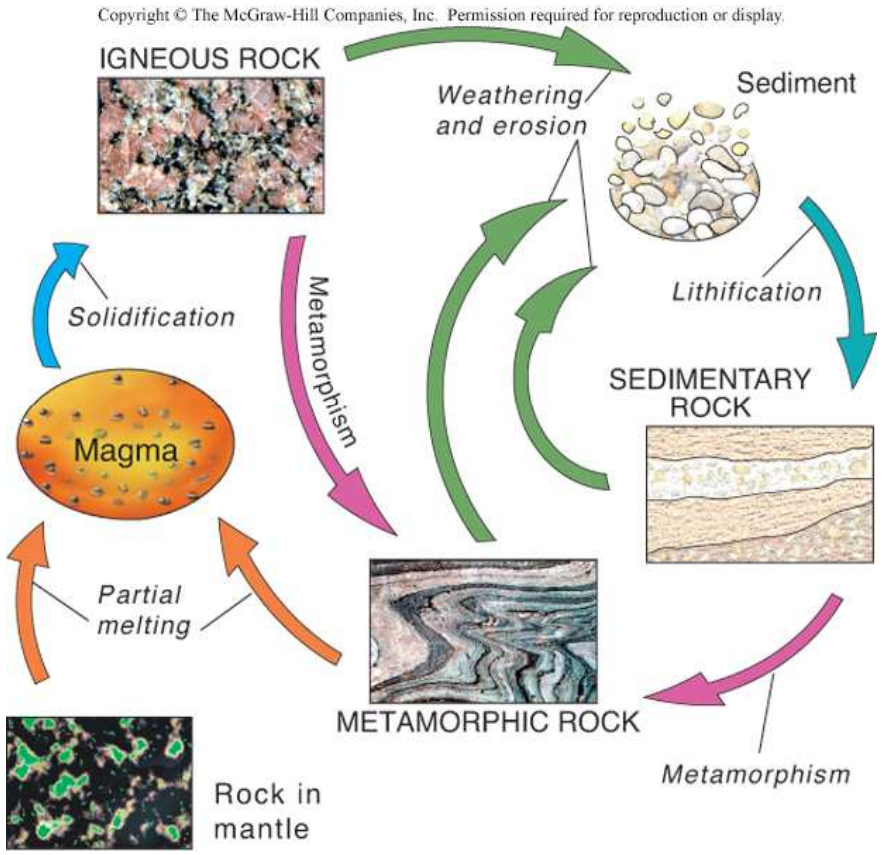
Intrusive Activity, and the Origin of Igneous Rocks

Chapter 11

The Rock Cycle

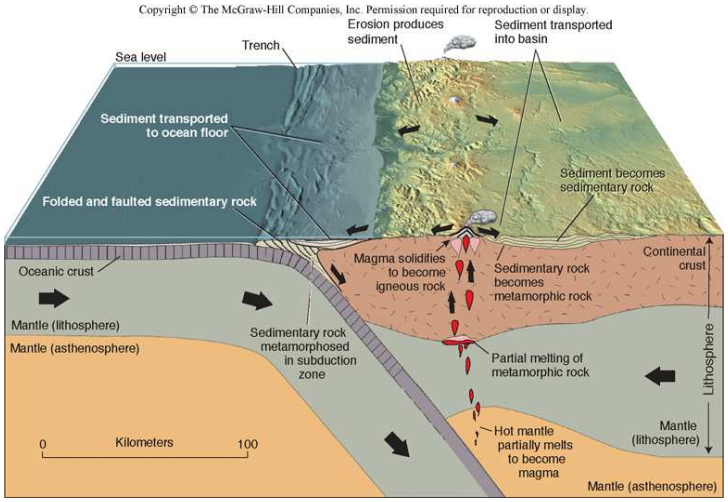
- A *rock* is a naturally formed, consolidated material usually composed of grains of one or more minerals

- The *rock cycle* shows how one type of rocky material gets transformed into another



The Rock Cycle and Plate Tectonics

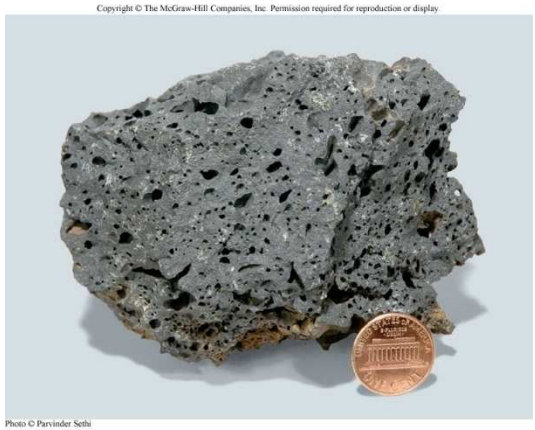
- *Magma* is created by melting of rock above a subduction zone
- Less dense magma rises and cools to form *igneous rock*
- Igneous rock exposed at surface gets weathered into *sediment*
- Sediments transported to low areas, buried and hardened into *sedimentary rock*
- Sedimentary rock heated and squeezed at depth to form *metamorphic rock*
- Metamorphic rock may heat up and melt at depth to form *magma*



Igneous Rocks

- *Magma* is molten rock
- *Igneous rocks* form when magma cools and solidifies
  - *Intrusive* igneous rocks form when magma solidifies underground
    - Granite is a common example
  - *Extrusive* igneous rocks form when magma solidifies at the Earth's surface (lava)
    - Basalt is a common example

Granite



Basalt

Basic Definitions

- **Igneous Rock** –formed from cooling magma
- **Magma –** molten rock
- **Lava –** magma on the surface
- **Extrusive Igneous Rocks –** formed on the surface
- **Intrusive Igneous Rocks –** formed within the interior of the Earth

Igneous Rock Textures and Identification

Igneous Rock Textures

- *Texture* refers to the size, shape and arrangement of grains or other constituents within a rock

- Texture of igneous rocks is primarily controlled by *cooling rate*

- Extrusive igneous rocks cool quickly at or near Earth's surface and are typically *fine-grained* (most crystals <1 mm)

- Intrusive igneous rocks cool slowly deep beneath Earth's surface and are typically *coarse-grained* (most crystals >1 mm)

Fine-grained igneous rock

Coarse-grained igneous rock

Intrusive Igneous Rocks

- Form within the interior of the Earth
- Cool more slowly than extrusive
- Grow bigger crystals

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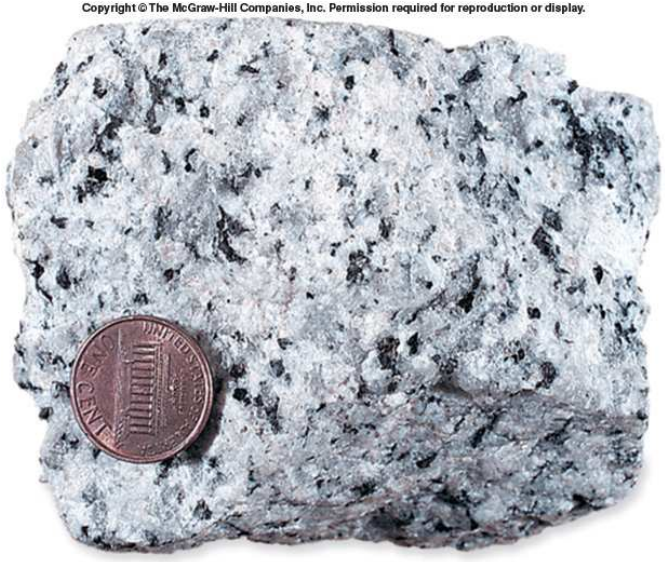


Granite

C.C. Plummer

Special Igneous Textures

- A *pegmatite* is an extremely coarse-grained igneous rock (most crystals >5 cm) formed when magma cools *very slowly* at depth

Pegmatitic igneous rock

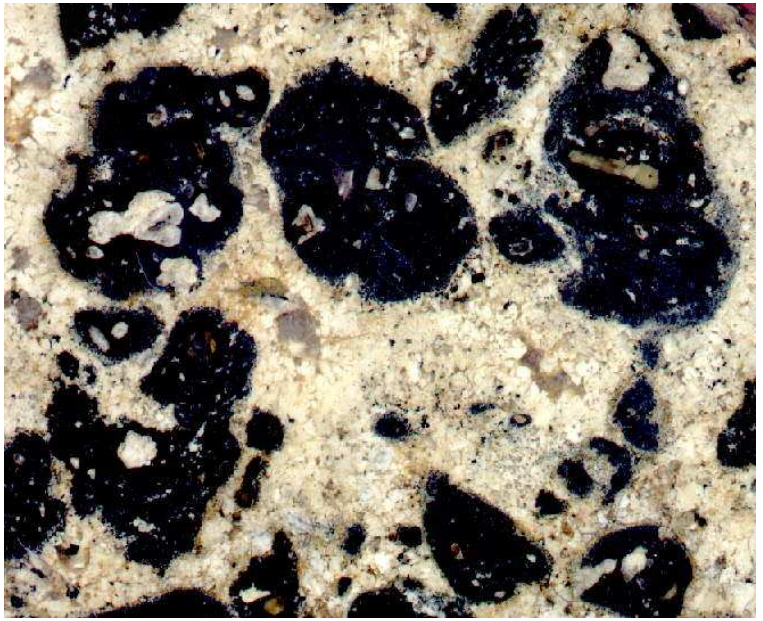
- A *glassy* texture contains no crystals at all, and is formed by extremely rapid cooling

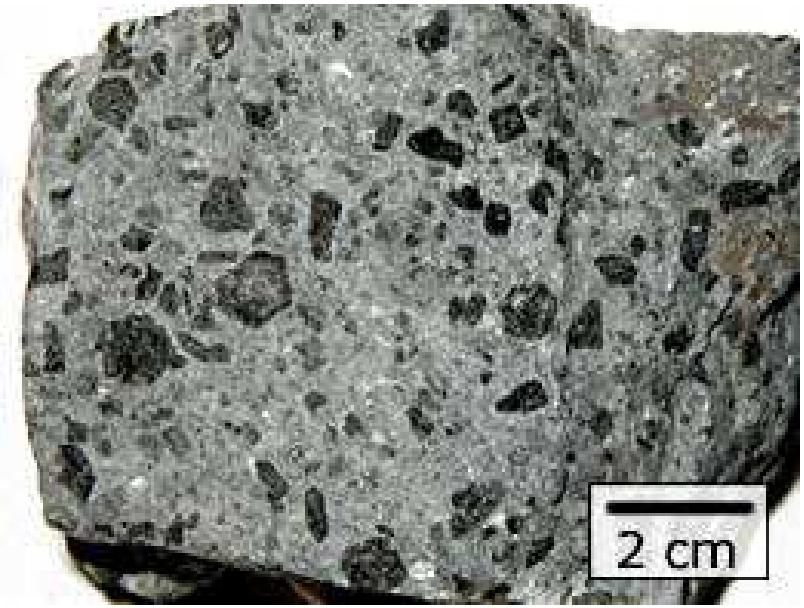
- A *porphyritic* texture includes two distinct crystal sizes, with the larger having formed first during slow cooling underground and the small forming during more rapid cooling at the Earth's surface

Porphyritic igneous rock

Porphyritic Texture

- Large crystals (phenocrysts) surrounded by a finer grained matrix (groundmass)
- Begin crystallizing (cooling) slowly, followed by rapid crystallization (eruption?)



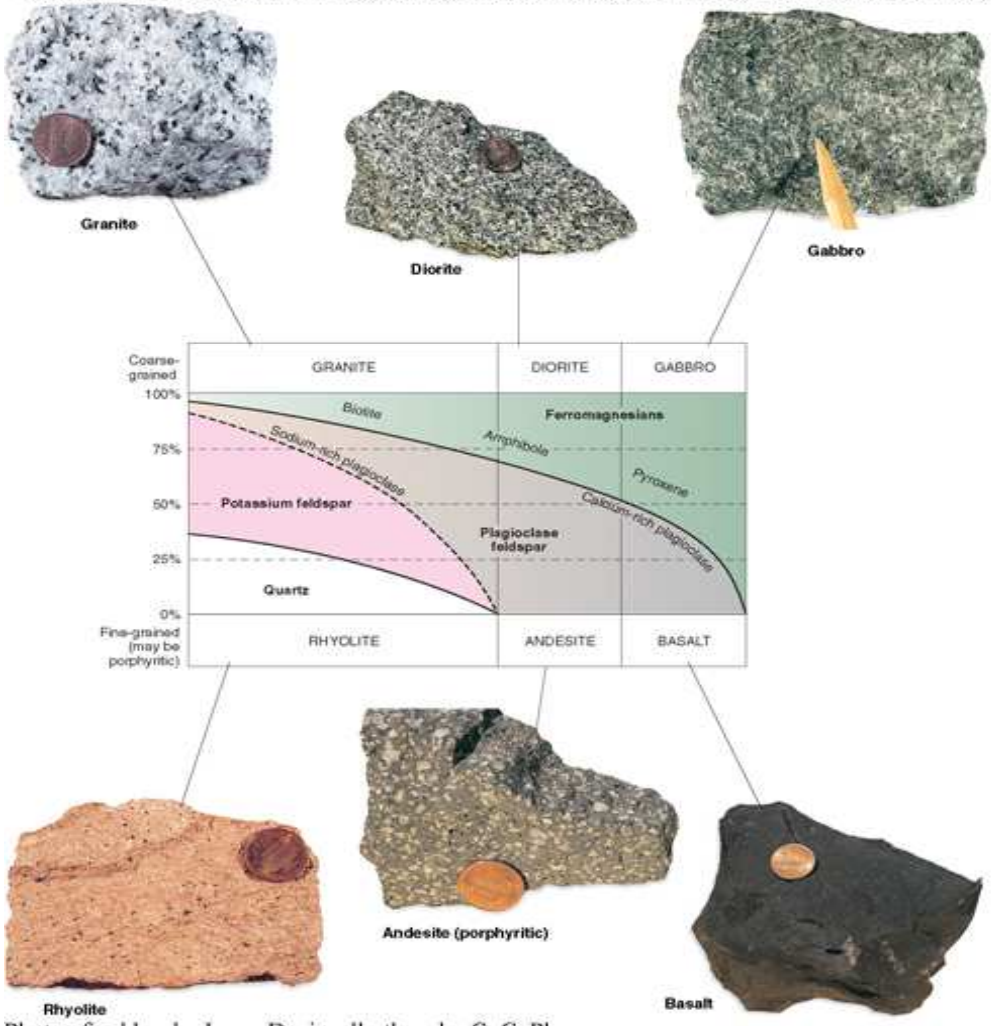


Extremely coarse-grained crystals

Pegmatites

Igneous Rock Identification

- Igneous rock names are based on *texture* (grain size) and mineralogic *composition*



Intrusive Rocks

Extrusive Rocks

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

Granite
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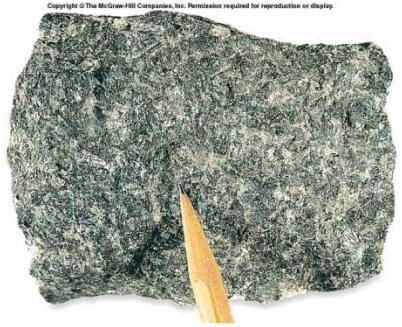
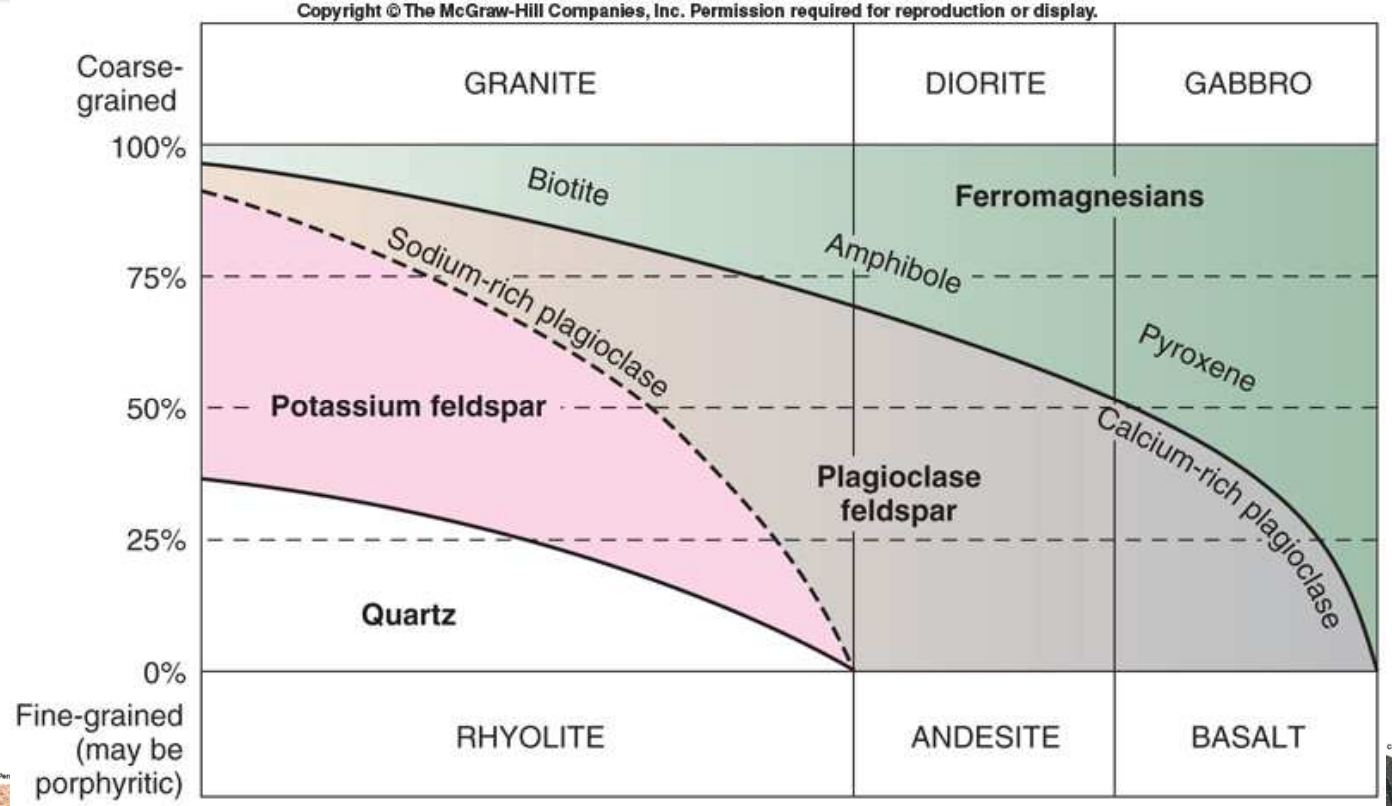
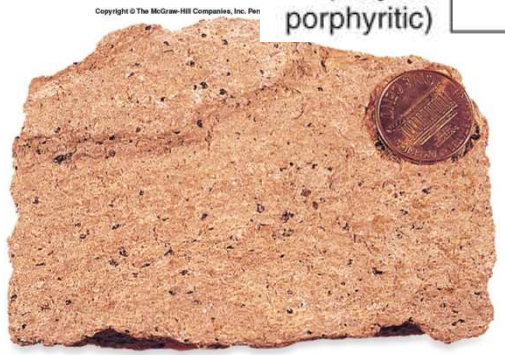


Gabbro
Larry Davis





Basalt
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Igneous Rock Identification

- Igneous rock names are based on *texture* (grain size) and mineralogic *composition*

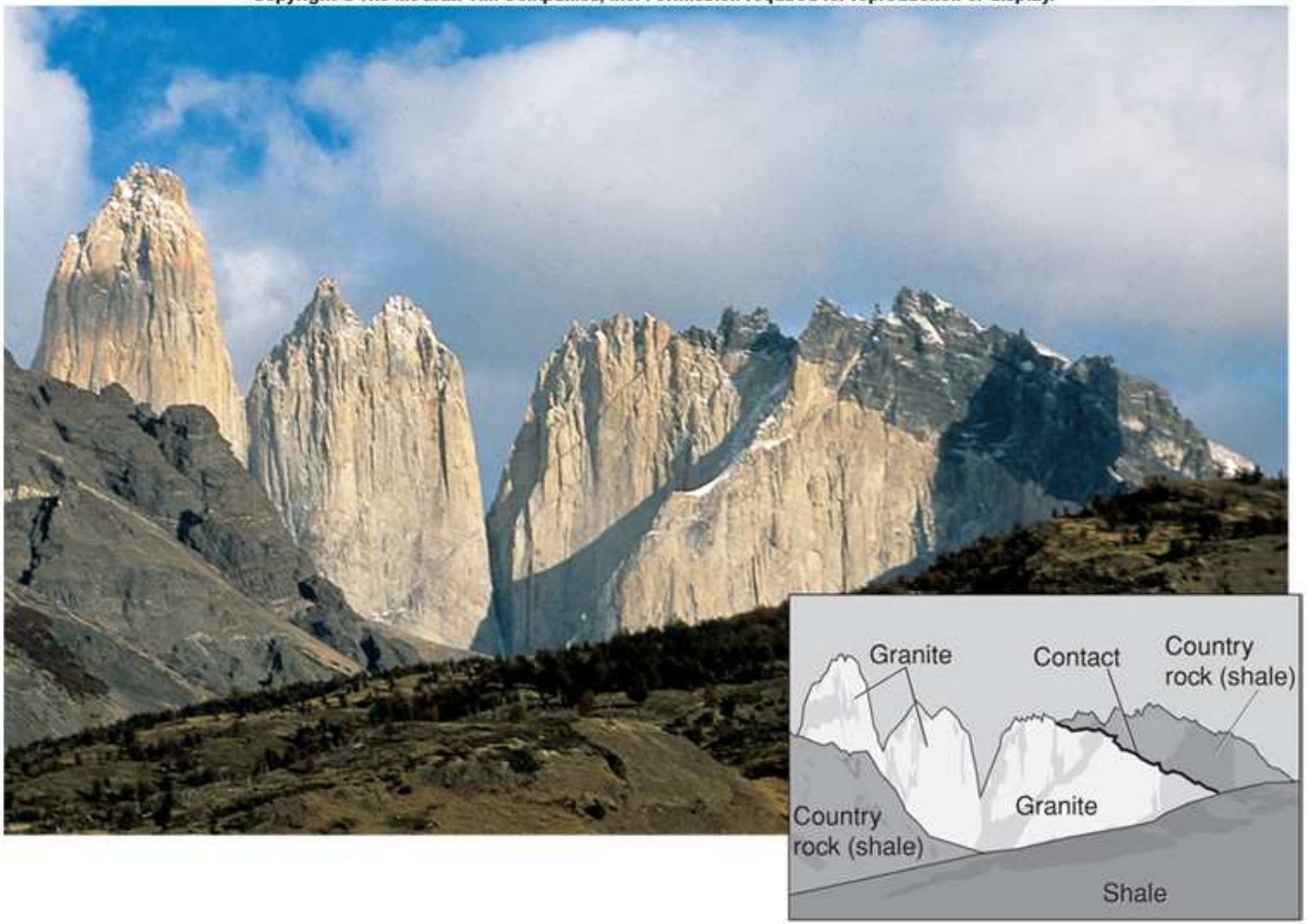
- *Textural classification*
  - ***Plutonic* rocks (intrusive rocks)** (gabbro-diorite-granite) are coarse-grained and cooled slowly at depth
  - ***Volcanic* rocks (extrusive rocks)** (basalt-andesite-rhyolite) are typically fine-grained and cooled rapidly at the Earth's surface

- *Compositional classification*
  - ***Mafic* rocks** (gabbro-basalt) contain abundant dark-colored ferromagnesian minerals
  - ***Intermediate* rocks** (diorite-andesite) contain roughly equal amounts of dark- and light-colored minerals
  - ***Felsic* rocks** (granite-rhyolite) contain abundant light-colored minerals

Igneous Rock Chemistry

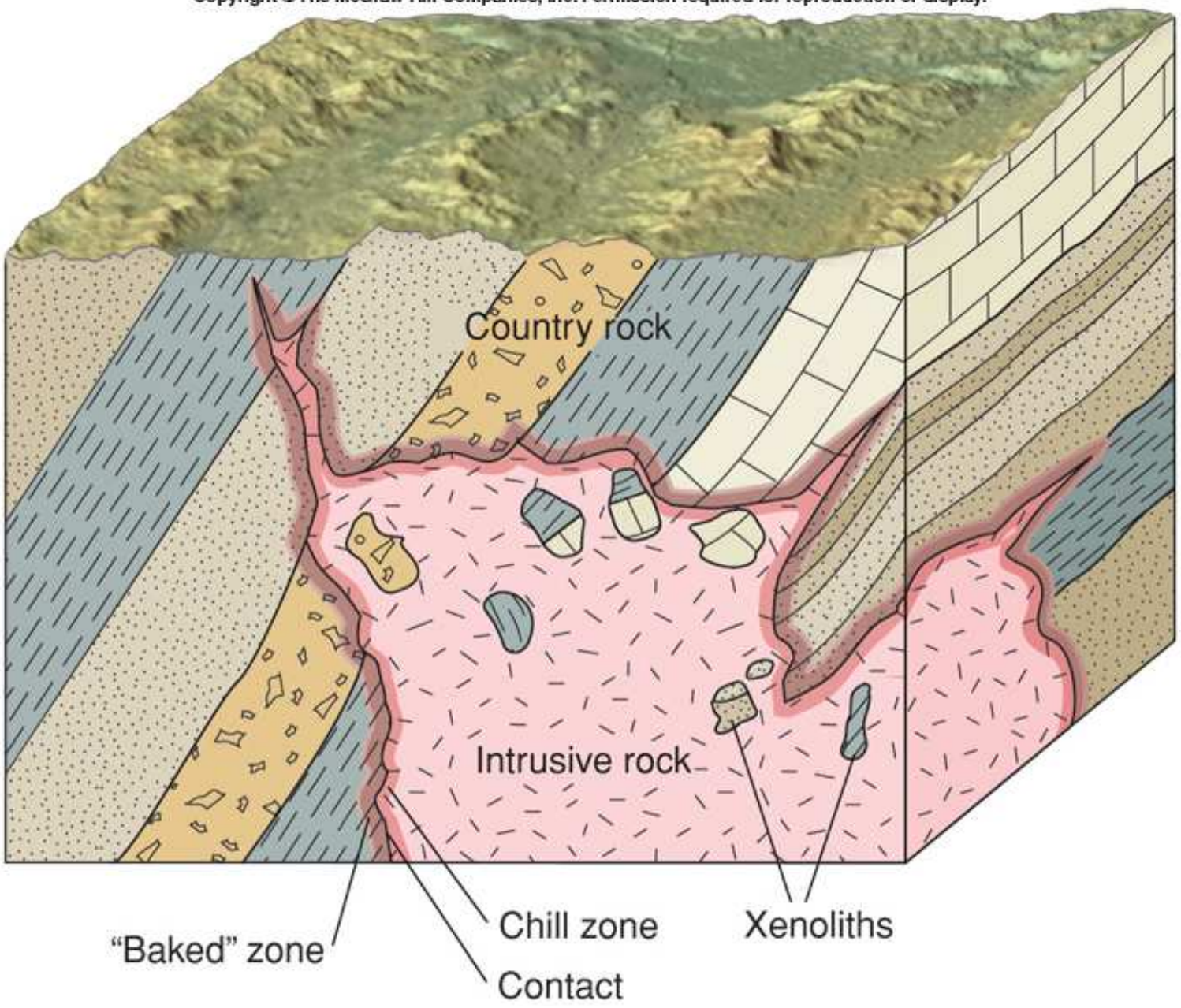
- Rock chemistry, particularly *silica* (SiO_2) content, determines mineral content and general color of igneous rocks
  - *Mafic* rocks have ~50% silica, by weight, and contain dark-colored minerals that are abundant in iron, magnesium and calcium
    - Intrusive/extrusive mafic rocks - gabbro/basalt
  - *Felsic* rocks have >65% silica, by weight, and contain light-colored minerals that are abundant in silica, aluminum, sodium and potassium
    - Intrusive/extrusive felsic rocks - granite/rhyolite
  - *Intermediate* rocks have silica contents between those of mafic and felsic rocks
    - Intrusive/extrusive intermediate rocks - diorite/andesite
  - *Ultramafic* rocks have <45% silica, by weight, and are composed almost entirely of dark-colored ferromagnesian minerals
    - Most common ultramafic rock is **peridotite** (intrusive)

Types of
Intrusive Rock Bodies



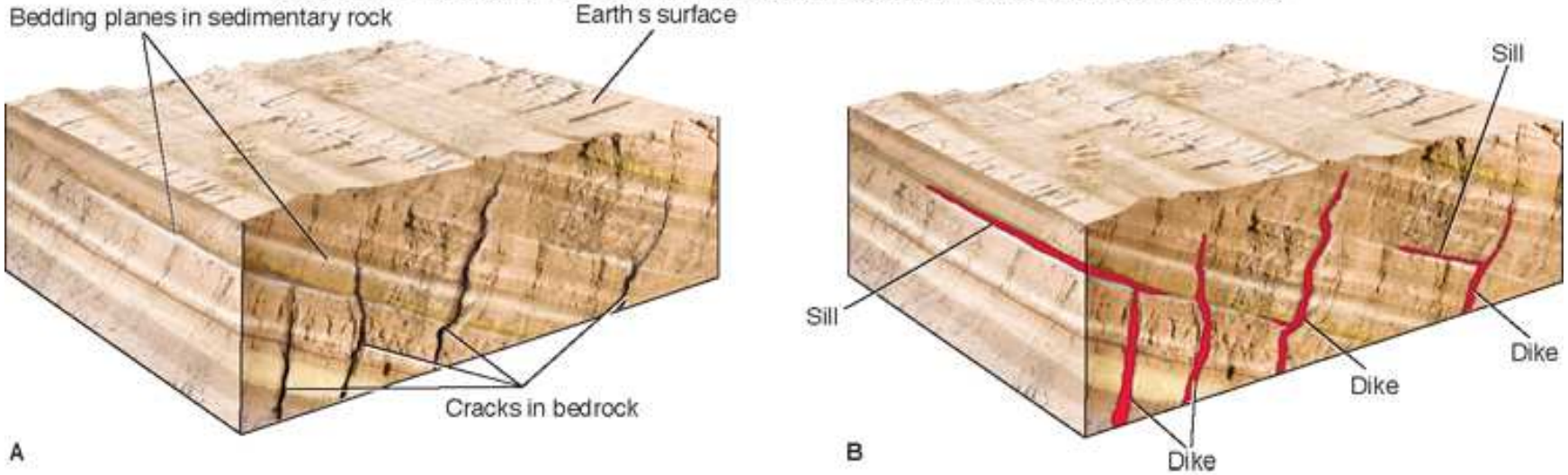
Geologist's View

Kay Kepler



Intrusive Rock Bodies

- Intrusive rocks exist in bodies or structures that cut through pre-existing *country rock*
- *Intrusive bodies* are given names based on their size, shape and relationship to country rock
  - Shallow intrusions: *Dikes and sills*
    - Chill and solidify fairly quickly in cool country rock
    - Generally composed of fine-grained rocks



Dike and Sill

- *Dike*
  - Tabular intrusive structure that cuts across any layering in country rock

Light-colored dikes

- *Sill*
  - Tabular intrusive structure that parallels layering in country rock

Basaltic sill

C.C. Plummer

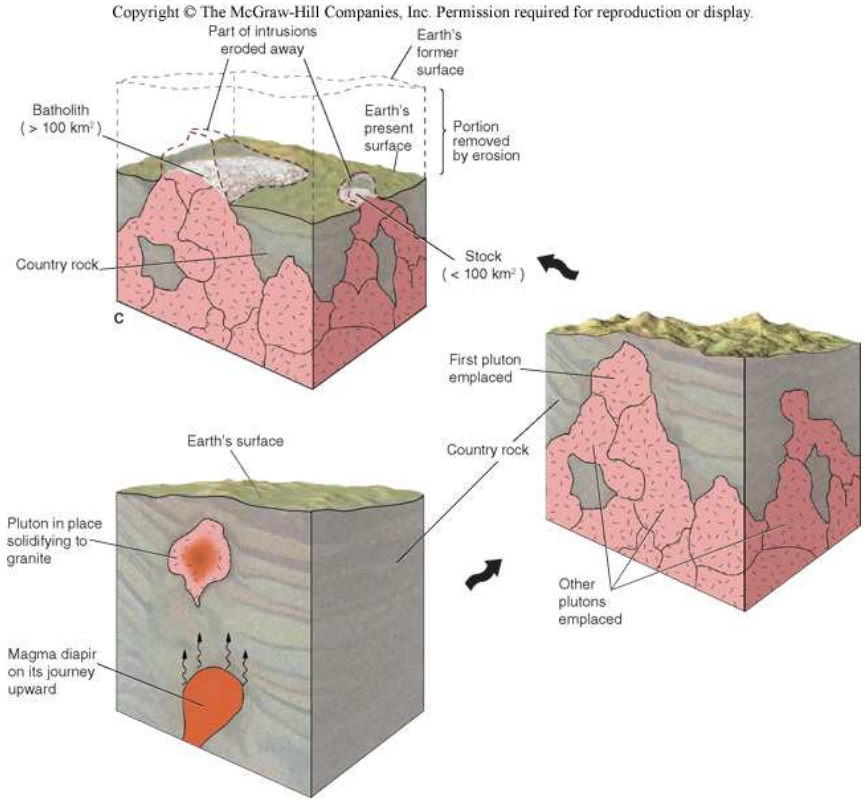
Light Colored Dike

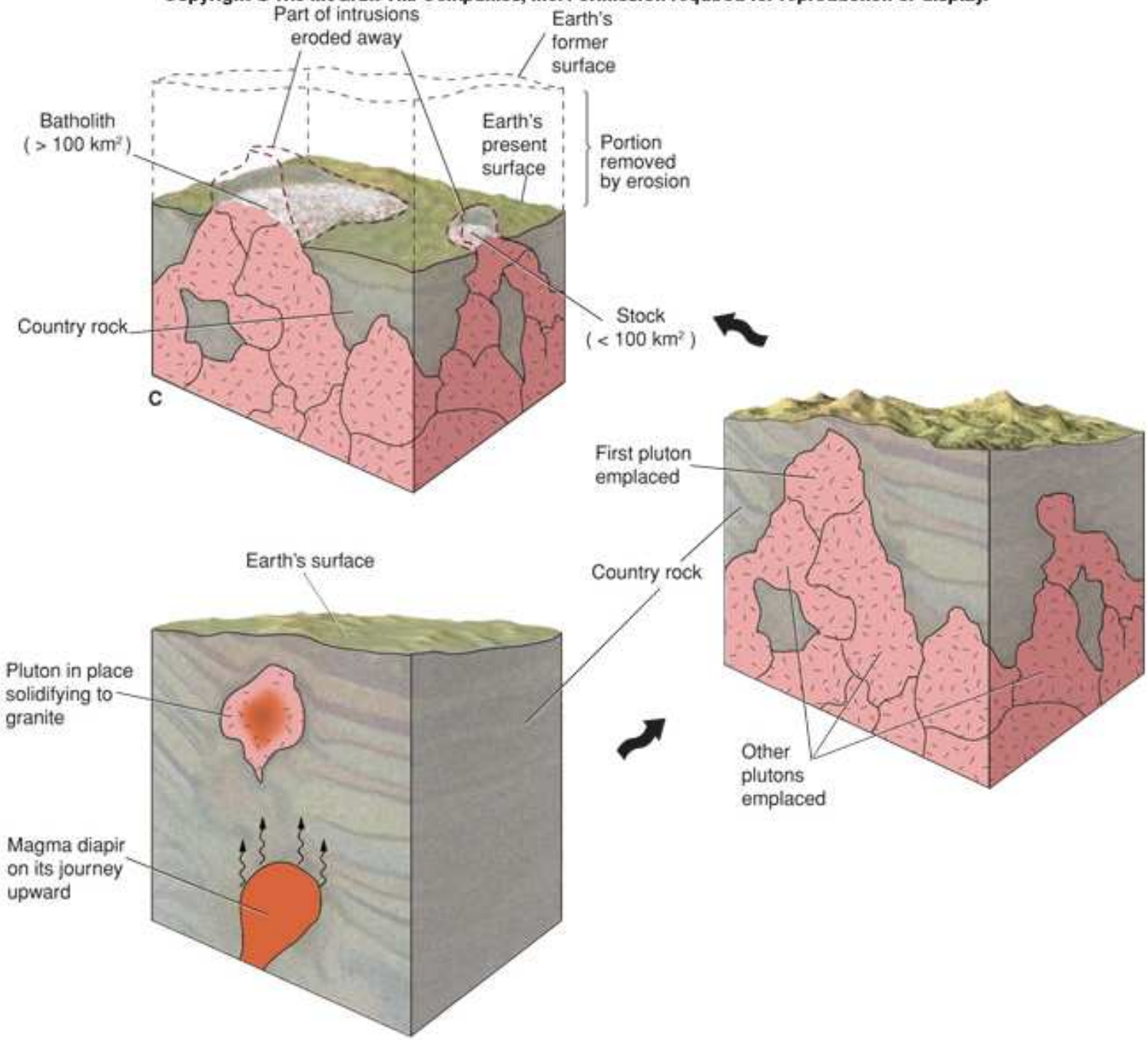
Basaltic Sill

Intrusive Rock Bodies

Deep intrusions: ***Plutons***

- Form at considerable depth beneath Earth's surface when rising blobs of magma get trapped within the crust
- Crystallize very slowly
- Generally composed of coarse-grained rocks





Other Intrusive Rock Bodies

- *Pluton*
  - Large, blob-shaped intrusive body formed of coarse-grained igneous rock, commonly granitic
  - Small plutons (exposed over <100 km^2) are called ***stocks***, large plutons (exposed over >100 km^2) are called ***batholiths***

- *Volcanic neck*
  - Shallow intrusion formed when magma solidifies in throat of volcano

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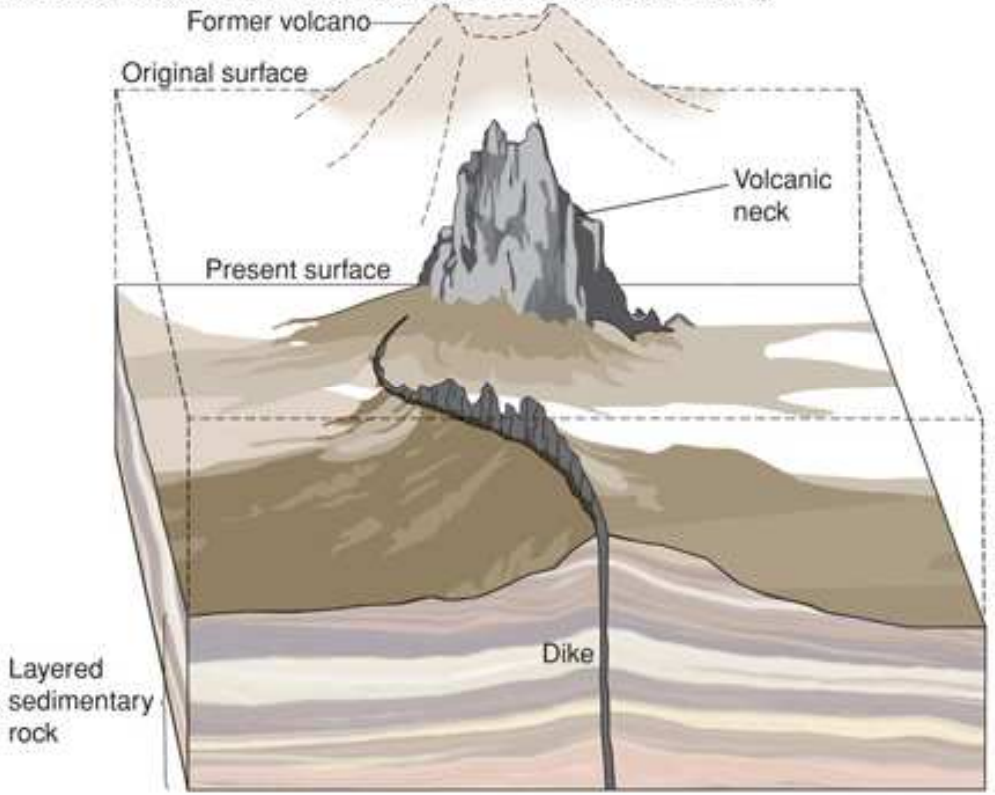

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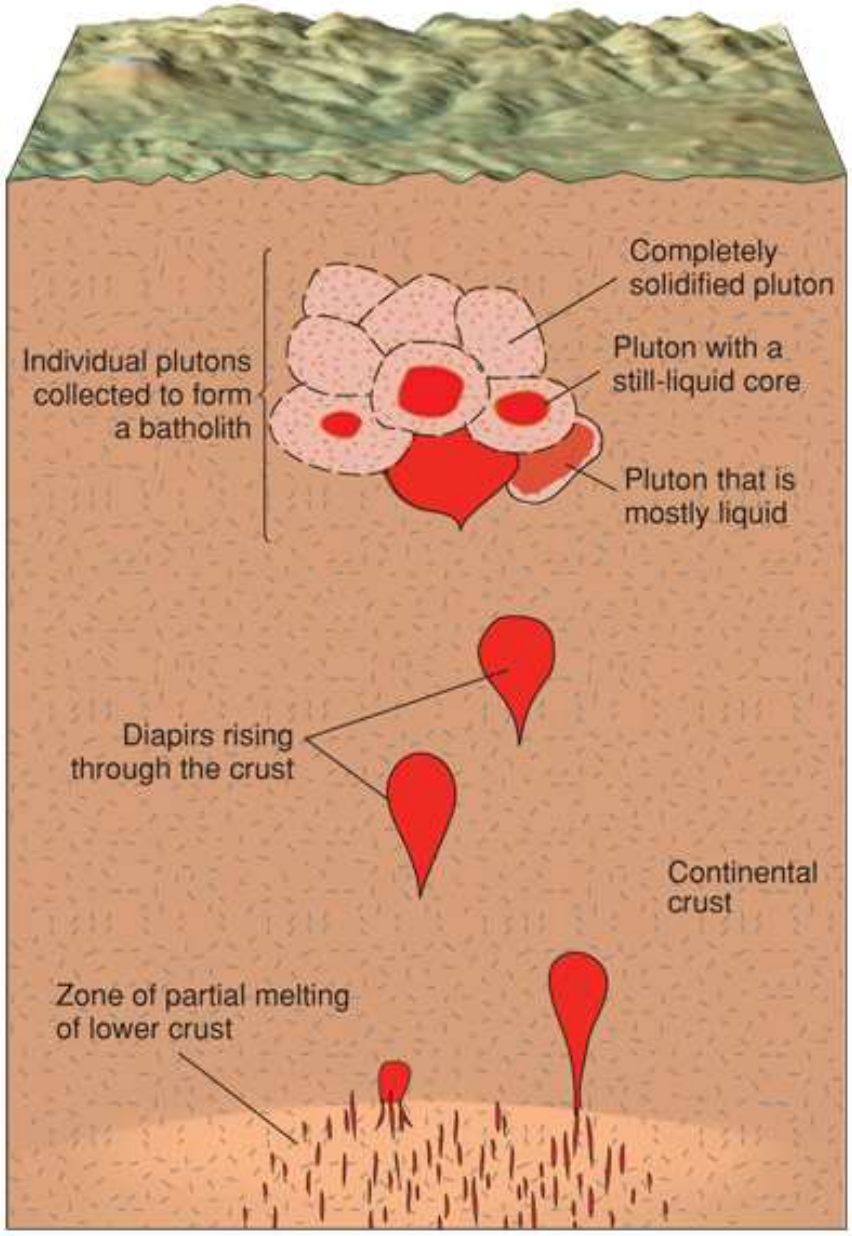
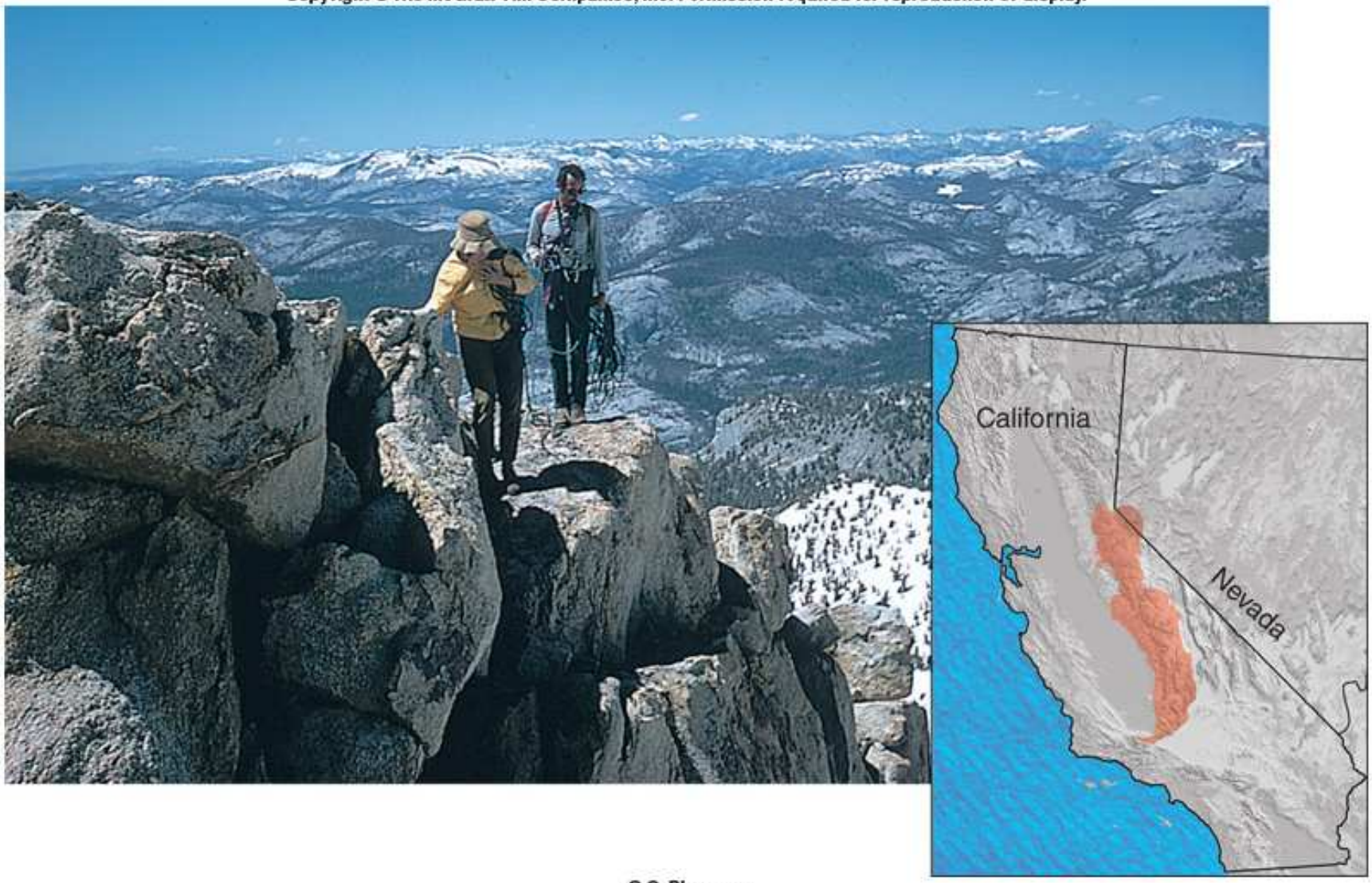
Frank M. Hanna

Mountains at Earth's surface





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Types of Igneous Rocks

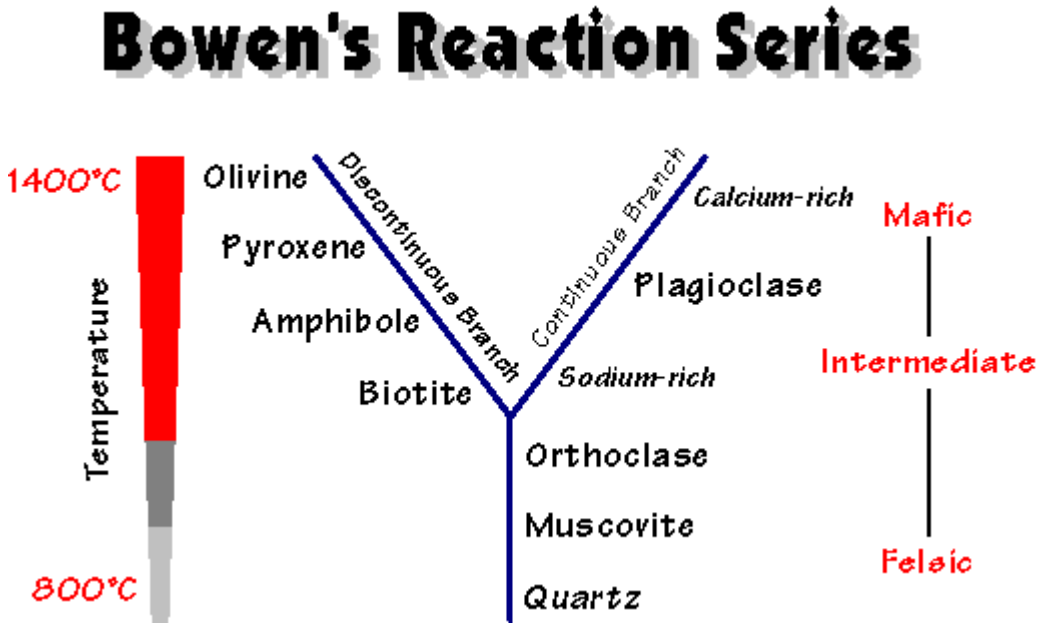
Depends on the

1. Mineral content

2. Temperature and pressure during crystallization

Magma Crystallization and Melting Sequence

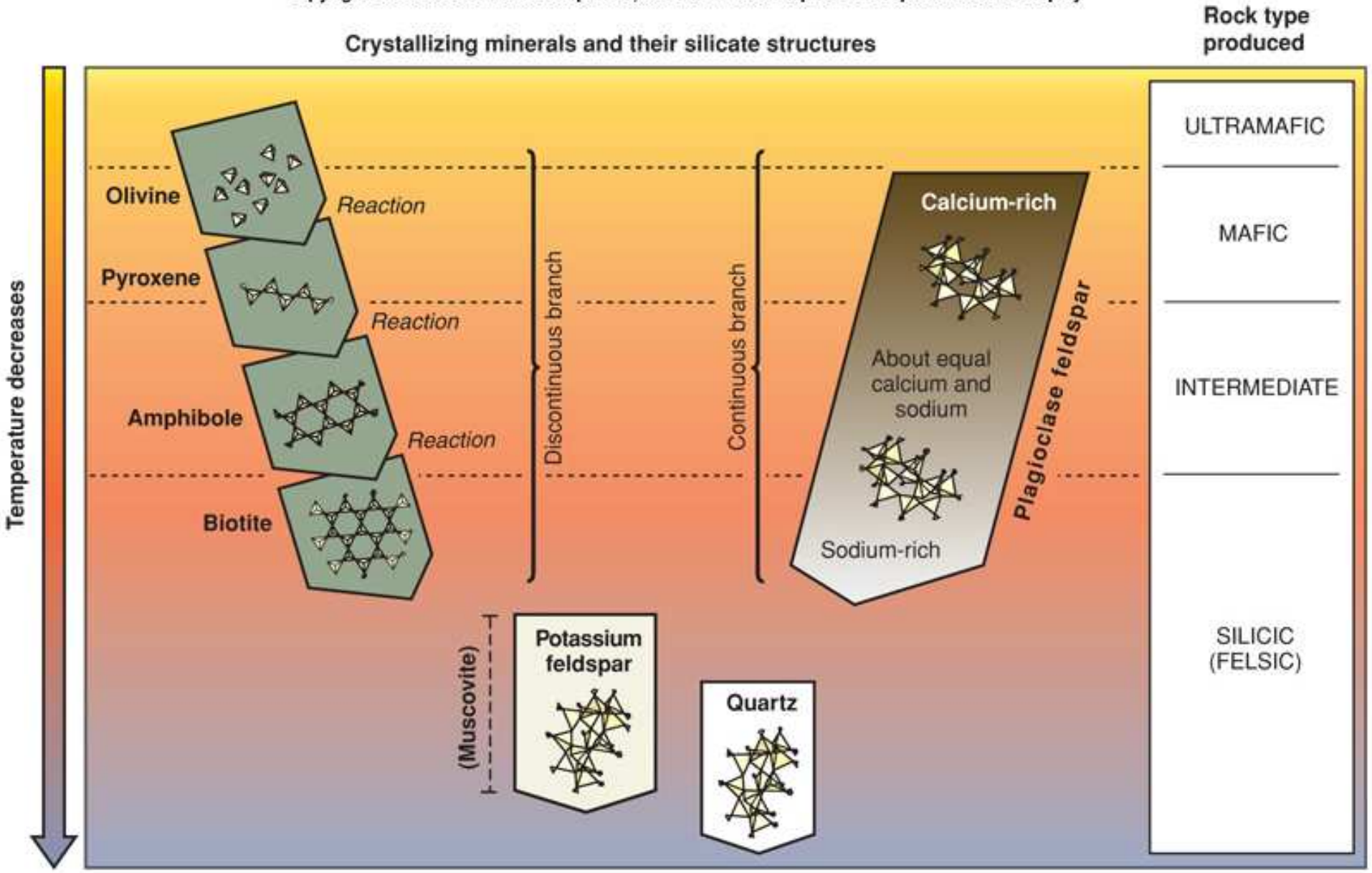
- Minerals crystallize in a predictable order (and melt in the reverse order), over a large temperature range, as described by *Bowen's Reaction Series*



Magma Crystallization and Melting Sequence

- *Discontinuous branch*
  - Ferromagnesian minerals (olivine, pyroxene, amphibole, biotite) crystallize in sequence with decreasing temperature
  - As one mineral becomes chemically unstable in the remaining magma, another begins to form

- *Continuous branch*
  - Ca-rich to Na-rich with decreasing temperature

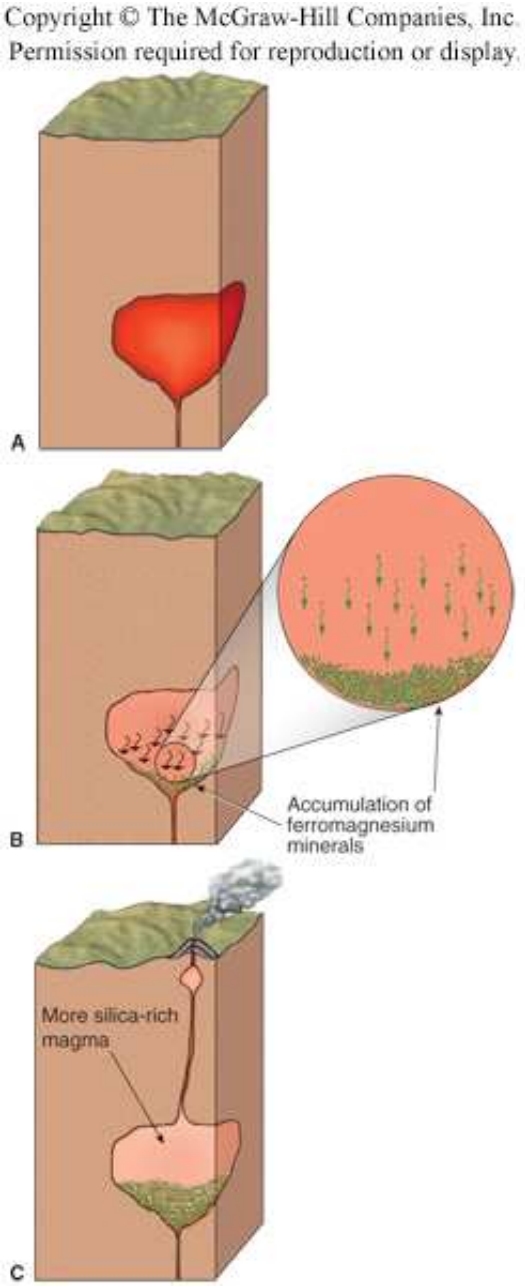


Lessons from Bowen's Reaction Series

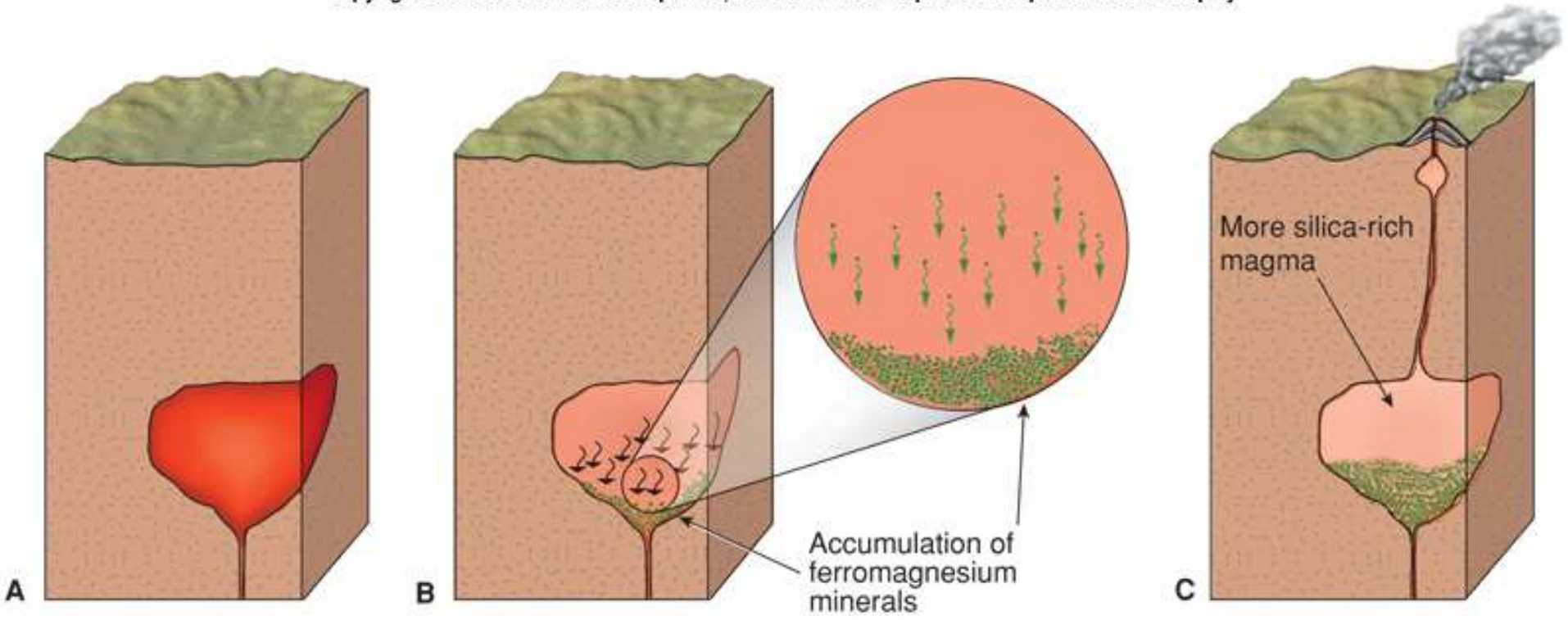
- Large variety of igneous rocks can be produced by *magma* at different temperature
- *Magma* will crystallize into *basalt* or *gabbro* if early-formed minerals are not removed from the magma
- *Magma* will similarly crystallize into *diorite* or *andesite* if minerals are not removed
- Separation of early-formed ferromagnesian minerals from a magma body increases the silica content of the remaining magma
- Minerals melt in the reverse order of that in which they crystallize from a magma

Magma Evolution

- A change in the composition of a magma body is known as *magma evolution*
- Magma evolution can occur by *differentiation*, *assimilation*, or *magma mixing*
- *Differentiation* involves the changing of magma composition by the removal of denser early-formed ferromagnesian minerals by *crystal settling*

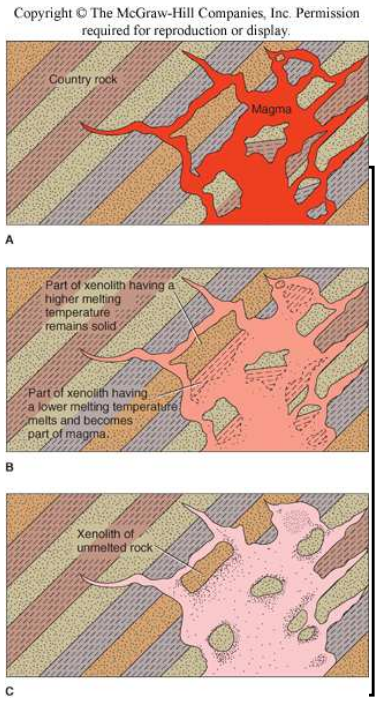


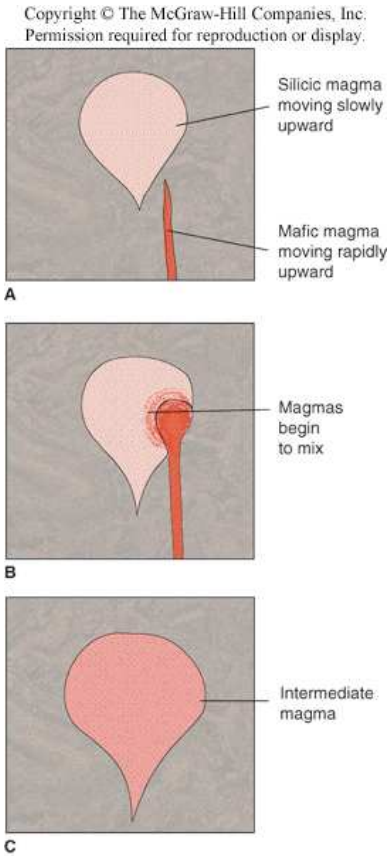
Fractional Crystallization – Differentiation

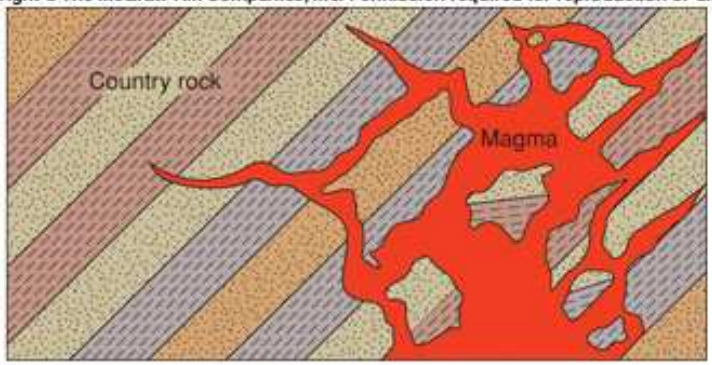


Magma Evolution

- *Assimilation* occurs when a hot magma, melts and incorporates more felsic surrounding country rock
- *Magma mixing* involves the mixing of more and less mafic magmas to produce one of intermediate composition







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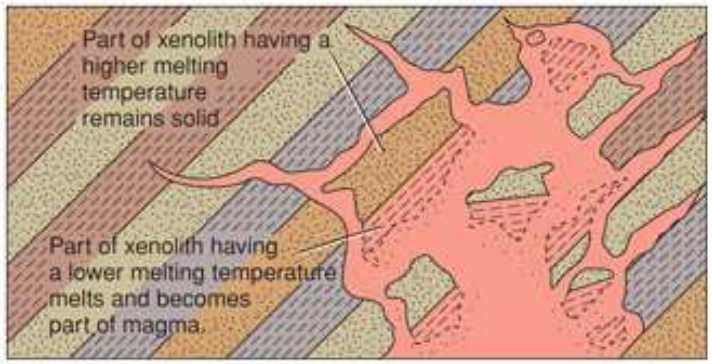

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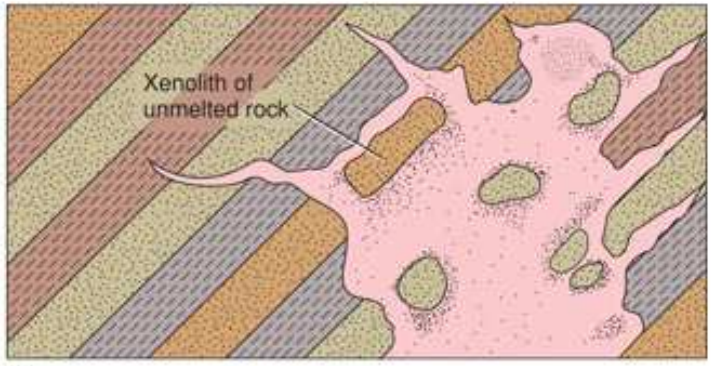

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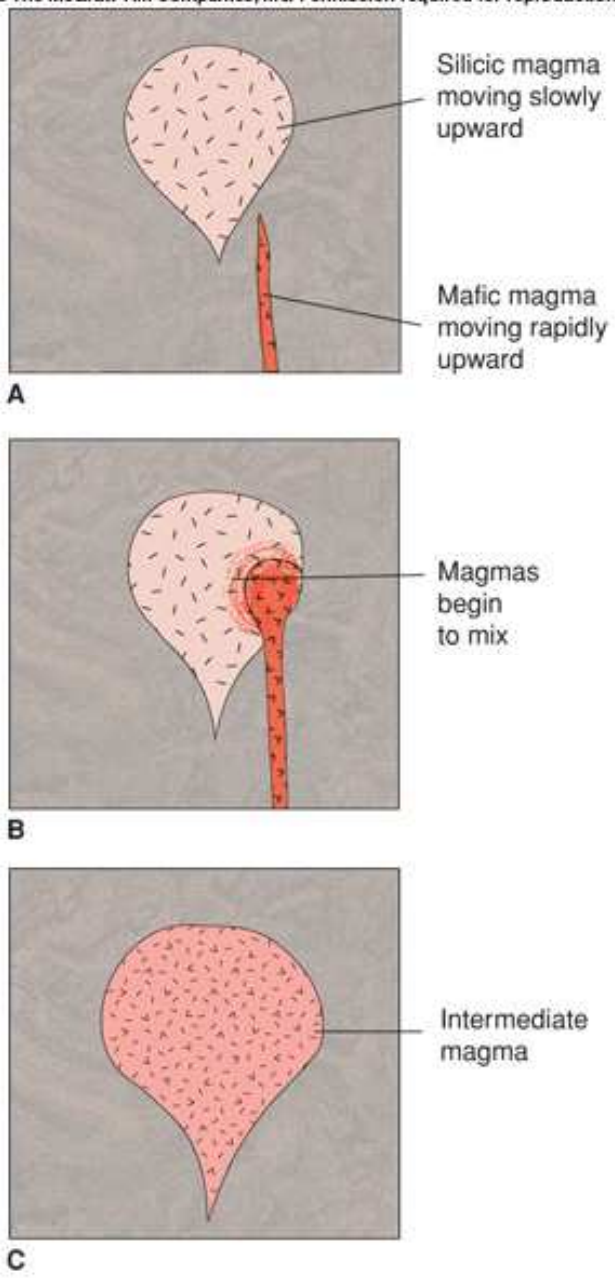
Assimilation



Magma Mixing

Igneous Activity and Plate Tectonics

- Igneous activity occurs primarily at or near tectonic plate boundaries

- Mafic igneous rocks are commonly formed at *divergent boundaries*

- Intermediate and felsic igneous rocks are commonly formed at *convergent boundaries*
  - Assimilation of basaltic oceanic crust with granitic continental crust produces intermediate magmas

Igneous Activity and Plate Tectonics

- ***Intra-plate volcanism***
  - Rising mantle plumes or localized hotspots produce magmas that rise through oceanic or continental crust
  - If the hot spot or mantle plume rises through the oceanic crust: Igneous rock will be **Mafic**
  - If the hot spot or mantle plume rises through the continental crust: Igneous rock will be **Felsic**

End of Chapter 11