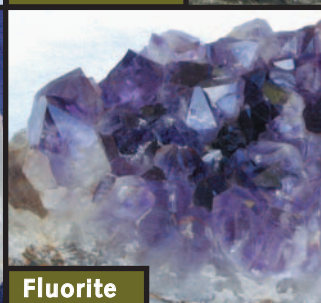
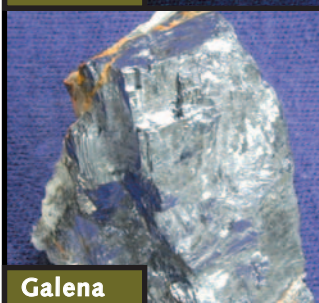


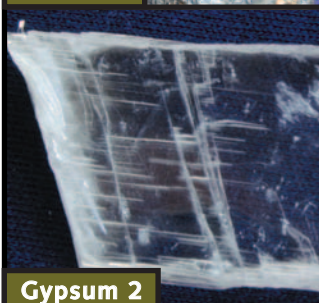
# ROCKS & MINERALS

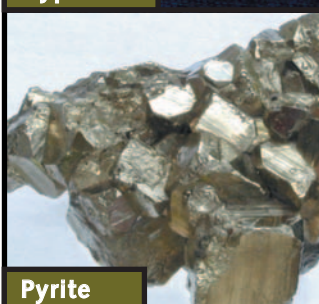
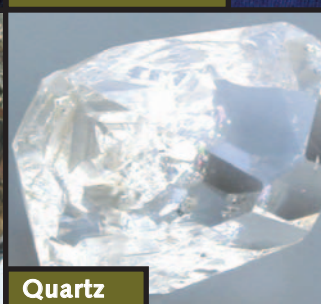
## A PICTORIAL GUIDE TO MINERALOGY


**Agate**

**Biotite Mica**

**Calcite**

**Fluorite**

**Galena**

**Gypsum 1**

**Gypsum 2**

**Muscovite Mica**

**Pyrite**

**Quartz**

**Quartz (Rose)**

**Sulfur (Native)**

### METALLIC LUSTER

| Mineral       | Hardness | Streak Color | Specific Gravity | Other Properties                          |
|---------------|----------|--------------|------------------|---|
| Bornite       | 3.0      | black/gray   | 5.1              | red, purple, iridescent, brittle, soft    |
| Chalcopyrite  | 3.5-4    | dark gray    | 4.2              | yellow, brittle, conchoidal fracture      |
| Chromite      | 5.5      | brown        | 4.7              | silver, black, weakly magnetic            |
| Galena        | 2.5      | gray         | 7.5              | silver, cubic cleavage                    |
| Goethite      | 5-5.5    | brown/yellow | 4.3              | brown to black                            |
| Graphite      | 1.0      | dark gray    | 2.2              | black, greasy, writes                     |
| Hematite      | 5-6.5    | reddish      | 4.9-5.2          | silver, reddish, no cleavage              |
| Limonite      | 5-5.5    | brown/yellow | 4.2              | brown, amorphous                          |
| Magnetite     | 6.0      | dark gray    | 5.2              | black, magnetic                           |
| Marcasite     | 6-6.5    | dark gray    | 4.9              | yellow/gold, brittle, no cleavage         |
| Native Copper | 2.5-3    | copper       | 8.9              | copper, brown, malleable                  |
| Pyrite        | 6-6.5    | dark gray    | 5.0              | fool's gold, cubic crystals               |
| Sphalerite    | 3.5-4    | white/yellow | 4.0              | brown, dodecahedral cleavage, transparent |

### NON-METALLIC LUSTER

| Mineral              | Hardness | Streak Color | Specific Gravity | Luster           | Other Properties   |
|----------------------|----------|--------------|------------------|------------------|--|
| Agate (Quartz)       | 7        | white        | 2.5-2.8          | vitreous         | varying banded colors, no cleavage                           |
| Apatite              | 5        | white        | 3.1              | vitreous         | brown, yellow, green, conchoidal fracture                    |
| Augite               | 5.5      | white        | 3.3-3.5          | vitreous         | green, 2 cleavage@90°  |
| Azurite              | 3.5-4    | light blue   | 3.7              | earthy           | blue, reacts w/HCl   |
| Barite               | 3        | white        | 4.5              | vitreous         | crystals, 3 cleavage not@90°                                 |
| Biotite Mica         | 2.5-3    | gray-brown   | 2.7-3.1          | pearly           | brown, one cleavage  |
| Calcite              | 3        | white        | 2.7              | vitreous         | colorless, rhombohedral cleavage                             |
| Chalcedony (Quartz)  | 7        | white        | 2.5-2.8          | waxy             | white, cryptocrystalline                                     |
| Chert (Quartz)       | 7        | white        | 2.5-2.8          | waxy             | gray, cryptocrystalline                                      |
| Chlorite             | 2        | white        | 2.6-3.0          | vitreous         | green, one cleavage  |
| Chrysocolla          | 2-4      | light blue   | 2.0-2.4          | vitreous         | blue, amorphous, conchoidal fracture                         |
| Corundum             | 9        | white        | 4.0              | adamantine       | brown, red, blue, purple, hard                               |
| Diamond              | 10       | white        | 3.52             | adamantine       | colorless, hardest, conchoidal fracture, octahedral cleavage |
| Dolomite             | 3.5-4    | white        | 2.8              | vitreous         | white, gray, pink, rhombohedral cleavage                     |
| Epidote              | 6-7      | white        | 3.4              | vitreous         | green-yellow, one cleavage                                   |
| Flint (Quartz)       | 7        | white        | 2.5-2.8          | waxy             | black, cryptocrystalline                                     |
| Fluorite             | 4        | white        | 3.0-3.3          | vitreous         | violet, blue, octahedral cleavage                            |
| Garnet               | 7        | white        | 3.4-4.3          | vitreous         | dark red, no cleavage  |
| Glaucinite           | 2-2.5    | green        | 2.4-2.9          | greasy           | green, marine origin   |
| Gypsum               | 2        | white        | 2.3              | silky            | colorless, white, one cleavage                               |
| Halite               | 2.5      | white        | 2.1-2.6          | vitreous         | colorless, cubic cleavage                                    |
| Hematite             | 1.5-5.5  | red/brown    | 4.9-5.3          | earthy           | red, no cleavage   |
| Hornblende           | 5.5      | green        | 3.0-3.3          | vitreous         | green, brown, cleavage@60°-120°                              |
| Jasper (Quartz)      | 7        | white        | 2.5-2.8          | waxy             | red, cryptocrystalline                                       |
| Kaolinite            | 1-2      | white        | 2.6              | earthy           | white, gray, brown, one cleavage                             |
| Limonite             | 1.5-5.5  | yellow/brown | 3.6-4.0          | vitreous to dull | yellow-brown, amorphous                                      |
| Malachite            | 3.5-4    | green        | 3.9-4.0          | silky            | green, will react with HCl                                   |
| Muscovite Mica       | 2-2.5    | white        | 2.7-3.0          | pearly           | colorless or silvery-white, one cleavage                     |
| Native Sulfur        | 1.5-2.5  | yellow       | 2.1              | resinous         | yellow, conchoidal fracture                                  |
| Olivine              | 7        | white        | 3.3              | vitreous         | green-yellow, conchoidal fracture                            |
| Opal                 | 6        | white        | 1.9-2.3          | greasy           | colorless, white, amorphous                                  |
| Plagioclase Feldspar | 6        | white        | 2.6-2.8          | vitreous         | black, white, gray, 2 cleavage@90°                           |
| Potassium Feldspar   | 6        | white        | 2.6              | vitreous         | pink, white, 2 cleavage @ 90°                                |
| Quartz               | 7        | white        | 2.7              | vitreous         | many colors, conchoidal fracture                             |
| Serpentine           | 2-5      | white        | 2.2-2.6          | silky or waxy    | green, gray, brown, fibrous                                  |
| Talc                 | 1        | white        | 2.7              | pearly or greasy | white, greenish-white, gray                                  |
| Topaz                | 8        | white        | 3.5              | vitreous         | yellow, brown, blue, green, basal cleavage                   |
| Tourmaline           | 7-7.5    | white        | 3.1              | vitreous         | yellow, green, brown, no cleavage, conchoidal fracture       |
| Turquoise            | 5-6      | pale blue    | 2.7              | waxy             | light blue green, microcrystalline, conchoidal fracture      |

# MINERALS

A **mineral** is a naturally occurring, inorganic, solid material with a defined chemical composition and crystalline structure

## A. Atoms and Crystal Form:

- Atom:** The smallest particle of an element that maintains the element's properties
- Atoms are composed of neutrons, protons, and electrons
  - Atomic Structure:** The arrangement of protons, neutrons and electrons
  - Atomic Number:** Number of protons in a nucleus
  - Atomic Weight:** Average weight of an atom
  - Isotope:** Forms of an element with identical atomic numbers, but different numbers of neutrons in the nucleus
- Crystalline Structure:** The specific and repeated arrangement of atoms
- Crystal Form:** The geometric shape of a crystal, determined by crystalline structure, can usually be observed at the surface of the mineral
  - Crystal Face:** Each flat surface of a mineral
  - Cryptocrystalline:** Crystals too small to see with the bare eye
  - Amorphous:** Noncrystalline, or lacking atomic structure due to rapid cooling, glassy appearance; **example:** opal
  - There are 64 crystal forms separated into 6 classes:
    - Isometric class:** Equal measure
    - Tetragonal class:** Square cross sections, rectangular faces
    - Hexagonal/Triagonal class:** Six-sided
    - Orthorhombic class:** Rectangular profile, rectangular faces
    - Monoclinic class:** Rectangular faces and trapezoid faces
    - Triclinic class:** Trapezoid faces

## EXAMPLES OF CRYSTAL FORMS:

Cube (Isometric class):  
Galena



Octahedron (Isometric class):  
Magnetite



Hexagonal pyramid (Hexagonal class):  
Nepheline



Rhombohedral (Hexagonal class):  
Dolomite



Scalenohehron (Tetragonal class):  
Chalcopyrite



## B. Mining

- Ore:** Useful metallic mineral found in large enough quantities to be profitable in mining
- Variables in mining ores:
  - Amount of metal present** compared to total amount in Earth's crust; small amounts may not be worth mining
  - Cost to mine** or accessibility to ore, i.e., an ore deep in the oceanic crust is more difficult and costly to mine than in the continental crust
  - Value of the ore:** Depends on the demand; a more precious metal may be mined in smaller quantities if in demand

## C. Mineral Groups

- Silicates:** Minerals with silicon and oxygen

- Silica tetrahedron:** Silicon forms a pyramid-shaped structure with oxygen, basic building block for silicate minerals
- Silicate structures and examples:  
Isolated (single) olivine  
Single Chain augite (pyroxene)  
Double Chain hornblende (amphibole)  
Sheet biotite (mica)  
3-D Framework feldspars, quartz

## 2. Non-Silicates

- Carbonates:** Minerals with carbon and oxygen, including calcite, from which we procure limestone (roads) and marble (decorative slabs)
- Oxides:** Oxygen-based solids; **example:** magnetite
- Sulfides:** Contain sulfur; **example:** pyrite
- Sulfates:** Contain sulfur and oxygen; **example:** gypsum
- Halides:** Contain a halogen element and a metal, halite
- Native metals:** Iron, zinc, gold, silver, nickel, copper

## D. Properties of Minerals

- Luster:** Appearance or quality of light reflected from the surface
  - Metallic:** Resembles metal; **example:** gold, silver, pyrite
  - Nonmetallic:** Unlike metal
    - Adamantine:** Resembles a diamond, brightest luster
    - Resinous:** Resembles resin; **example:** sulfur
    - Vitreous:** Resembles glass, most common; **example:** quartz and fluorite
    - Pearly:** Resembles Mother of Pearl; **example:** muscovite, biotite (mica)
    - Silky:** Mineral with fine fibers; **example:** gypsum
    - Waxy:** Resembles wax; **example:** chalcedony
    - Earthy:** Resembles earthy materials like dirt, having no reflection; **example:** bauxite, clay, diatomaceous earth
- Color:** The surface color of a mineral
  - Most minerals have a variety of colors; **example:** quartz
  - Some minerals have a unique color that may help identify it; **example:** sulfur is yellow
- Hardness:** The ability to withstand scratching
  - Tested using an object or mineral of known hardness on a mineral of unknown hardness or vice versa
  - Moh's hardness scale relates 10 common minerals from hardest to softest
  - Scratch Test:** Higher-numbered materials can scratch lower-numbered materials

## MOH'S SCALE

| Hardness | Mineral  | Object of known hardness |
|----------|----------|--------------------------|
| 10       | Diamond  |                          |
| 9        | Corundum |                          |
| 8        | Topaz    |                          |
| 7        | Quartz   |                          |
| 6        | Feldspar |                          |
| 5.5      |          | Glass, knife             |
| 5        | Apatite  |                          |
| 4        | Fluorite |                          |
| 3.5      |          | Penny (copper)           |
| 3        | Calcite  |                          |
| 2.5      |          | Finger nail              |
| 2        | Gypsum   |                          |
| 1        | Talc     |                          |

- Streak:** Color of mineral in powdered form
  - Created by scratching mineral on streak plate or unglazed porcelain (applies to minerals with a hardness of 6 or less; if greater than 6, the powdered form of the mineral is the streak color)
  - Color of streak may differ from surface color; **example:** hematite is metallic silver while the streak is red-brown
- Cleavage:** Tendency to break or separate along a flat surface due to a lack of or weakness in atomic structure; **example:** muscovite, biotite (mica)
  - Cleavage plane:** Flat surface created from cleavage breakage
  - Striation:** Thin, straight cuts on the cleavage plane
  - Fracture:** Surface created from breakage not related to atomic structure
    - Uneven:** Irregular, rough
    - Conchoidal:** Curved, smooth surface; **example:** obsidian

## NUMBER OF CLEAVAGE

| Planes & Directions                  | Drawing | Example           |
|--------------------------------------|---------|-------------------|
| 1 (basal cleavage)                   |         | micas, chlorite   |
| 2 at 90°                             |         | feldspar          |
| 2 not at 90°                         |         | amphibole         |
| 3 at 90° (cubic cleavage)            |         | galena            |
| 3 not at 90° (rhombohedral cleavage) |         | dolomite, calcite |
| 4 (octahedral cleavage)              |         | fluorite          |
| 6 (dodecahedral cleavage)            |         | sphalerite        |

## 6. Specific Gravity

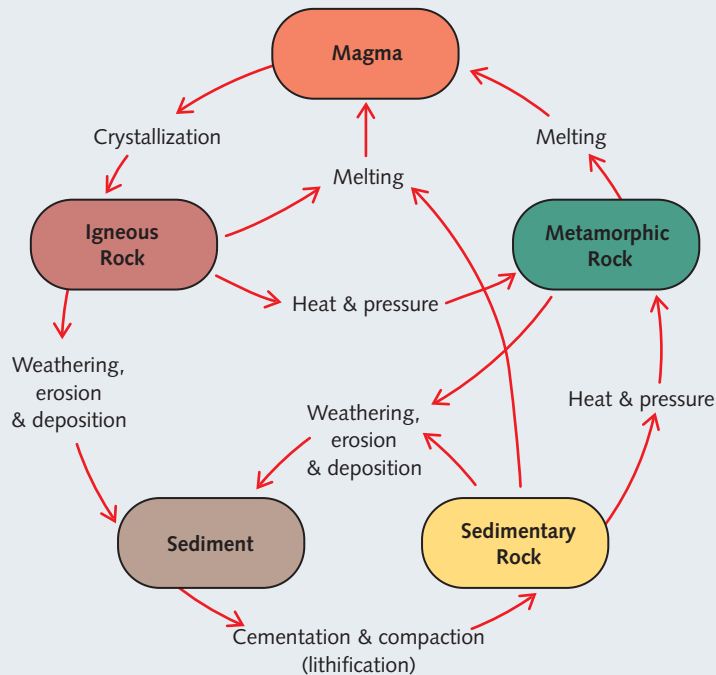
- The ratio of the weight of a mineral to the weight of an equal volume of water
  - Density of water** = 1gm/cm<sup>3</sup>=1gm/ml i.e., lead = 7.7, or is 7.7 times heavier than an equal volume of water
  - Useful in comparing relative weights between minerals
- Tenacity:** Ability to withstand breakage
    - Brittle:** Will shatter when struck
    - Malleable:** Can be shaped
    - Elastic:** Returns to initial form
    - Flexible:** Pliable
    - Splintery:** Similar to wood

## 8. Special Properties

- Taste:** Some minerals can be identified by taste; **example:** halite (salty)
- Smell:** May help identify a mineral; **example:** kaolinite smells moldy when moist; sulfur has a unique smell
- Feel:** Texture can be determined
- Reaction to Acid:** Carbonate minerals will react to hydrochloric acid or vinegar
- Magnetic:** Will be drawn to a magnet; **example:** magnetite



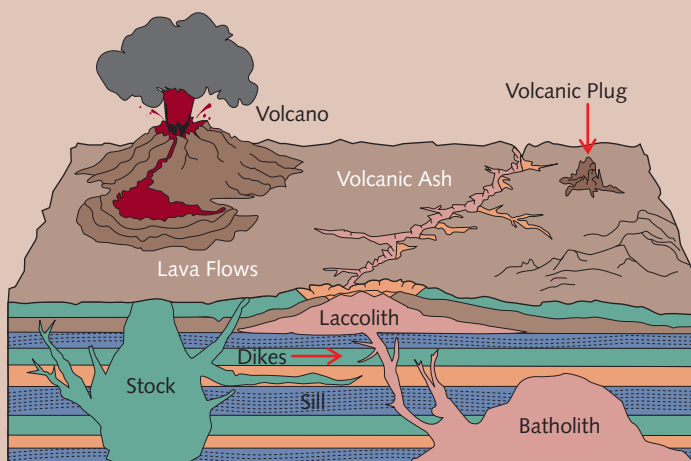
# ROCK CYCLE



## IGNEOUS ROCKS

- A. **Igneous Rocks:** Molten rock from deep within the Earth that has cooled
- Magma:** Molten rock inside the Earth
    - Produces intrusive igneous rocks
    - Consists mainly of silicate materials
    - Contains gases, such as water vapor
    - Differs in rate of cooling, composition of chemicals, and amount of gases
  - Lava:** Molten rock on the surface of the Earth
    - Produces extrusive igneous rocks
    - Most gaseous elements have escaped

### IGNEOUS ROCK FORMATIONS



#### B. Formations

- Intrusive Igneous Rock:** Formed inside the Earth's crust in varying rock bodies
  - Batholith:** Largest intrusive igneous rock body, greater than 100 square miles, widens with depth (plutonic, very deep)
  - Stock:** Similar to but smaller than batholith, less than 100 square miles
  - Laccolith:** Bulge of magma parallel to bedding plane
  - Sill:** Thin sheet, runs parallel to bedding plane
  - Dike:** Cuts through formations, usually in fractures
- Extrusive Igneous Rock:** Formed on the surface of the Earth (volcanic)
  - Lava flows:** Lava seeping out of volcanoes

- Pyroclasts:** Lava projected from volcanic explosions that quickly cools
  - Ash*, less than 2 mm in size
  - Lapilli*, between 2 and 64 mm in size
  - Blocks*, greater than 64 mm in size

#### C. Properties of Igneous Rocks

- Texture:** Determined by rate of cooling; faster cooling results in smaller crystals
  - Pegmatitic:** Grains larger than 1 cm, very coarse, very slow-cooling; **example:** diorite-pegmatite
  - Phaneritic:** Grains between 1 and 10 cm, coarse; **example:** granite
  - Porphyritic:** Large crystals embedded in small crystals; **example:** basalt porphyry
    - Phenocrysts:* Large crystals, due to slow cooling
    - Groundmass:* Small crystals, due to rapid cooling
  - Aphanitic:** Grains less than 1 mm, very fine, very fast-cooling; **example:** rhyolite
  - Glassy:** No crystals, amorphous; **example:** obsidian
  - Vesicular:** Contains varying sizes of gas pockets that remain in the lava, leaving the rock with voids; **example:** pumice
  - Frothy:** Formed from gas pockets, porous texture; **example:** scoria
  - Pyroclastic:** Made of pyroclasts; **example:** tuff
- Mineral Composition:** Determined by evaluating the percent present of the following common minerals:
  - Plagioclase feldspar
  - Olivine
  - Potassium feldspar
  - Pyroxene
  - Quartz
  - Amphibole
  - Biotite
  - Muscovite
- Color:** Helps determine the mineral composition
  - Felsic:** Light-colored, made of feldspars and silicates
    - Quartz
    - Plagioclase feldspar
    - Potassium feldspar
    - Muscovite
  - Mafic:** Dark-colored, made of magnesium and iron (ferric)
    - Olivine
    - Pyroxene
    - Amphibole
    - Biotite
  - Ultramafic:** Very dark-colored
  - Intermediate:** Between light- and dark-colored

#### D. Bowen's Reaction Series

If a mineral, which has already formed, remains in the magma, it will react with the remaining magma to produce the next mineral in the sequence; for **example**, olivine forms first; olivine then reacts with remaining magma to form pyroxene

### BOWEN'S REACTION SERIES

| Magma Temperature            | Discontinuous Reaction Series (Mafic Minerals) | Continuous Reaction Series (Felsic Minerals) | Rock Types          |
|------------------------------|--|--|---------------------|
| High (early crystallization) | Olivine  | (Calcium-rich)                               | Peridotite          |
|                              | Pyroxene                                       |  | Gabbro or Basalt    |
|                              | Amphibole                                      | Plagioclase                                  | Diorite or Andesite |
|                              | Biotite  | (Sodium-rich)                                | Granite or Rhyolite |
| Low (late crystallization)   | Potassium feldspar<br>Muscovite<br>Quartz      |  |                     |

- Continuous Reaction Series** (Right side of the Bowen Series)
  - Calcium-rich parts of the magma form small crystals of feldspar
  - These react with sodium in the magma to become more and more sodium rich
  - Crystal structure does not change
- Discontinuous Reaction Series** (Left side of the Bowen Series)
  - Minerals that form react with remaining magma to form new mineral
  - New mineral is the result of a structural change of previous mineral
- End of Cooling**
  - When everything is almost cool, remaining magma will have high silica content, and quartz will form
  - When cooling is complete, minerals that cooled at the same time will usually be close to one another (feldspar, micas and quartz cool near one another to make granite)

## IGNEOUS ROCKS

Basalt

Granite

Obsidian

Pumice

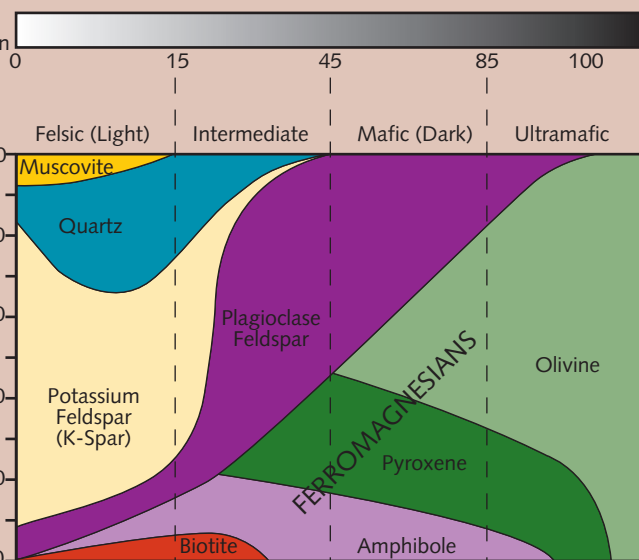
Red Granite

Red Scoria

Rhyolite

Volcanic Rock with Obsidian

## TABLE OF IGNEOUS ROCK

Color Index &  
Graphic Illustration

| Origin    | Texture                          | Rock Names  |                                  |                                 |
|-----------|----------------------------------|---|----------------------------------|---------------------------------|
| Intrusive | Pegmatic:<br>Very coarse-grained | GRANITE-<br>PEGMATITE   | DIORITE-<br>PEGMATITE            | GABBRO-<br>PEGMATITE            |
|           | Phaneritic:<br>Coarse-grained    | GRANITE   | DIORITE                          | GABBRO                          |
|           |                                  |   |                                  | PERIDOTITE                      |
| Extrusive | Porphyritic                      | RHYOLITE/<br>GRANITE  | PORPHYRITIC/<br>ANDESITE/DIORITE | PORPHYRITIC/<br>BASALT/GABBRO   |
|           | Aphanitic:<br>Fine-grained       | RHYOLITE  | ANDESITE                         | BASALT                          |
|           | Glassy                           | OBSIDIAN  |                                  |                                 |
|           | Frothy                           | PUMICE  |                                  | SCORIA<br>(VESICULAR<br>BASALT) |
|           | Pyroclastic or<br>fragmental     | VOLCANIC TUFF (fragments ≤ 2 mm)<br>VOLCANIC BRECCIA (fragments > 2 mm) |                                  |                                 |
|           |                                  |   |                                  | Rarely<br>Encountered           |

## SEDIMENTARY ROCKS

A. **Sediments:** Pieces or fragments from existing rock that accumulate on the Earth's surface

1. **Weathering:** Physical or chemical breakdown of rock that creates sediments at or near the surface of the Earth

a. **Mechanical weathering and erosion**

- Frost wedging
- Unloading
- Biological activity: Roots, burrows

b. **Chemical weathering**

- Water to rust (oxidation)
- CO<sub>2</sub> and water make carbonic acid
- Granite reacts with water and gas to make clay minerals + potassium and silica

2. **Transport:** Method of moving sediments

- Running water, rivers
- Glaciers
- Wind
- Gravity
- Ground water
- Wave currents

3. **Depositional environment:** Places where the sediment is deposited

- Continental* - deserts, lakes, river beds, swamps, caves
- Continental and Marine* - deltas, sand bars, lagunes, estuaries
- Marine* - the ocean floor

4. **Lithification:** Method of sediments becoming consolidated sedimentary rocks

- Compaction:** Weight compresses deeper sediments
- Cementation:** Materials are "cemented" together from precipitation of a mineral in spaces between sediment
- Crystallization:** Sedimentary rock created from a solution

B. **Sedimentary rocks:** Rocks formed from existing sediments through lithification

1. **Clastic rocks:** (detrital)

- Accumulated debris from weathering and transport
- Made up of mostly clay minerals and quartz
- Conglomerate:** Made up of gravel-sized particles

2. **Chemical rocks:** Created from chemical precipitation

- Formed from materials in solution in bodies of water
- Most abundant form is limestone

3. **Organic (Biochemical) rocks:** Created from biological remnants, such as plants, shells, bones, or other organic matter

C. **Shapes, Sizes and Sorting of Sediments**

1. **Shapes**

- Angular:** Sediment has sharp corners and edges
- Rounded:** Sediment has undergone abrasion and has rounded, smoothed edges

2. **Sizes**

- Clay:** < 1/256 mm, creates mudstone
- Silt:** Between 1/256 and 1/6 mm, creates siltstone
- Sand:** Between 1/6 and 2 mm, creates sandstone
- Pebble:** Between 2 and 64 mm, creates a conglomerate
- Cobble:** Between 64 and 256 mm, creates a conglomerate
- Boulder:** > 256 mm, creates a conglomerate

3. **Sorting**

- Poorly-sorted:** Particles of different sizes together, i.e., a glacier does not sort sediments
- Well-sorted:** Particles of the same size together, i.e., a river sorts rocks from heaviest (upstream) to lightest (downstream)





## D. Properties of Sedimentary Rocks

### 1. Texture

- Clastic:** Made of transported sediments and deposition; observe particle size, shape of grain and how well-sorted
- Bioclastic:** Remains of organic material
- Crystalline:** Interlocking crystals of different sizes, considered dense if crystals are less than  $\frac{1}{4}$  mm
- Amorphous:** Dense, having no crystal structure
- Oolitic:** Made of oolites, small round particles made of calcium carbonate

### 2. Composition: Possible matter found in sedimentary rocks

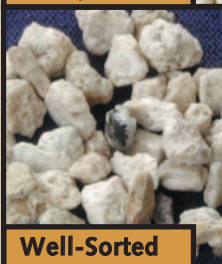
- Carbonate**, test with HCl; **examples:** calcite and dolomite
- Silica**; **examples:** quartz and chert
- Clay minerals**; **examples:** kaolinite, silicate
- Organic matter**; **examples:** plants, shells, bones
- Evaporites**, minerals created from a solution; **example:** gypsum
- Rock Particles**; **example:** conglomerates
- Heavy Minerals**; **example:** garnet
- Feldspar**, known as arkosic

### E. Sedimentary Structures: Structural features resulting from sediment transportation and deposition

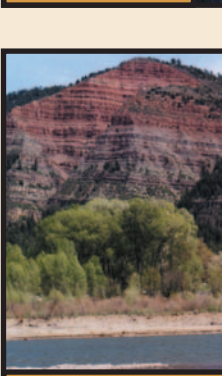
- Stratification:** Distinct layers (strata or bed) formed from moving and depositing sediments
- Cross Bedding:** Stratification at an angle
- Graded Bedding:** Each bed is comprised of sediments that increase in size as the depth of the bed increases (coarsest on bottom); common for deep marine environments
- Surface Impressions:** Impressions preserved in the bed
  - Ripple Marks:** Marks preserved from flow in one direction (asymmetrical)
  - Oscillation Marks:** Marks preserved from flow back and forth (symmetrical)
  - Mud Cracks (Desiccation marks):** Marks preserved from exposure to air
  - Raindrop Impressions:** Marks preserved from rain
  - Trace Fossils:** Marks preserved from the movement of animals



Poorly-Sorted



Well-Sorted



Sedimentary Rock: Durango, CO



Chert



Coquina



Dolomite



Limestone



Shale



Sandstone

## CLASTIC SEDIMENTARY ROCKS

| Name         | Texture (of sediments)       | General Description                    |
|--------------|------------------------------|--|
| Arkose       | coarse sand, angular         | feldspar and quartz present            |
| Breccia      | pebble-sized, angular        | in matrix of cemented sand             |
| Calcarenite  | sand size                    | calcite present                        |
| Claystone    | clay size                    | minerals not visible, smooth           |
| Conglomerate | pebble-sized, round          | in matrix of cemented sand             |
| Graywacke    | sand and clay size           | quartz/sand mixed with clay            |
| Lithic       | sandstone sand size          | rock fragments                         |
| Quartz       | sandstone sand size, rounded | quartz present                         |
| Shale        | clay and silt size           | claystone or siltstone that has layers |
| Siltstone    | silt size                    | minerals not visible, earthy           |

## CHEMICAL SEDIMENTARY ROCKS

| Name               | Texture (of sediments) | General Description           |
|--------------------|------------------------|-------------------------------|
| Chemical Limestone | visible crystals       | has calcite, will react w/HCl |
| Chert              | dense                  | conchoidal fracture           |
| Dolomite           | crystalline, dense     | powder will react w/HCl       |
| Ironstone          | dense                  | iron present, dark-colored    |
| Rock Gypsum        | visible crystals       | gypsum present                |
| Rock Salt          | visible crystals       | halite present, salty         |
| Travertine         | dense                  | will react w/HCl, dark bands  |

## ORGANIC (BIOCHEMICAL) SEDIMENTARY ROCKS

| Name               | Texture (of sediments) | General Description         |
|--------------------|------------------------|-----------------------------|
| Bituminous         | coal bioclastic, dense | black, like soot            |
| Chalk              | bioclastic             | white, will react w/HCl     |
| Coquina            | bioclastic             | cemented shells             |
| Diatomite          | bioclastic             | like chalk, no HCl reaction |
| Peat               | bioclastic             | plant material              |
| Skeletal Limestone | bioclastic             | shells, will react w/HCl    |

## METAMORPHIC ROCKS

- A. **Metamorphism:** To change form within the Earth from existing rocks through heat, pressure and chemical activity, not a result of weathering or sedimentation

### 1. Heat

- Most important agent
- Provides energy for chemical reactions
- Created from igneous rock bodies movement through the existing rock
- Created from geothermal gradient,  $25^{\circ}\text{C}$  increase in temperature with each kilometer increase in depth (geothermal gradient)
- For **example**, clay recrystallizes into feldspar and mica at high temperatures

### 2. Pressure and Stresses

#### a. Confining pressure

- Equal pressure on all sides due to deep burial
- Depth determines amount of pressure
- For **example**, an object in the water has equal amounts of pressure on all sides

#### b. Directed Stress:

Specific pressure to a rock, not uniform, such as in the forming of a mountain

#### i. Differential stress:

Stresses in different directions, not equal

#### ii. Compressive stress:

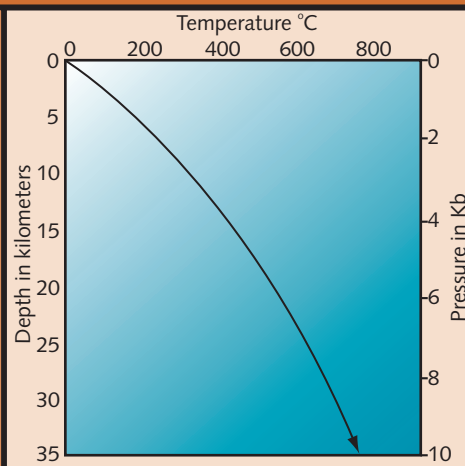
Stress that causes the object to be squeezed

- Shear stress:** Stresses in opposite directions that cause the object to move parallel to the stress

### 3. Chemical Activity

- Change in atomic composition due to heat and/or pressure may cause crystal to recrystallize
- Water is the most common chemical agent

## GEOTHERMAL GRADIENT



**B. Types of Metamorphism**

1. **Contact metamorphism:** Changes caused by proximity to magma or deep, hot rock
2. **Regional metamorphism:** Changes caused by intense stress and high temperatures
3. **Hydrothermal metamorphism:** Changes caused by hot liquids
4. **Fault Zone metamorphism:** Changes caused by fault movement

**C. Degrees of Metamorphism**

1. **Metamorphic grade:** Degree of metamorphism applied to rock
  - a. **High-grade:** Very high amounts of heat and pressure; **example:** gneiss
  - b. **Intermediate-grade:** Medium amounts of heat and pressure; **example:** schist
  - c. **Low-grade:** Lower amounts of heat and pressure, more dense and compact; **example:** slate
2. **Metamorphic facies:** Minerals present in metamorphic rock correlate to amount of heat and pressure
  - a. Low pressure, high temperature; hornfels facies
  - b. High pressure, high temperature; granulite facies, amphibolite facies, and greenschist facies
  - c. High pressure, low temperature; blueschist facies and eclogite facies

**D. Changes in Mineralogy:** Changes in texture or composition of the mineral due to heat and pressure

1. **Recrystallization:** Changed by smaller crystals joining to create larger crystals of the same mineral; common
2. **Neomorphism:** New minerals created from existing mineralogical compositions
3. **Metamorphism:** New minerals created through gaining or losing chemicals

**E. Properties of Metamorphic Rocks**

1. **Texture**
  - a. **Foliated texture:** Contains foliations, minerals brought into line or with one another; layers, due to heat and pressure, common for regional metamorphism; type of foliation can identify rock
  - i. **Slaty:** Caused by low-grade metamorphism; dense rock containing very fine-grained mica minerals, separates in sheets, texture of slate

- ii. **Phyllitic:** Caused by low-grade to intermediate-grade metamorphism; rock containing very fine-grained mica and chlorite minerals that form in a wave-like manner; glossy luster; looks wrinkled; texture of phyllite

- iii. **Schistose:** Caused by intermediate-grade metamorphism; medium- to coarse-grained platy minerals such as micas, chlorite, and quartz present, texture of schist

- iv. **Gneissic:** Caused by intermediate-grade to high-grade metamorphism; rock containing layers of varying medium to coarse minerals, light and dark layers alternating, texture of gneiss

- v. **Migmatitic:** Caused by extreme heat and pressure, melting; rock containing igneous (granite) and metamorphic rock, texture of migmatite

2. **Nonfoliated texture:** Lacks foliations, or layers, of minerals; granular, common for contact metamorphism

- i. **Cataclastic:** Made of fragments or angular pieces of existing rocks created by grinding, often near faults, hydrothermal veins

- ii. **Granular:** Rocks containing minerals of similar size crystals that can be seen with the bare eye, such as quartzite

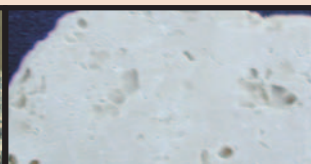
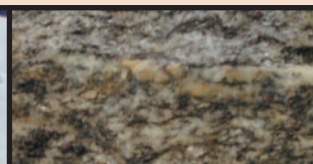
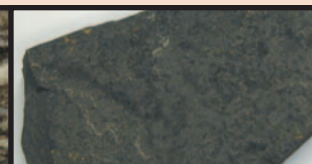
- iii. **Microgranular:** Rock containing minerals of similar size that cannot be seen with the bare eye, such as hornfels

- iv. **Glassy:** No crystals can be seen, smooth, has conchoidal fracture; **example:** anthracite coal

- v. **Porphyroblastic:** Rock containing large crystals (porphyroblasts) in a matrix of finer crystals, schist

2. **Composition:** Assists in identification of nonfoliated rocks; some properties of the metamorphosed rock (sedimentary, igneous or metamorphic) can remain in the new rock

- a. Sandstone: Can create quartzite
- b. Limestone: Can create marble
- c. Basalt: Can create schist or amphibolite
- d. Shale: Can create slate
- e. Granite: Can create schist
- f. Rhyolite: Can create schist

**Black Canyon of Gunnison****Anthracite coal****Gneiss****Marble****Schist****Slate****TABLE OF METAMORPHIC ROCKS**

| Name            | Texture                    | Type of Metamorphism  | Preexisting Rock      | Description   |
|-----------------|----------------------------|-----------------------|-----------------------|---|
| Anthracite Coal | nonfoliated, glassy        | regional metamorphism | bituminous coal       | shiny, black, conchoidal fracture   |
| Gneiss          | foliated, gneissic         | regional metamorphism | schist                | coarse grains, undergoes neomorphism, contains layers of light and dark bands, quartz and micas present |
| Greenstone      | nonfoliated, granular      | regional metamorphism | gabbro or basalt      | undergoes metasomatism  |
| Hornfels        | nonfoliated, microgranular | contact metamorphism  | many rocks            | conchoidal fracture, dense, dark gray to black  |
| Marble          | nonfoliated, granular      | contact metamorphism  | limestone or dolomite | recrystallized, white, gray, pink   |
| Migmatite       | foliated, migmatitic       | regional metamorphism | gneiss and granite    | alternating metamorphic and igneous rock  |
| Phyllite        | foliated, phyllitic        | regional metamorphism | slate                 | wrinkly, contains micas, crystals not visible, shiny  |
| Quartzite       | nonfoliated, granular      | contact metamorphism  | quartz sandstone      | hard, recrystallized, white, brownish   |
| Schist          | foliated, schistose        | regional metamorphism | phyllite              | wrinkly, porphyroblasts, crystals visible   |
| Serpentine      | nonfoliated, granular      | regional metamorphism | basalt or gabbro      | undergoes metasomatism  |
| Skarn           | nonfoliated, granular      | contact metamorphism  | limestone or dolomite | undergoes metasomatism  |
| Slate           | foliated, slaty            | regional metamorphism | shale or mudstone     | breaks along flat surface, black to dark gray, dense  |

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**PRICE**

U.S. \$5.95  
Canada \$8.95

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ISBN-13: 978-142320700-9  
ISBN-10: 142320700-9



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