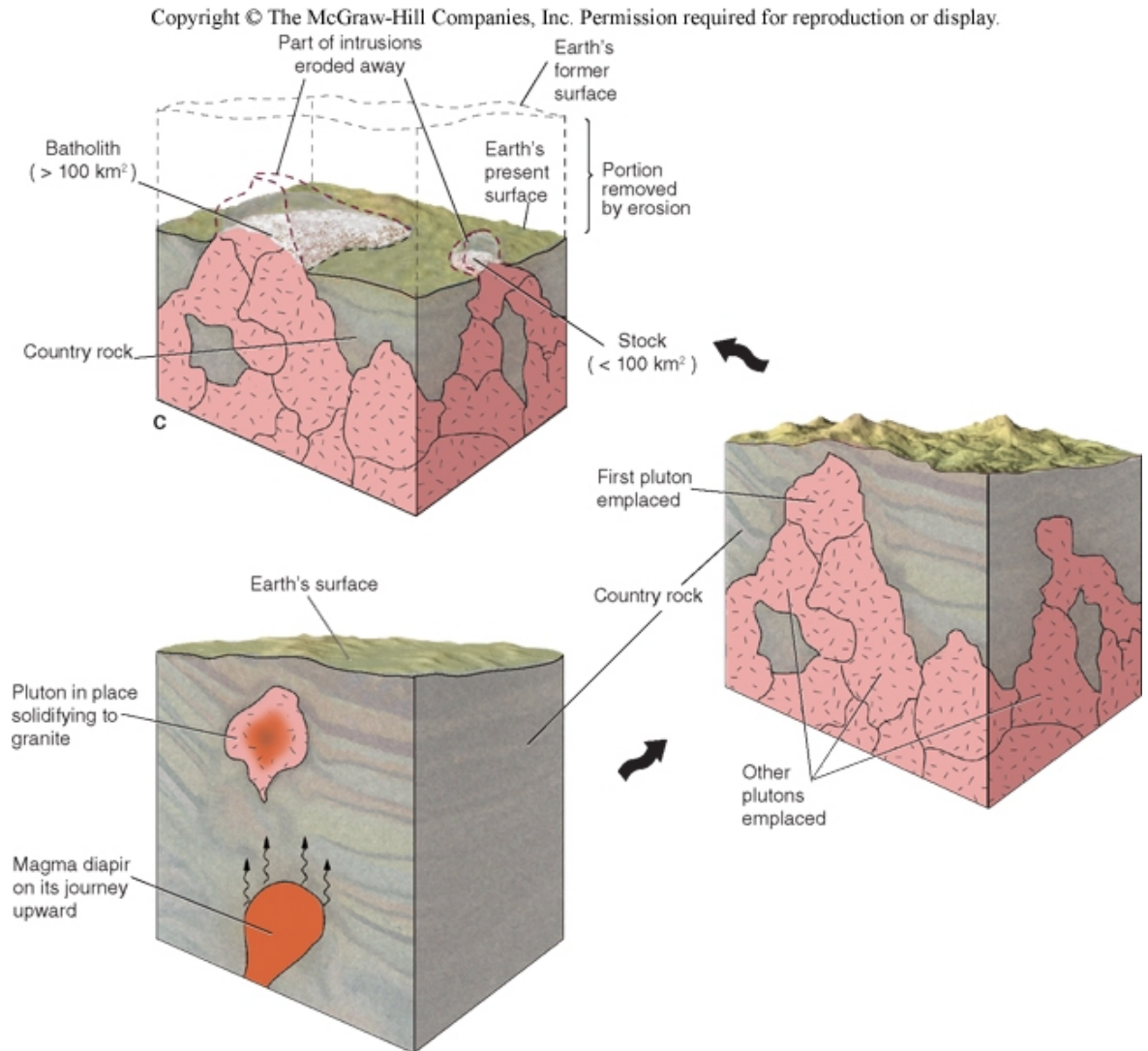
B

- Intrusive rocks exist in bodies or structures that penetrate or cut through pre-existing *country rock*
- Shallow intrusions: *Dikes* and *sills*
 - Form <2 km beneath Earth's surface
 - Chill and solidify quickly in cool country rock

Intrusive Rock Bodies

- *Plutons*: deep magmatic intrusions

- Form at considerable depth beneath the surface when rising blobs of magma (*diapirs*) get trapped within the crust

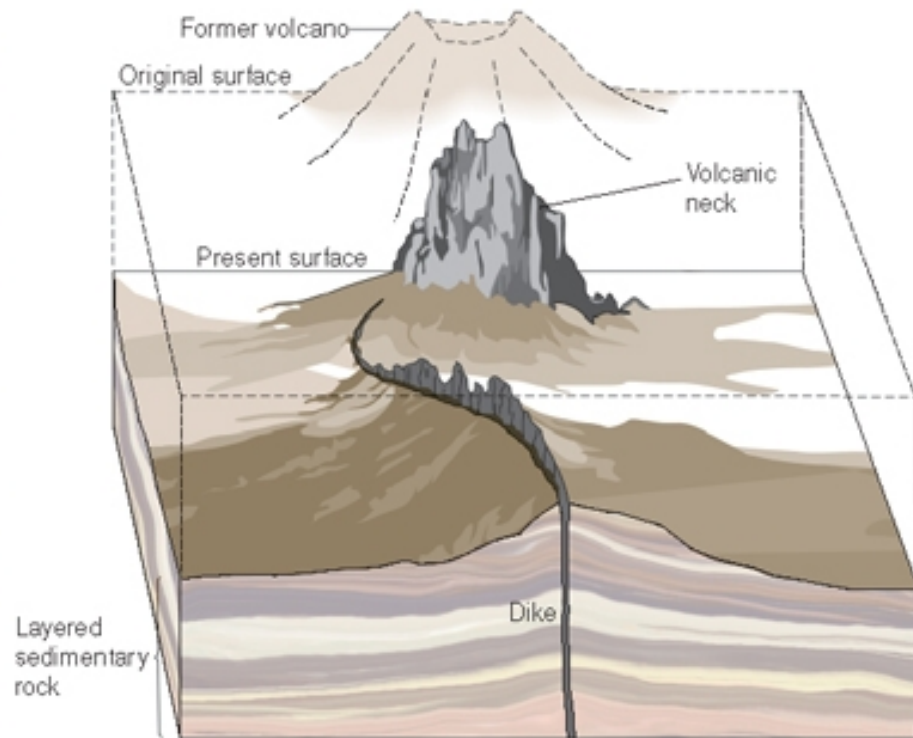


Pluton in Ship Rock, New Mexico

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A



B

Intrusive Rock Bodies

- *Volcanic neck*
 - Shallow intrusion formed when magma solidifies in throat of volcano
- *Dike*
 - Tabular intrusive structure that cuts across any layering in country rock
- *Sill*
 - Tabular intrusive structure that parallels layering in country rock



Light-colored dikes



Basaltic sill

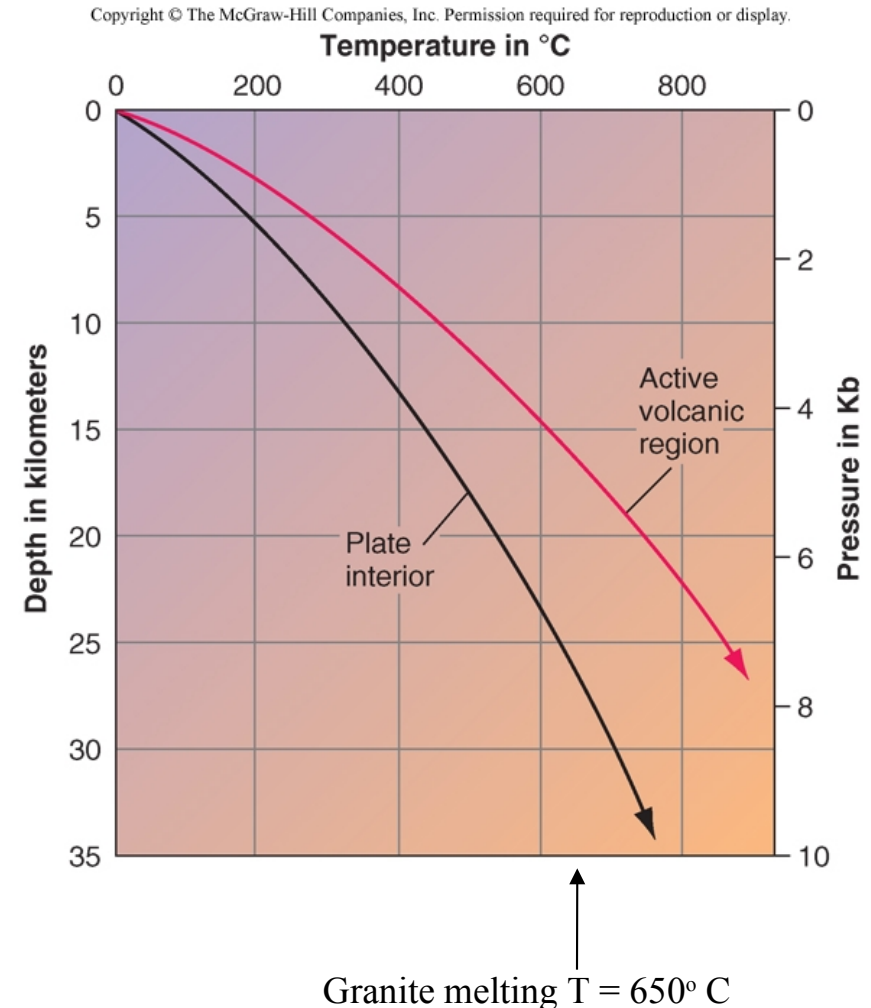


Sierra Nevada batholith

How Magma Forms

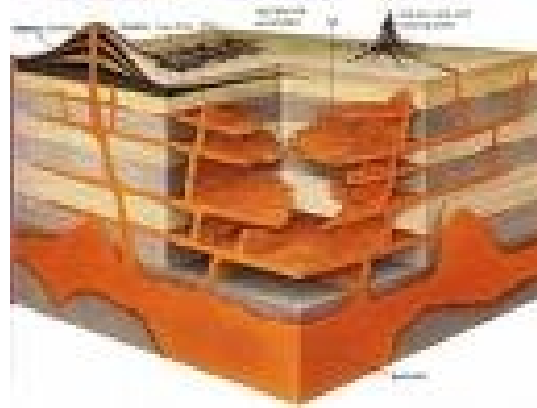
Heat from below

- Melting Temp (T_m) of granite is 650°C and basalt is 1000°C
- **Geothermal gradient:** Rate at which temperature increases with depth beneath the surface is $30^{\circ}/\text{km}$
- **Volcanic geotherm** is higher due to rise of hot magma, gases (water), or composition change

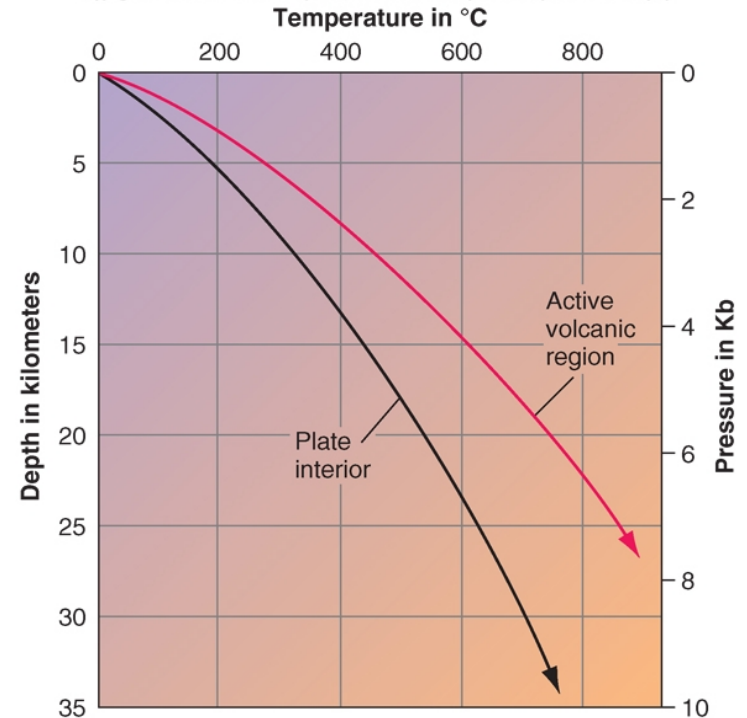


Melting Temperature can be Effected by:

- Increasing temperature
- Decrease in pressure
- Addition of water
- Mixed mineral composition



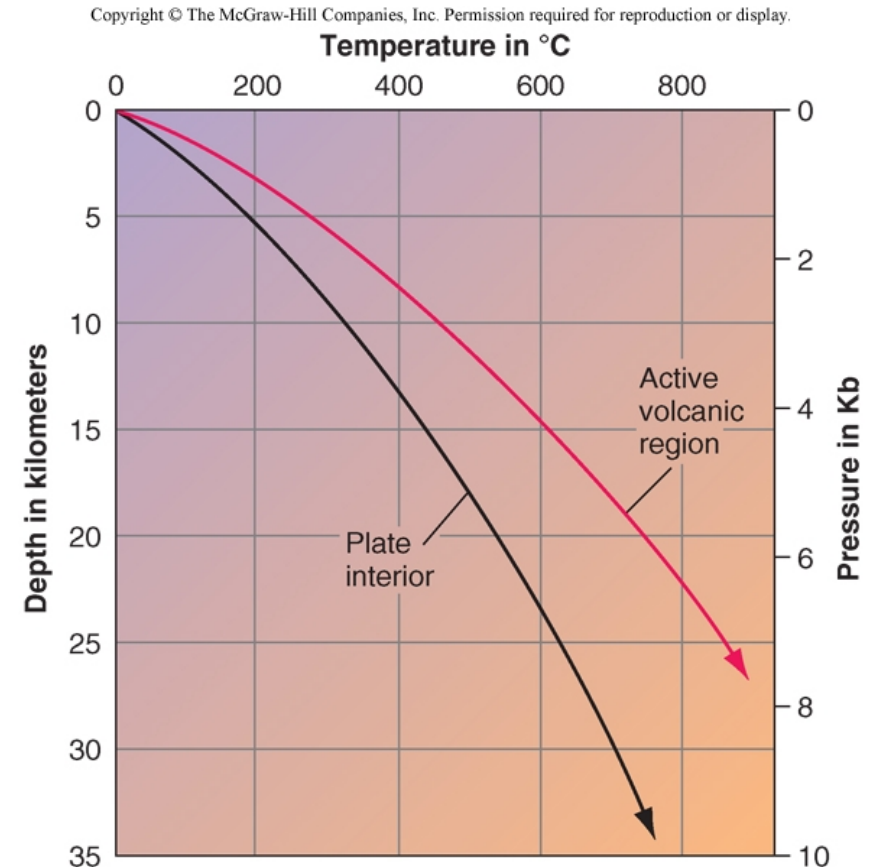
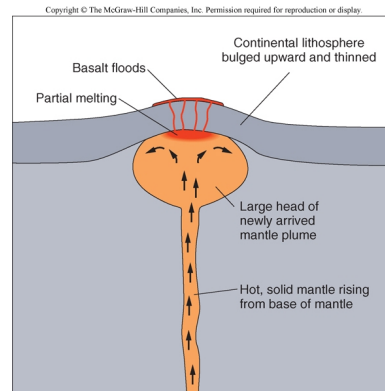
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Melting Temperature can be Effected by:

- *Heat vs. pressure*

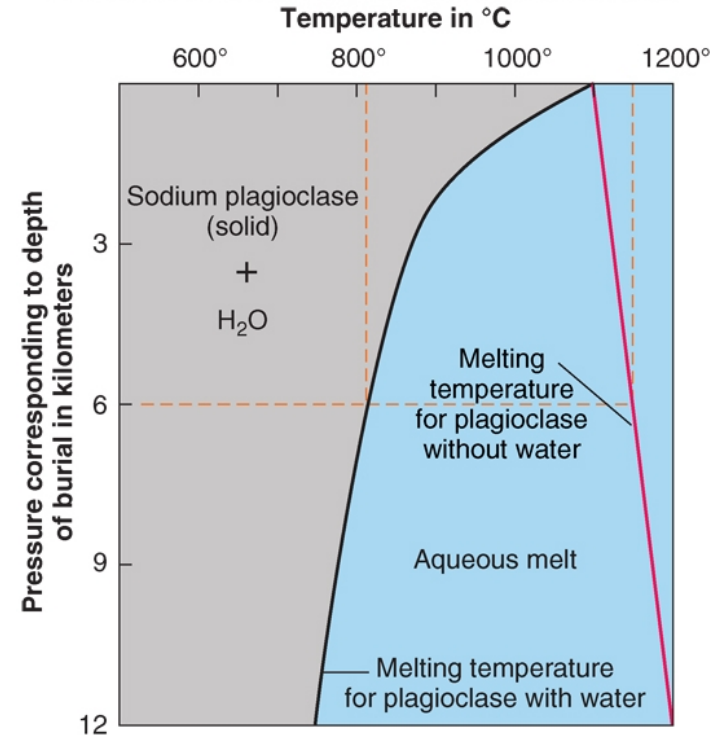
- Melting point of minerals generally increases with increasing pressure
- *Decompression melting* can occur when hot mantle rock moves upward and pressure is reduced enough to drop melting point to the temperature of the rising rock body



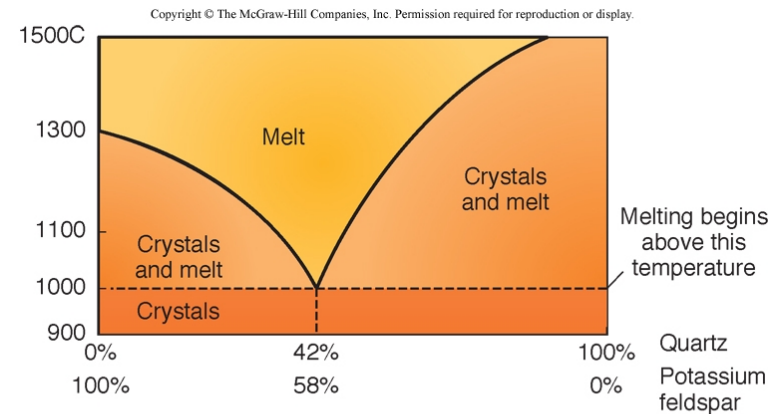
... Melting Temperature

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- *Hot water under pressure*
 - Water becomes increasingly reactive at higher temperatures
 - Highly reactive water vapor can reduce the melting point of rocks by over 200°C
- *Mineral mixtures*
 - Mixtures of minerals, such as quartz and potassium feldspar, can result in the melting of both at temperatures hundreds of degrees lower than either mineral would melt on its own



After Tuttle and Brown, Geologic Society of America, 1958

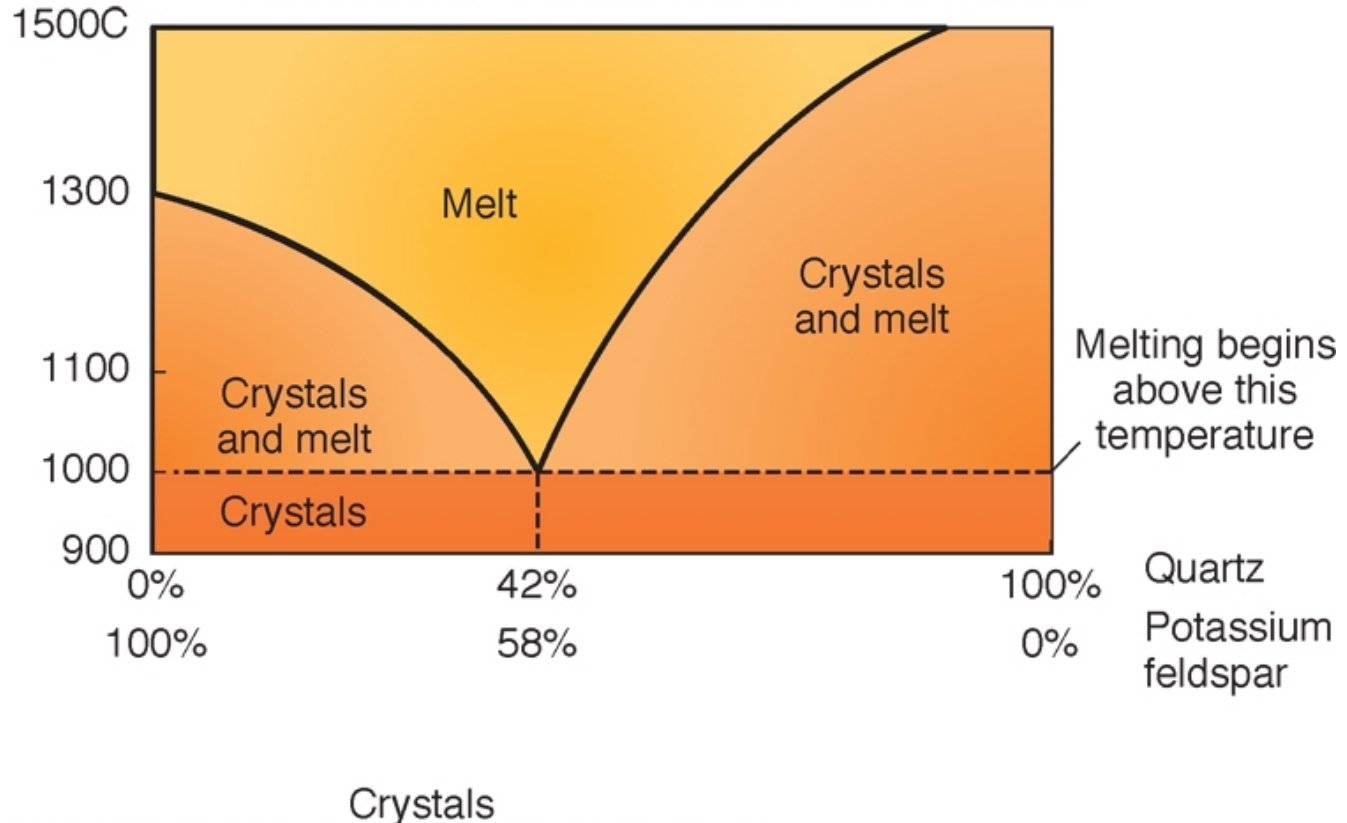


Crystals

Modified from Schairer and Bowen, 1956, V 254, p. 16, American Journal of Science

Magma Melting

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Modified from Schairer and Bowen, 1956. V 254, p. 16. American Journal of Science

Mixed magmas may have a lower melting temperature than either alone.

Magma Crystallization and Melting Sequence

Bowen's Reaction Series

- Minerals crystallize in a predictable order (and melt in the reverse order)
- Minerals *crystallize* in sequence with decreasing temperature

olivine

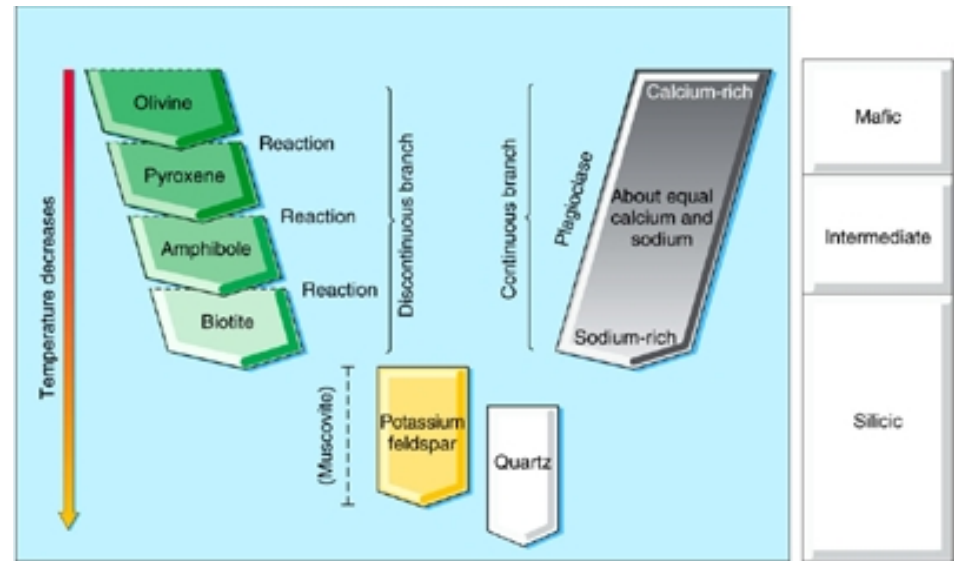
pyroxene

amphibole

biotite

feldspars

quartz



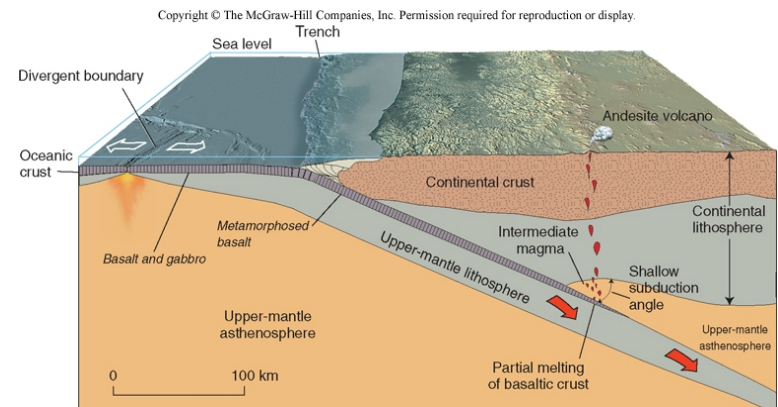
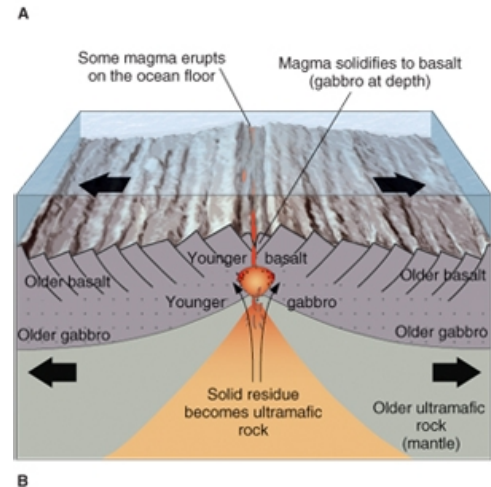
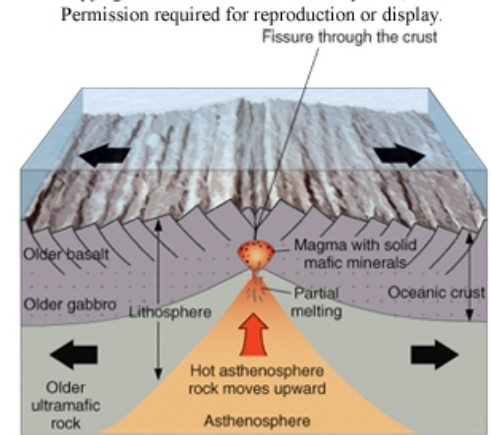
Bowen's Reaction Series

Lessons from Bowen's Reaction Series

- Variety of igneous rocks is produced by variety of *magma compositions*
- *Mafic magmas* will crystallize into *basalt* or *gabbro*
- *Intermediate magmas* will similarly crystallize into *diorite* or *andesite* if minerals are not removed
- Minerals melt in the *reverse order* of that in which they crystallize from a magma

Igneous Activity and Plate Tectonics

- Igneous activity occurs primarily at or near tectonic plate boundaries
- **Divergent boundaries:** typically produce *mafic* igneous rocks
 - Increased heat flow
 - *Decompression melting* at spreading centers
- **Convergent boundaries:** typically produce *intermediate* igneous rocks
 - High pressures and high temperatures induce melting
 - *Water release melting* occurs above subduction zones (*andesite, granite*)



Igneous Activity and Plate Tectonics

- Felsic igneous rocks are commonly formed adjacent to *convergent boundaries*
 - Hot rising magma causes partial melting of the granitic continental crust
- *Intraplate volcanism*
 - Rising mantle plumes can produce localized hotspots and volcanoes when they produce magmas that rise through oceanic or continental crust
 - Hawaii is an example

