



ECIV 3302
Engineering Geology

Chapter 3

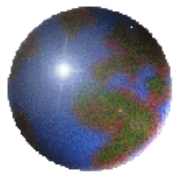
IGNEOUS ROCKS

Associate Professor Mazen Abualtayef

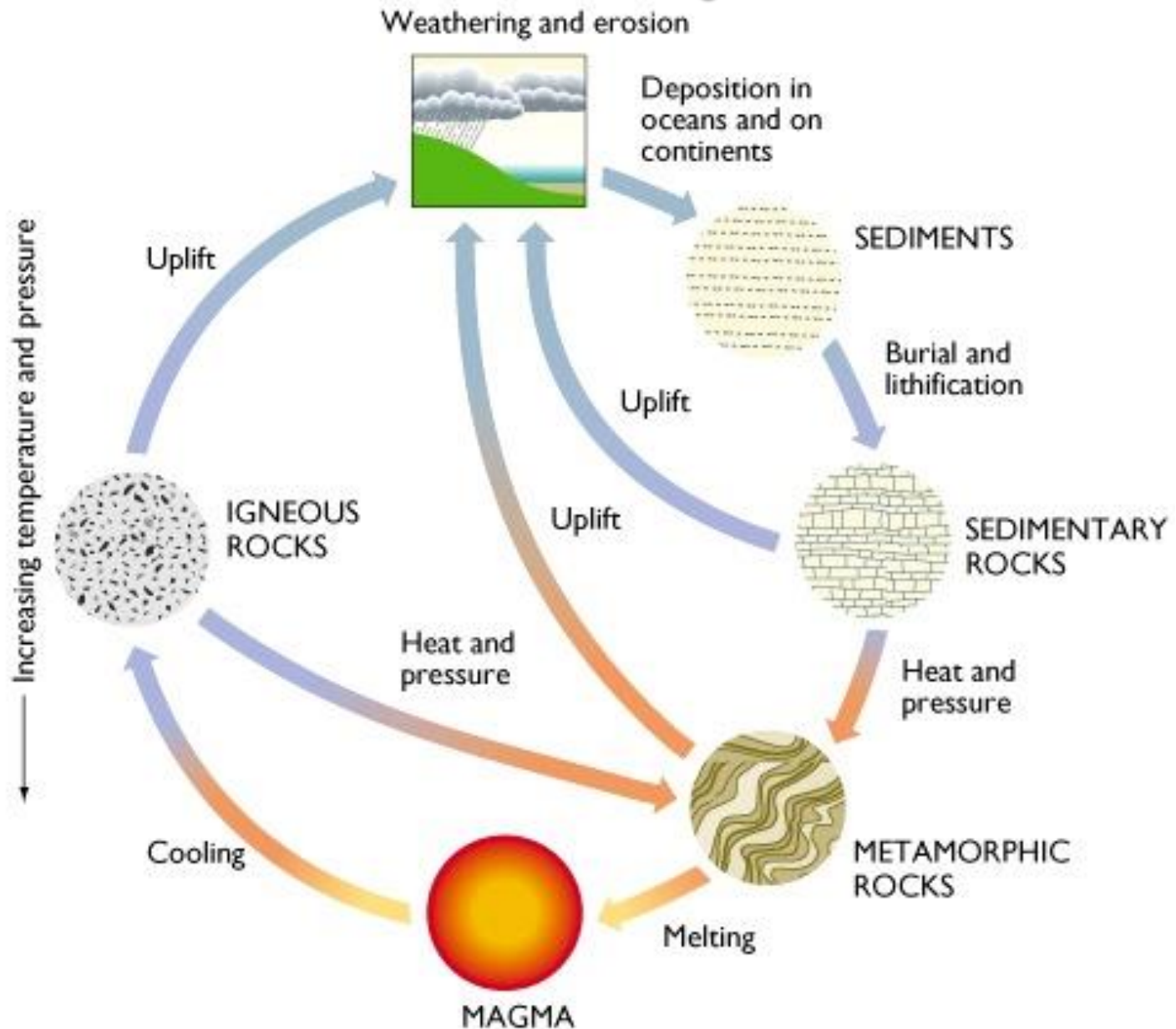
Civil and Environmental Engineering Department

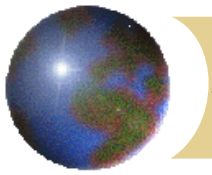
Islamic University of Gaza, Palestine

The materials are mostly adapted from the presentation of Stan & Cindy Hatfield



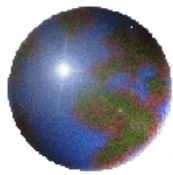
Rock Cycle



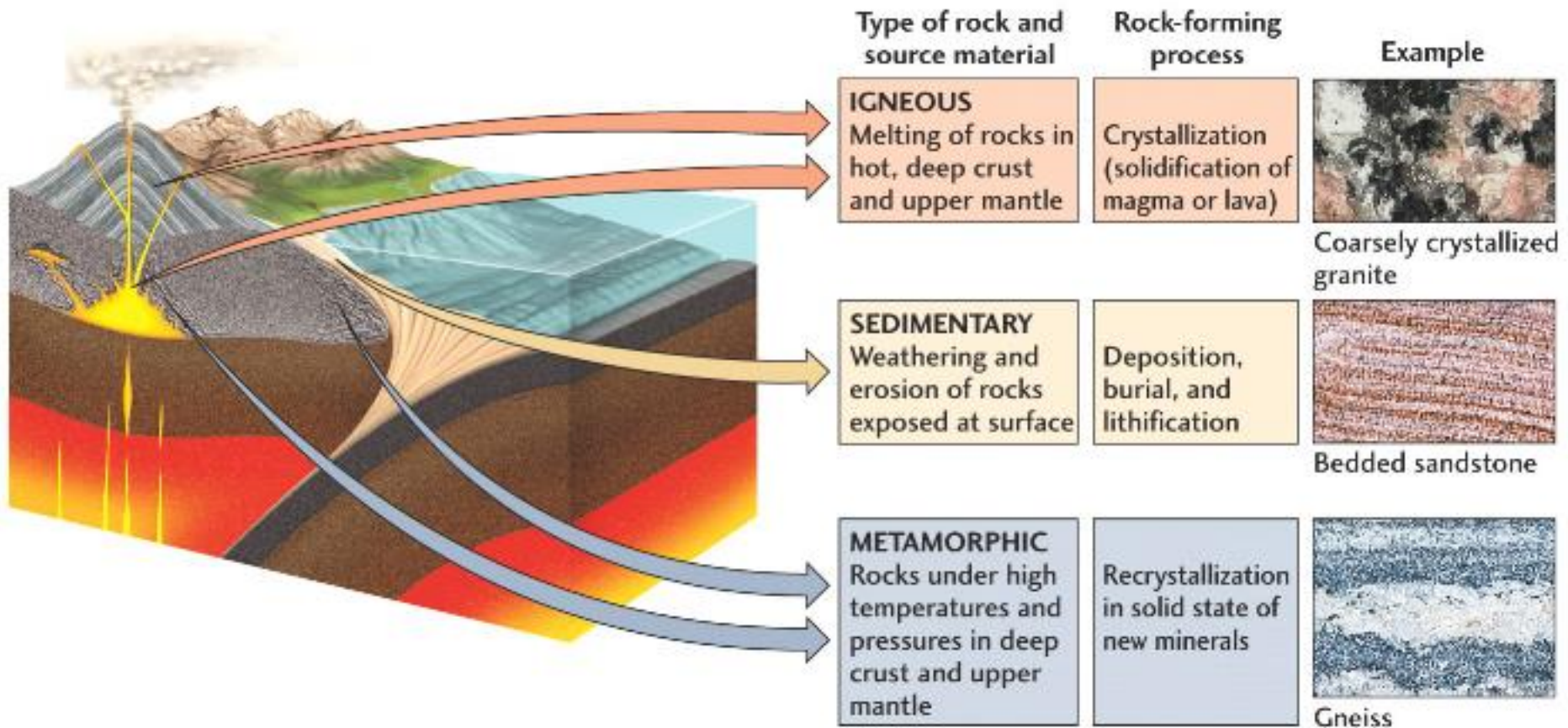


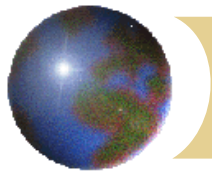
The Rock Cycle

-  The Rock Cycle is a group of changes, this change does not necessarily have to be a chemical change.
-  Igneous rock can change into sedimentary rock or into metamorphic rock.
-  Sedimentary rock can change into metamorphic rock or into igneous rock.
-  Metamorphic rock can change into igneous or sedimentary rock.
-  Almost all of rock today that we have on earth is made up of all the same stuff as the rocks that dinosaurs and other ancient life forms walked, crawled, or swam over
-  While the stuff that rocks are made of has stayed the same, the rocks themselves, have not
-  Over time rocks are recycled into other rocks
-  Moving tectonic plates are responsible for destroying and forming many types of rocks



Types of Rocks

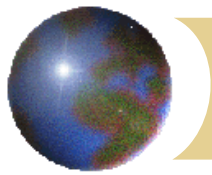




The Rock Divisions

- Rock divisions occur in three major families based on how they formed: igneous, sedimentary, and metamorphic.
- Each group contains a collection of rock types that differ from each other on the basis of the size, shape, and arrangement of mineral grains.
- Just remember 3 types of rocks=3 divisions. (igneous, sedimentary, and metamorphic)

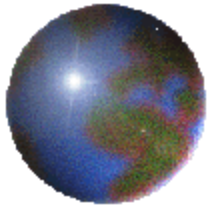




The Rock Divisions

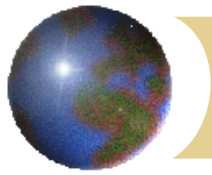
Key Characteristics of the Major Rock Groups

	<u>Igneous</u>	<u>Sedimentary</u>	<u>Metamorphic</u>
Source materials	• Melt from hot rocks in the mantle or deep in the crust (chemical evolution at source)	• Weathering and erosion of other rocks (chemical evolution at source)	• Preexisting rocks taken to elevated temperature and pressure
Rock-forming process	• Solidification from melt (typically crystallization; chemical evolution common)	• Deposition, burial, lithification (chemical evolution during formation)	• Recrystallization, formation of new minerals, deformation, loss of H₂O, CO₂
Textural features	• Volcanic — glassy or fine-grained • Intrusive — medium- to coarse-grained • Multiple grain sizes possible in both (e.g., porphyritic with 2 sizes)	• Clastic — consists of small to large particles (“clasts”) of minerals and/or rocks • Chemical — consists of inorganic or biochemical precipitates from water	• Non-foliated — minerals randomly oriented • Foliated — minerals aligned within the rock • Grain size ranges from fine to coarse, commonly uneven
Minerals	• Plagioclase, K-feldspar • Quartz • Mica • Pyroxene • Amphibole • Olivine	• Quartz • Clays • K-feldspar, Plagioclase • Calcite, Dolomite • Gypsum • Halite • Organic matter	• Quartz • K-feldspar, Plagioclase • Mica (and Chlorite) • Garnet • Pyroxene • Amphibole • Calcite



Igneous Rocks

- ✓ Magma: The Parent Material of Igneous Rock
- ✓ Igneous Textures
- ✓ Igneous Compositions
- ✓ Naming Igneous Rocks
- ✓ Origin of Magma



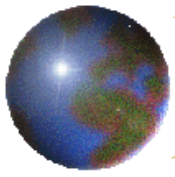
Characteristics of Magma

Igneous rock forms from magma that cools and solidifies in a process called crystallization

Two types of igneous rocks:

 **Intrusive Igneous Rocks** — When igneous rocks are formed by magma that **cools BENEATH Earth's** surface, they are called intrusive igneous rocks

 **Extrusive Igneous Rocks** — When igneous rocks are **formed by LAVA ON Earth's surface**, they are called extrusive igneous rocks



Characteristics of Magma

Extrusive

Pyroclastic

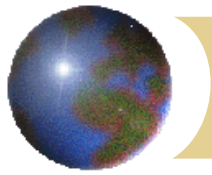
Lava Flow

Intrusive

Hypabyssal

Plutonic



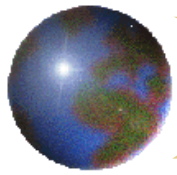


Characteristics of Magma

Extrusive igneous rock texture referred to as **pyroclastic**. This texture results from a very **explosive** eruption, which sends not only lava flying through the air, but also fragments of the volcano itself. All airborne volcanic fragments, referred to as **pyroclasts**.



Extrusive Igneous Rock - Lava (Hawaii)

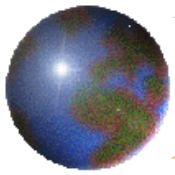


Characteristics of Magma

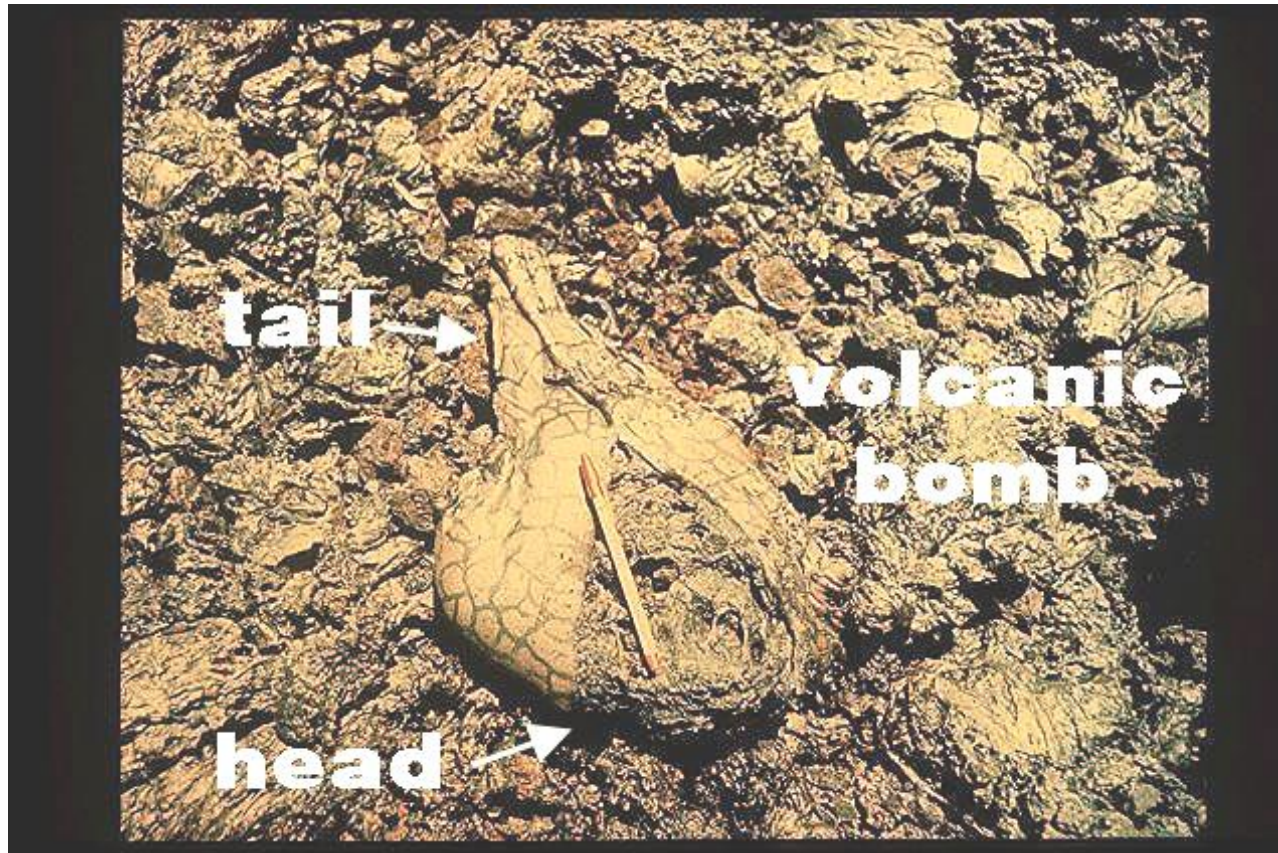
The rock fragments thrown out during volcanic eruption are called **Pyroclasts**.

Based of shape and size they are categorized, Pyroclasts come in many sizes: the **smallest** are called **ash**, **slightly larger** are **lapilli**, and the **biggest** are called blocks or **bombs**.

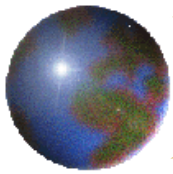




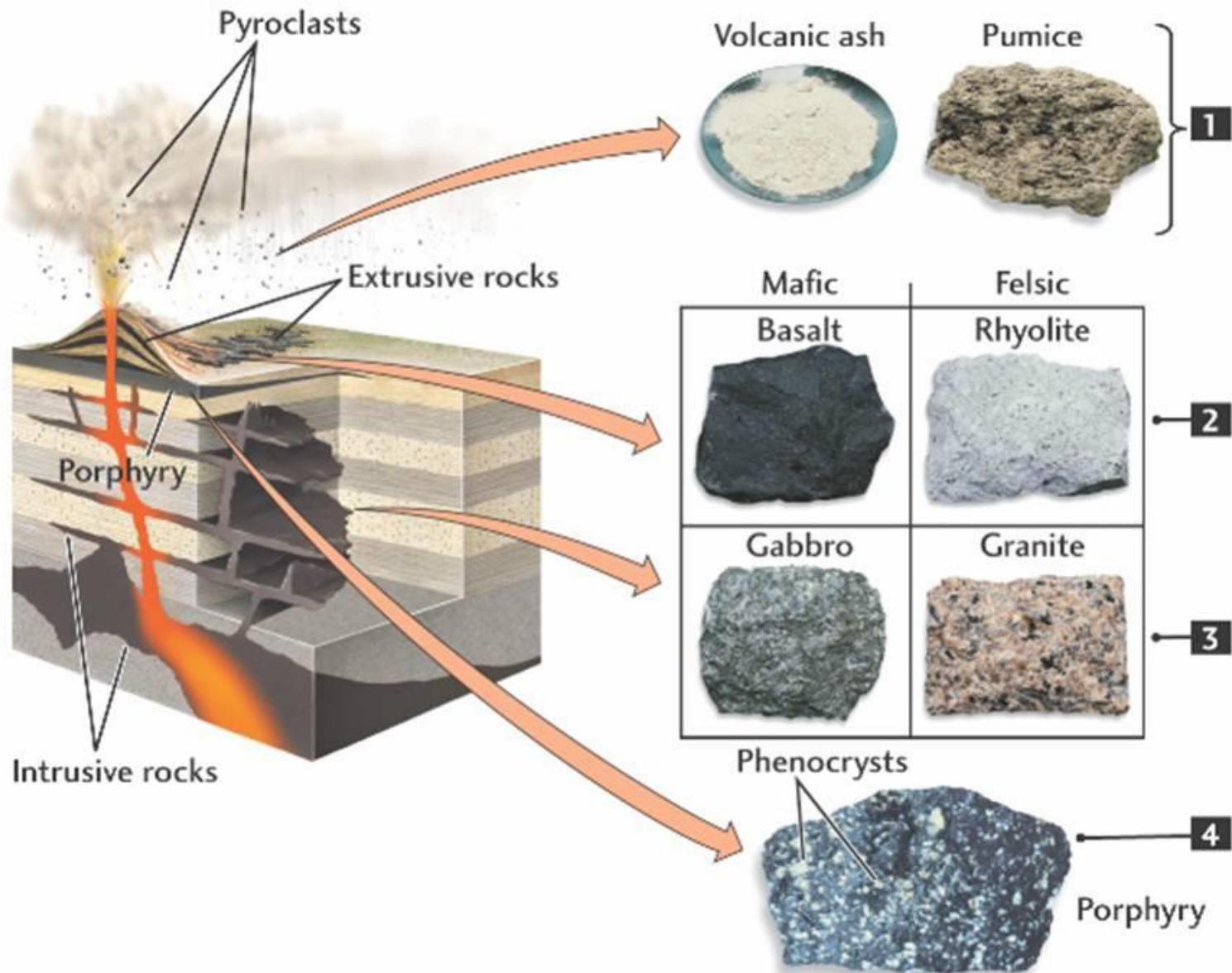
Characteristics of Magma



A large pyroclasts are known as volcanic bombs. Typical shape with head and a tail. Bombs can result into severe damage if they strike.



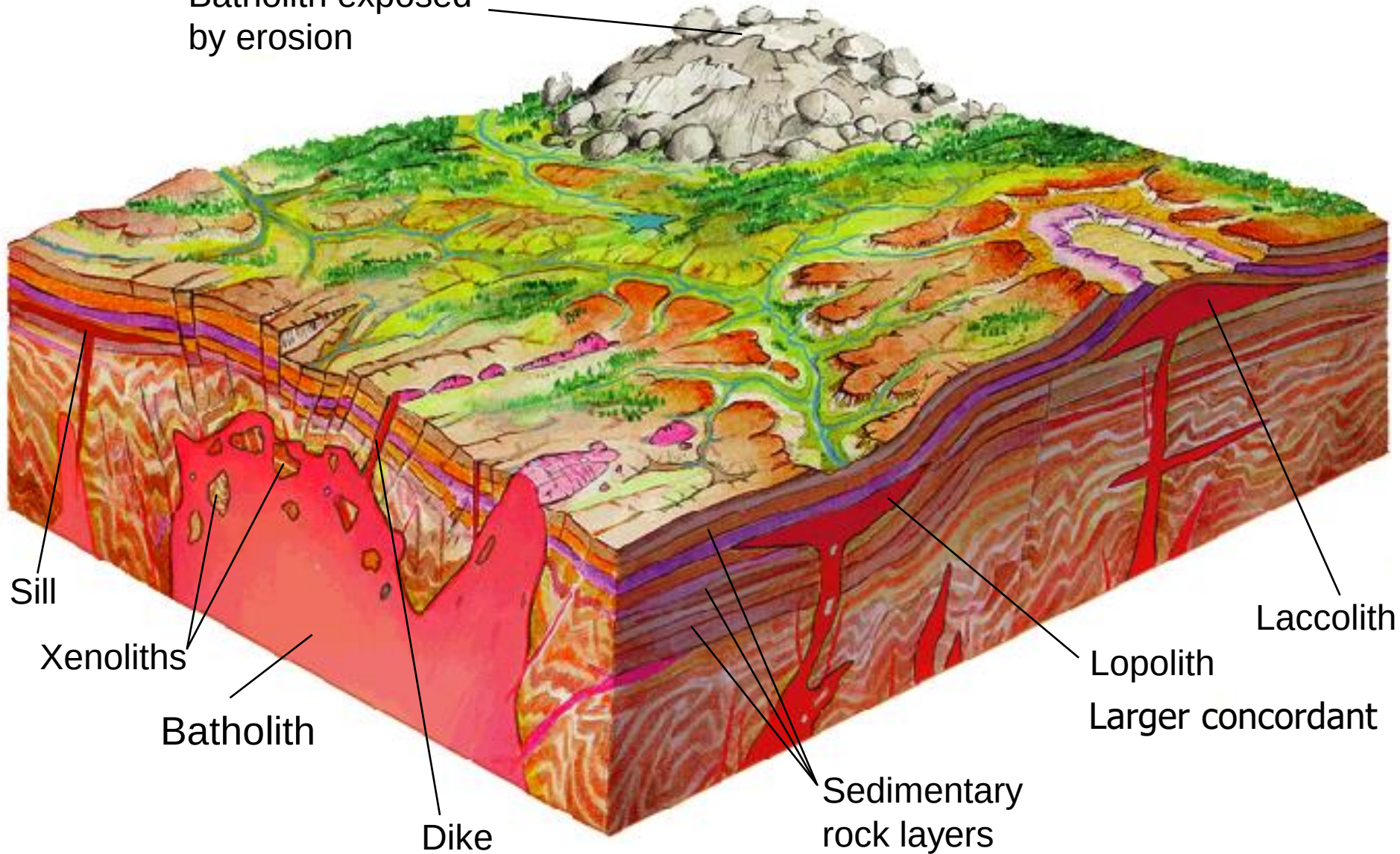
Characteristics of Magma

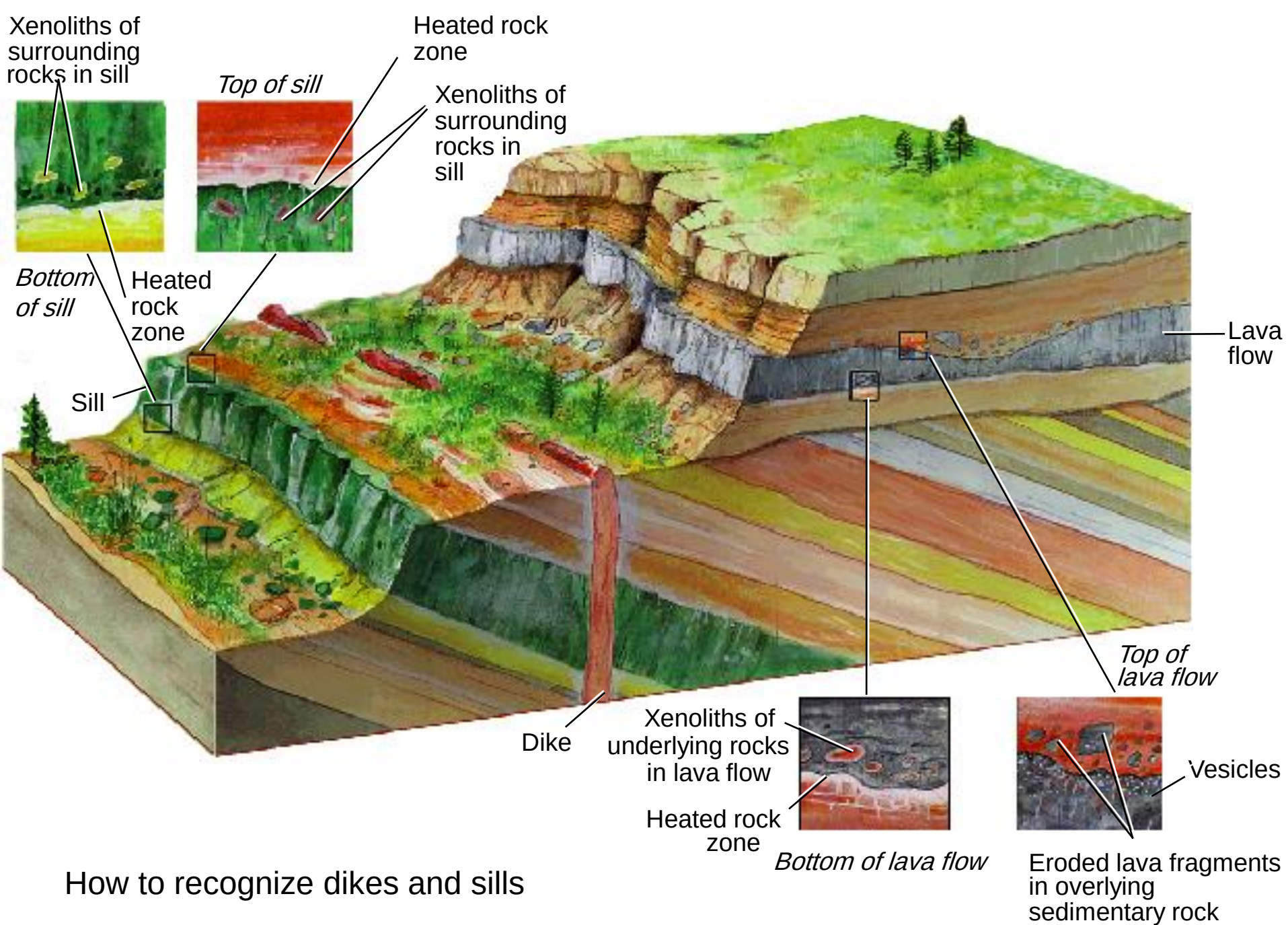




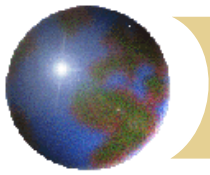
Some terminology:

Batholith exposed
by erosion





How to recognize dikes and sills

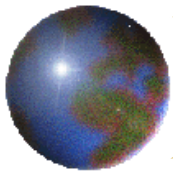


Characteristics of Magma

✚ The nature of magma:

Consists of three components:

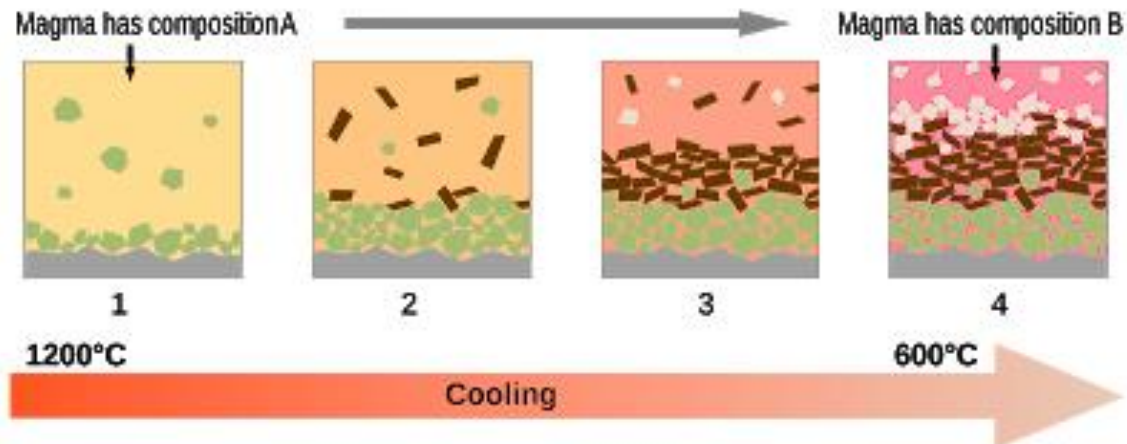
- ▣ Liquid portion = melt
- ▣ Solids, if any, are silicate minerals
- ▣ Volatiles = dissolved gases in the melt, including water vapor (H_2O), carbon dioxide (CO_2), and sulfur dioxide (SO_2)

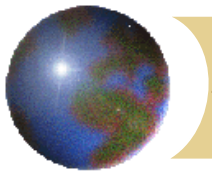


Characteristics of Magma

✚ Crystallization of magma:

- Cooling of magma results in the systematic arrangement of ions into orderly patterns
- The silicate minerals resulting from crystallization form in a predictable order
- Texture in igneous rocks is determined by the size and arrangement of mineral grains.





Characteristics of Magma



When classifying a rock sample, geologists observe the rock's color and texture and determine its mineral composition.



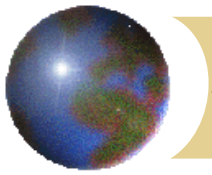
Texture: the size, shape and pattern of the rock's grain.



Color: the apparent color of the rock, on the inside and the outside.



Mineral composition: the minerals that make up the different parts of a rock.



Characteristics of Magma

Texture

✚ Crystal Size:

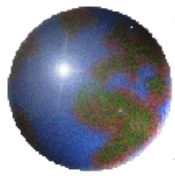
Fine-grained: $< 1\text{mm}$

Medium-grained: 1-2 mm

Coarse-grained: larger than 2 mm

Pegmatitic: very coarse-grained, approx. 5cm to as large as a house

✚ **Porphyry:** igneous rock with large crystals (Phenocrysts) set in a matrix of fine-grained crystals (Groundmass)



Characteristics of Magma

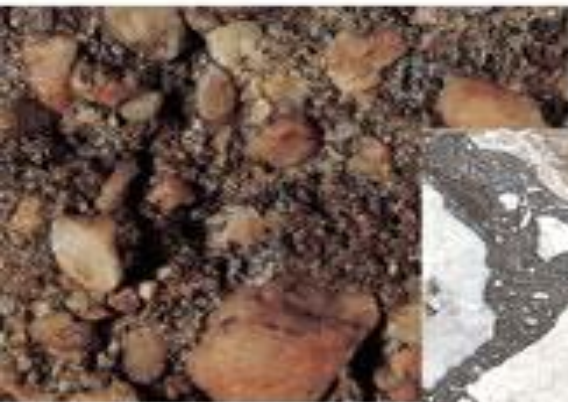
Different Types of Texture



Fine-grained
Slate



Coarse-grained
Diorite



Rounded grain
Conglomerate

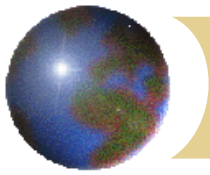


Jagged grain
Breccia

Nonbanded
Quartzite

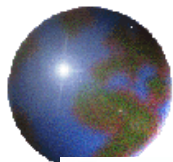


Banded
Gneiss

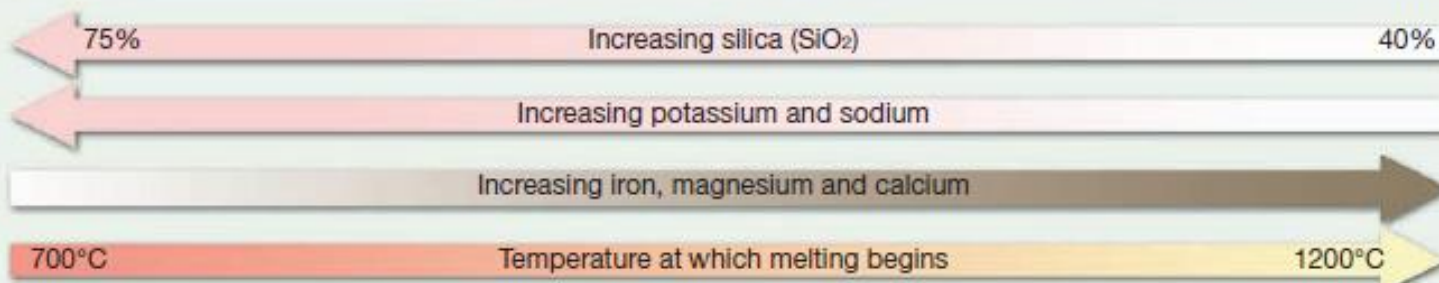
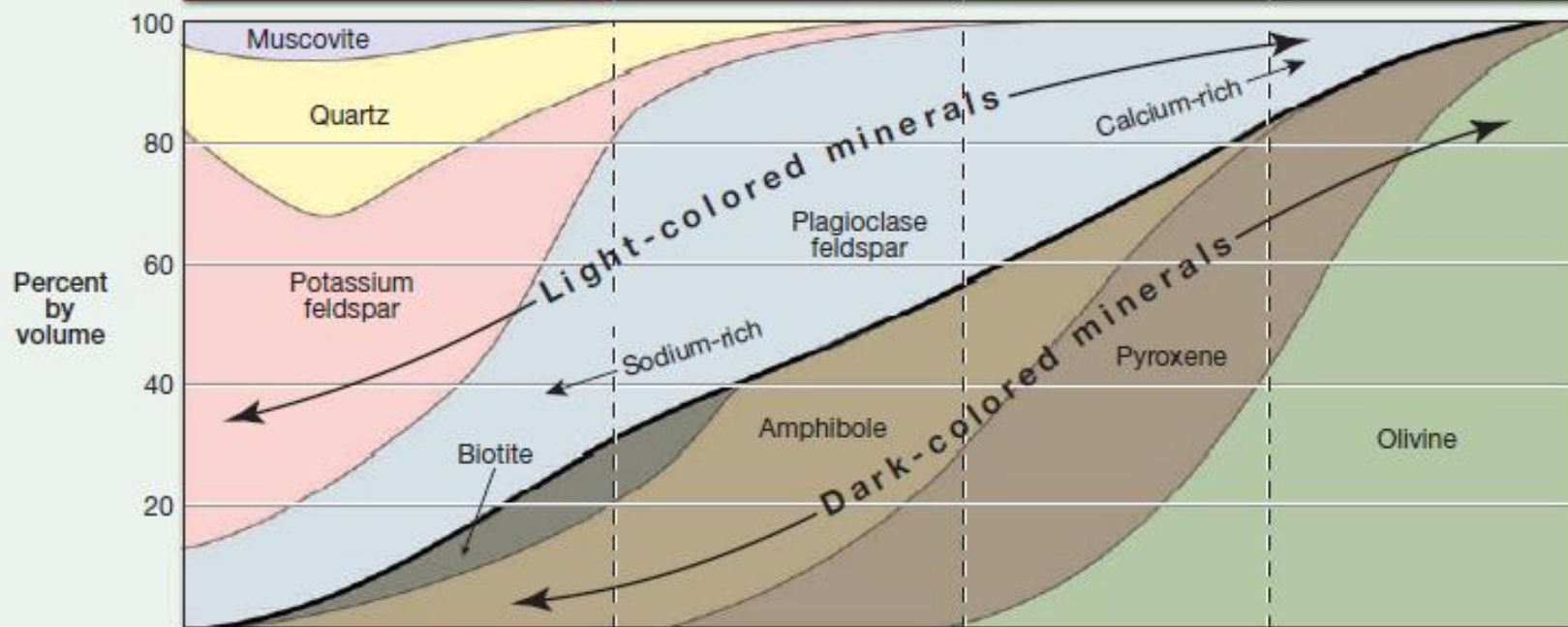


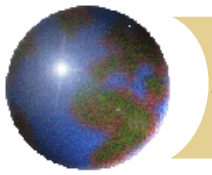
Characteristics of Magma

- ✚ Mafic (Basaltic) magma typically has a higher temperature than felsic magma.
- ✚ Higher-temperature magmas commonly have:
 - ▣ lower viscosity
 - ▣ lower volatile content
 - ▣ less explosive tendency (lava rather than pyroclastic material)
- ✚ Silica content influences a magma's behavior
 - (Felsic) Granitic magma
 - High silica content
 - Extremely viscous
 - Liquid exists at temperatures as low as 700°C



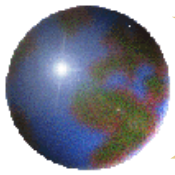
Composition	Felsic (Granitic)	Intermediate (Andesitic)	Mafic (Basaltic)	Ultramafic
Phaneritic (Coarse-grained)	Granite	Diorite	Gabbro	Peridotite
Aphanitic (Fine-grained)	Rhyolite	Andesite	Basalt	Komatiite (Rare)





Igneous Textures

- ✚ Texture is used to describe the overall appearance of a rock based on the size, shape, and arrangement of interlocking minerals
- ✚ Factors affecting crystal size
 - Rate of cooling
 - Slow rate promotes the growth of fewer but larger crystals
 - Fast rate forms many small crystals
 - Very fast rate forms glass
 - Amount of **silica** (SiO_2) present
 - Amount of dissolved gases

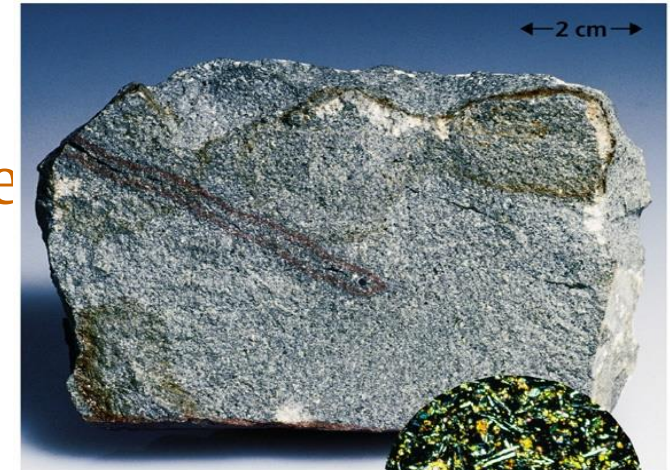


Igneous Textures

✚ Types of igneous textures

1. Aphanitic (fine-grained) texture

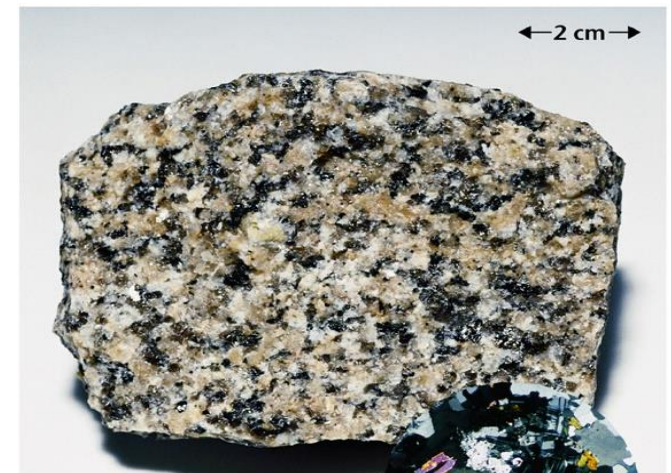
- Rapid rate of cooling of lava or magma
- Microscopic crystals
- May contain **vesicles** (holes from gas bubbles)



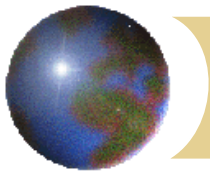
A. Aphanitic

2. Phaneritic (coarse-grained) texture

- Slow cooling
- Crystals can be identified without a microscope



B. Phaneritic

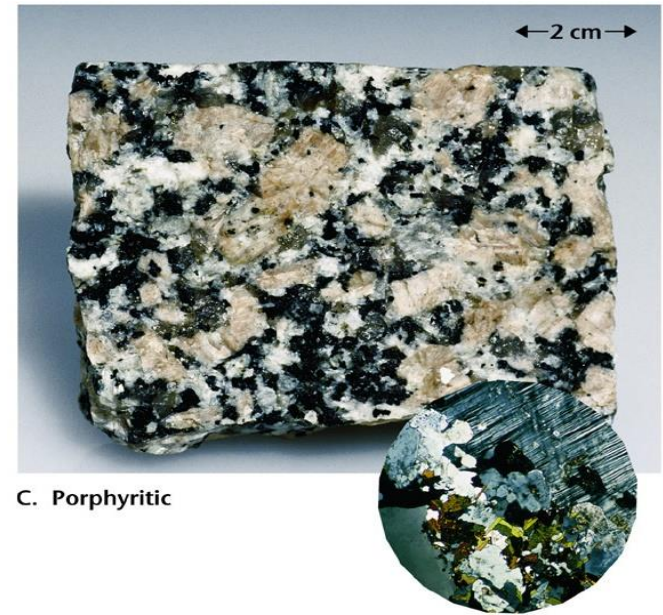


Igneous Textures

✚ Types of igneous textures

3. Porphyritic texture

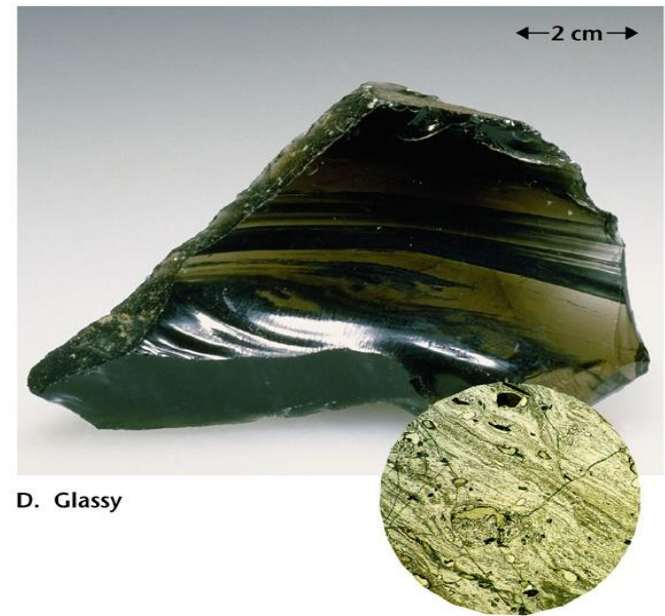
- Minerals form at different temperatures as well as differing rates
- Large crystals, called **phenocrysts**, are embedded in a matrix of smaller crystals, called the **groundmass**



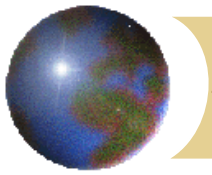
C. Porphyritic

4. Glassy texture

- Very rapid cooling of lava
- Resulting rock is called **obsidian**



D. Glassy



Igneous Textures

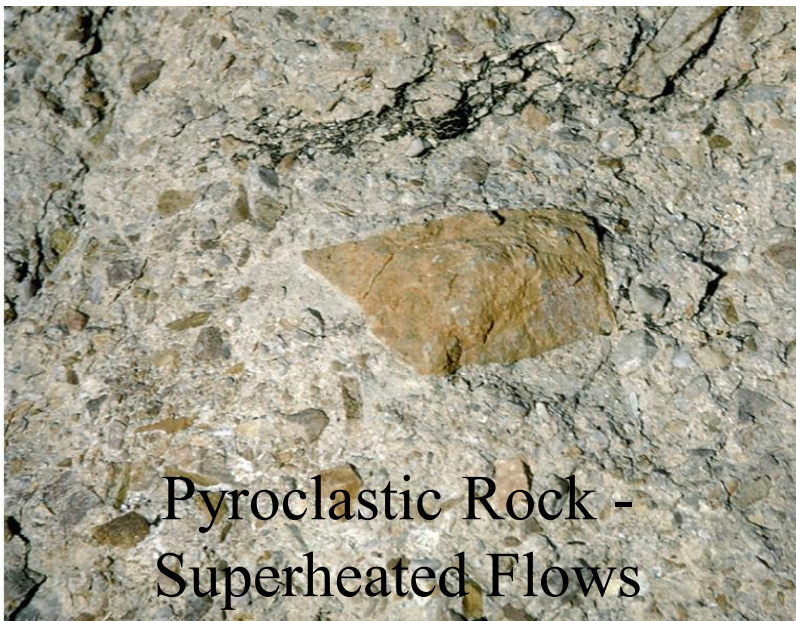
✚ Types of igneous textures

5. Pyroclastic (Fragmental) texture

- Various fragments ejected during a violent volcanic eruption
- Textures often appear to more similar to sedimentary rocks

6. Pegmatitic texture

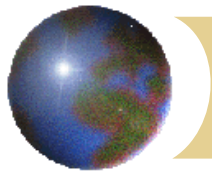
- Exceptionally coarse grained
- Form in late stages of crystallization of granitic magmas



Pyroclastic Rock -
Superheated Flows

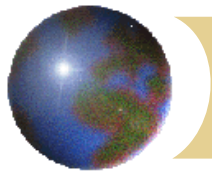


A Spectacular Pegmatite Vein
of Feldspar and Quartz



Igneous Compositions

- ✚ Igneous rocks are divided into broad compositional groups based on the percentage of dark and light silicate minerals they contain
 - Dark (or ferromagnesian) silicates
 - Olivine
 - Pyroxene
 - Amphibole
 - Biotite mica
 - Light (or nonferromagnesian) silicates
 - Quartz
 - Muscovite mica
 - Feldspars



Igneous Compositions

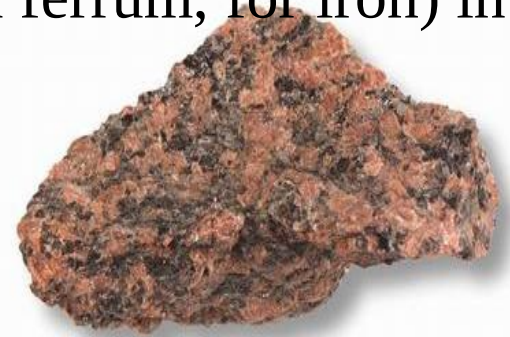
✚ Granitic versus basaltic compositions

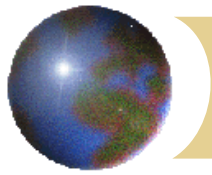
- **Granitic** composition

- Light-colored silicates and high silica content (SiO_2)
- Extremely viscous, liquid exists at temperatures as low as 700°C
- Termed felsic (feldspar and silica) in composition
- Major constituent of continental crust

- **Basaltic** composition

- Composed of dark silicates and calcium-rich feldspar
- Designated as being **mafic** (magnesium and ferrum, for iron) in composition
- More dense than granitic rocks
- Comprise the ocean floor as well as many volcanic islands





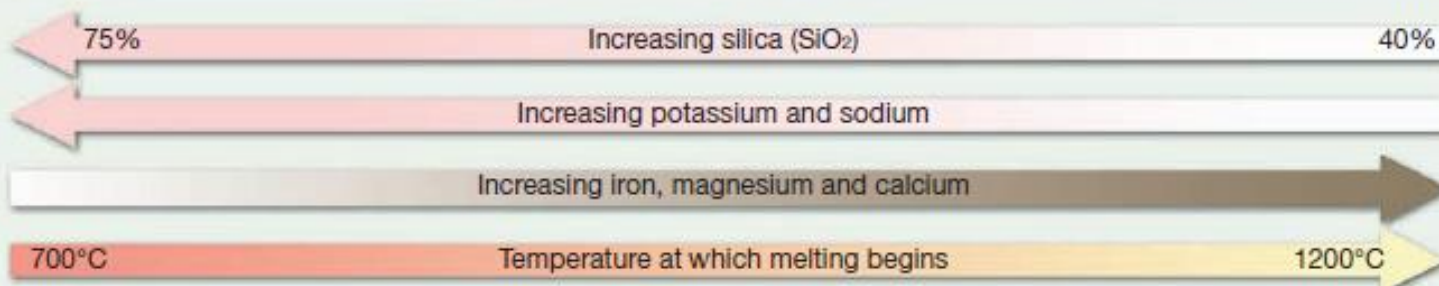
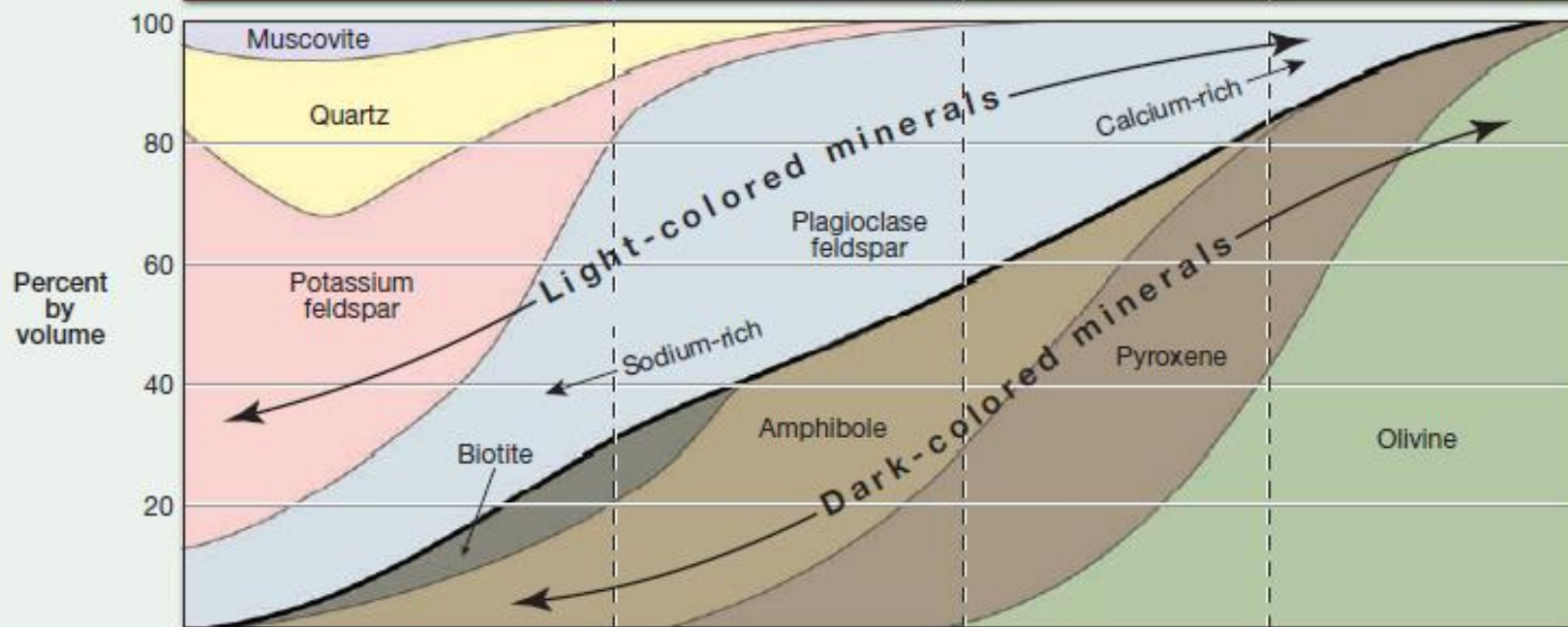
Igneous Compositions

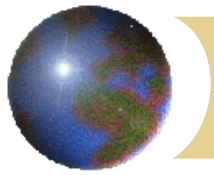
- ✚ Other compositional groups
 - Intermediate (or andesitic) composition
 - Contain 25% or more dark silicate minerals
 - Associated with explosive volcanic activity
 - Ultramafic composition
 - Rare composition that is high in magnesium and iron
 - Composed entirely of ferromagnesian silicates



Igneous Compositions

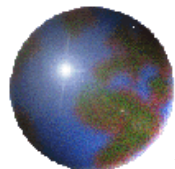
Composition	Felsic (Granitic)	Intermediate (Andesitic)	Mafic (Basaltic)	Ultramafic
Phaneritic (Coarse-grained)	Granite	Diorite	Gabbro	Peridotite
Aphanitic (Fine-grained)	Rhyolite	Andesite	Basalt	Komatiite (Rare)





Igneous Compositions

- ✚ Igneous rocks may be classified on the basis of what minerals they contain.
- ✚ A distinction is made between **essential (dominant)** minerals (those that must be present) and **accessory** minerals (often present, but not necessary).
- ✚ Example: Granite
 - **Essential**: Feldspar, Quartz
 - **Accessory**: Biotite, Hornblende
- ✚ Accessory minerals may become part of the rock name: Hornblende andesite, because hornblende is not an essential.

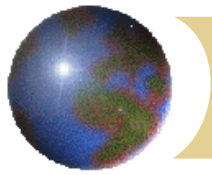


Igneous Compositions

Chemical Composition	Felsic (Granitic)	Intermediate (Andesitic)	Mafic (Basaltic)	Ultramafic
Dominant Minerals	Quartz Potassium feldspar Sodium-rich plagioclase feldspar	Amphibole Sodium- and calcium-rich plagioclase feldspar	Pyroxene Calcium-rich plagioclase feldspar	Olivine Pyroxene
Accessory Minerals	Amphibole Muscovite Biotite	Pyroxene Biotite	Amphibole Olivine	Calcium-rich plagioclase feldspar

Rock Color (based on % of dark minerals)	0% to 25%	25% to 45%	45% to 85%	85% to 100%

TEXTURE	Phaneritic (coarse-grained)		Granite	Diorite	Gabbro	Peridotite
	Aphanitic (fine-grained)		Rhyolite	Andesite	Basalt	Komatiite (rare)
	Porphyritic		"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts			
	Glassy		Obsidian (compact glass) Pumice (frothy glass)			
	Pyroclastic (fragmental)		Tuff (fragments less than 2 mm) Volcanic Breccia (fragments greater than 2 mm)			

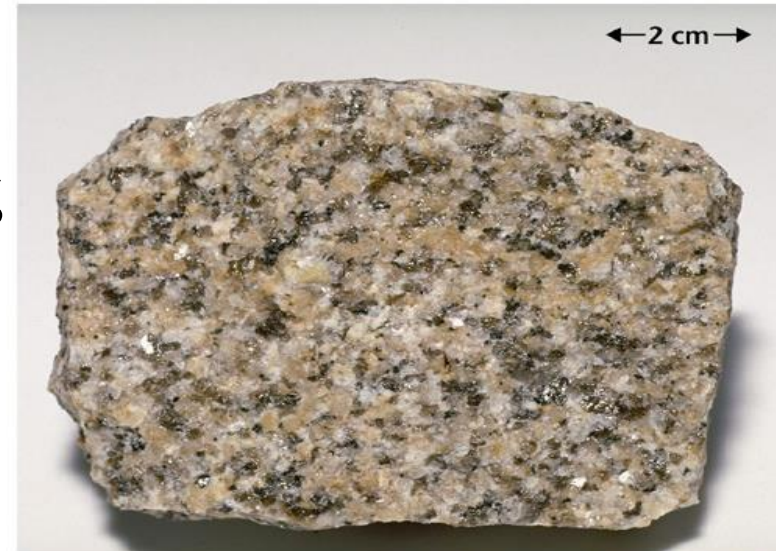


Igneous Compositions

✚ Naming igneous rocks – granitic (felsic) rocks

- Granite

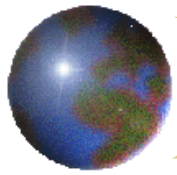
- Phaneritic
- Over 25% quartz, about 65% or more feldspar
- May exhibit a porphyritic texture
- Very abundant as it is often associated with mountain building
- The term granite covers a wide range of mineral compositions



A. Granite

Close up





Igneous Compositions

✚ Naming igneous rocks – granitic (felsic) rocks

- **Rhyolite**

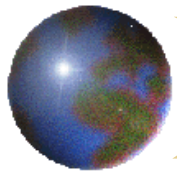
- Extrusive equivalent of granite
- May contain glass fragments and vesicles
- Aphanitic texture
- Less common and less voluminous than granite



B. Rhyolite

Close up





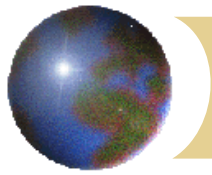
Igneous Compositions

✚ Naming igneous rocks – granitic (felsic) rocks

- Obsidian

- Dark colored
- Glassy texture





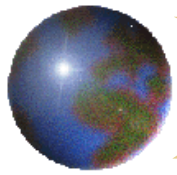
Igneous Compositions

✚ Naming igneous rocks – intermediate rocks

- Pumice

- Volcanic
- Glassy texture, very light weight, mostly air
- Frothy appearance with numerous voids (extrusive foam)
- Forms when lavas have a lot of water and other volatiles





Igneous Compositions

✚ Naming igneous rocks – intermediate rocks

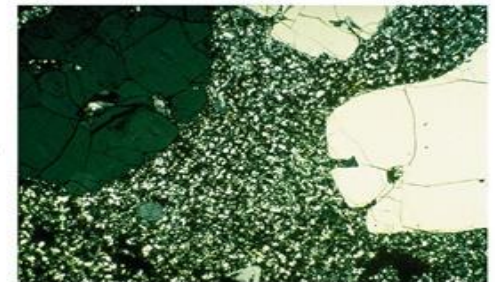
• Andesite

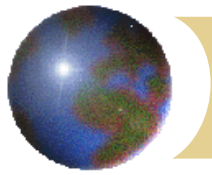
- Volcanic origin
- Aphanitic texture
- Often resembles rhyolite



A. Andesite porphyry

B. Close up



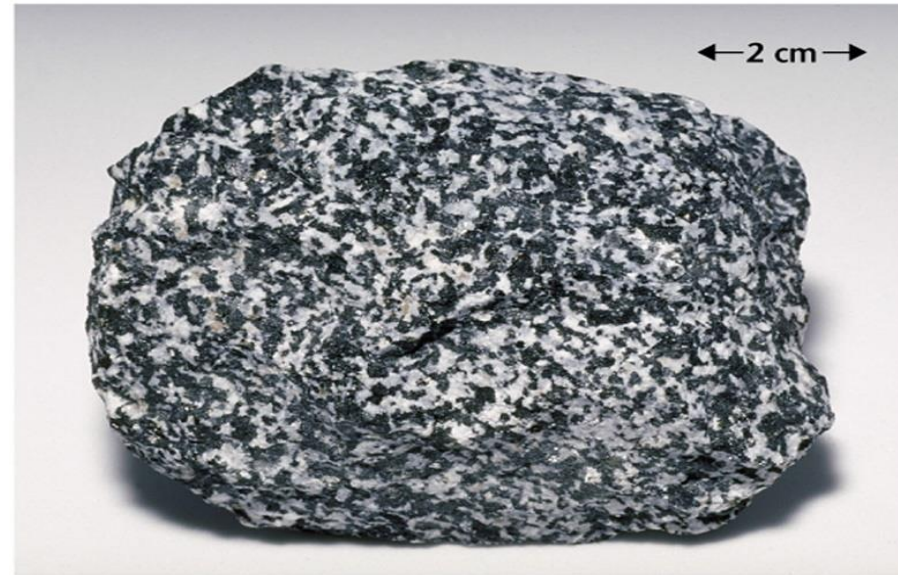


Igneous Compositions

✚ Naming igneous rocks – intermediate rocks

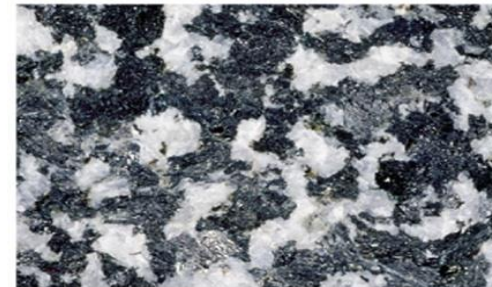
- Diorite

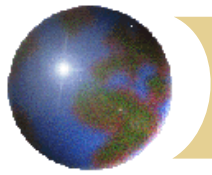
- Plutonic equivalent of andesite
- Coarse grained
- Intrusive
- Composed mainly of intermediate feldspar and amphibole



Diorite

Close up





Igneous Compositions

✚ Naming igneous rocks – basaltic (mafic) rocks

• Gabbro

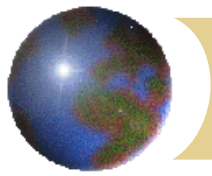
- Intrusive mafic igneous rock equivalent of basalt
- Phaneritic texture consisting of pyroxene and calcium-rich plagioclase
- Makes up a significant percentage of the oceanic crust



B. Gabbro

Close up





Igneous Compositions

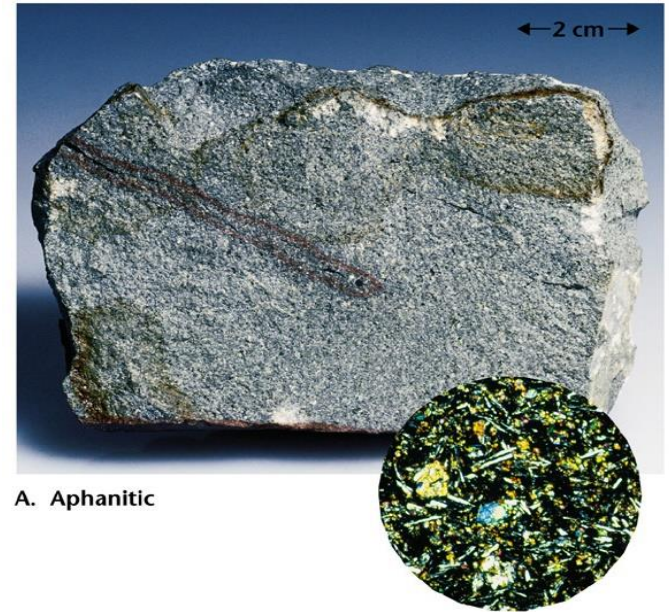
✚ Naming igneous rocks – basaltic (mafic) rocks

• Basalt

- Volcanic origin
- Aphanitic texture
- Composed mainly of pyroxene and calcium-rich plagioclase feldspar
- Most common extrusive igneous rock

• Basaltic magma

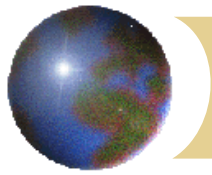
- Much lower silica content
- Fluid-like behavior
- Crystallizes at higher temperatures



A. Aphanitic



Basalt (Scoria)



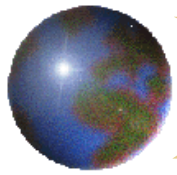
Igneous Compositions

Columnar basalts



Basalt with columnar jointing,
near Whistler, British Columbia

- ✪ Dark, fine grained volcanic rocks, chiefly basalt and andesite, are exposed at the northern edge of the Fraser Valley. These rocks formed as lavas, shallow intrusions, and volcanic ash deposits. Most volcanic rocks are resistant to erosion and form prominent hills in the Fraser Valley

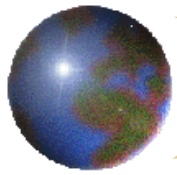


Igneous Compositions

Vesicular Basalt



- ❖ Gas in magma is trapped by rapid cooling, leaving vesicles

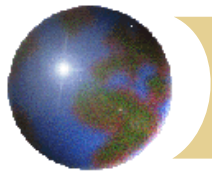


Igneous Compositions

Pillow basalts

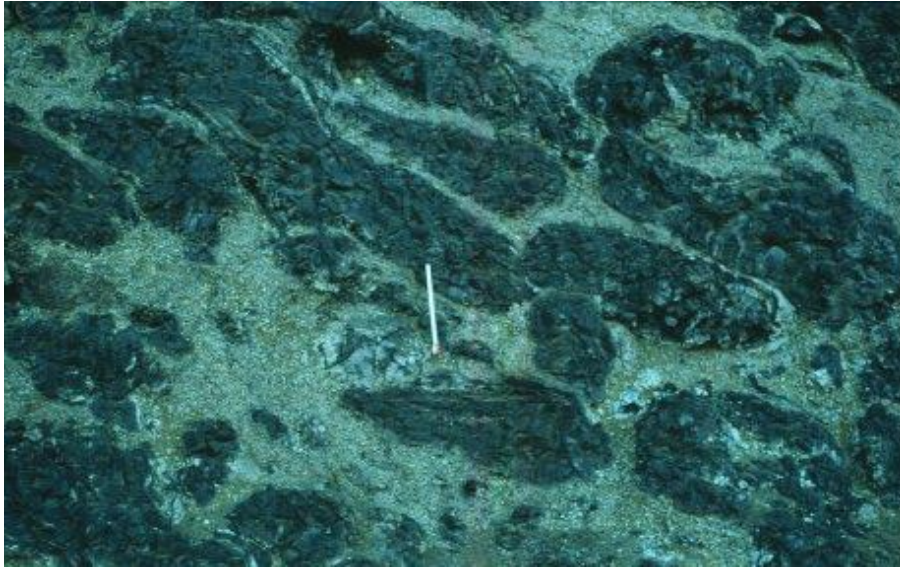


- ✚ Pillow basalts form during underwater eruptions
- ✚ This basalt was found in Marin County, California

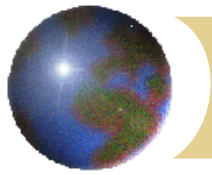


Igneous Compositions

Pillow basalt



- Pillow lava forms when eruptions are underwater or when lava flows enter a body of water
- Abundance of pillows and pillow deltas indicates rivers and lakes were common features during the formation of the Columbia River Flood Basalt Province

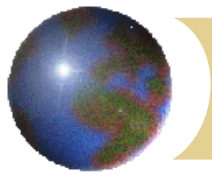


Igneous Compositions

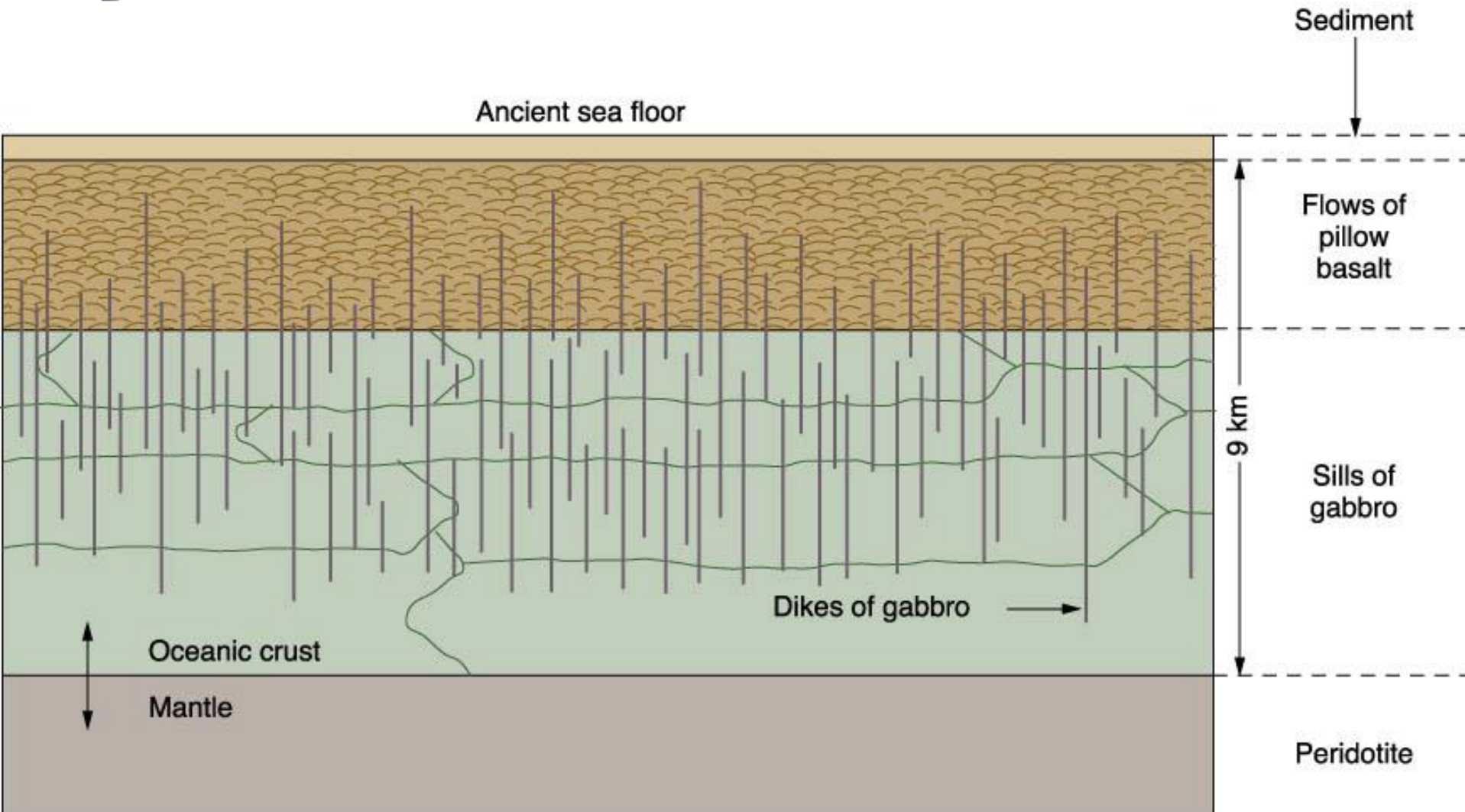
Pillow deltas

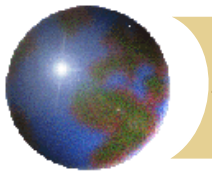


- Pillows can be up to 5 m long and about 0.5 to 1 m thick
- They are elongate in the direction of flow and dip 20-30 degrees



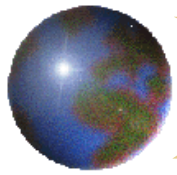
Igneous Compositions





Volcanic Terms

- ✚ **Pyroclastic rock**: explosively erupted as hot but nevertheless solid particles
- ✚ **Tuff**: explosively erupted, fine-grained volcanic rock whose grains are commonly welded together
- ✚ **Vesicles**: cavities in a volcanic rock, once occupied by gas bubbles



Igneous Compositions

✚ Naming igneous rocks – **pyroclastic rocks**

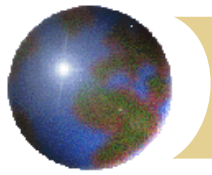
- Composed of fragments ejected during a volcanic eruption
- Varieties
 - **Tuff** – ash-sized fragments
 - **Volcanic breccia** – particles larger than ash



Tuff



breccia



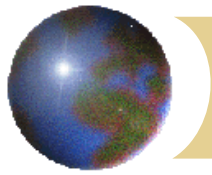
Origin of Magma

Generating magma from solid rock

✚ Role of heat

- Temperature increases in the upper crust (geothermal gradient) average between 20oC to 30oC per kilometer
- Rocks in the lower crust and upper mantle are near their melting points
- Any additional heat may induce melting

✚ Mineral contents



Origin of Magma

✚ Role of pressure

- Increases in confining pressure cause an increase in a rock's melting temperature
- When confining pressures drop, decompression melting occurs

✚ Role of volatiles

- Volatiles (primarily water) cause rocks to melt at lower temperatures
- Important factor where oceanic lithosphere descends into the mantle