Quick Study® ACADEMIC

ROCKS & MINERALS

A Pictorial Guide To Mineralogy


Agate

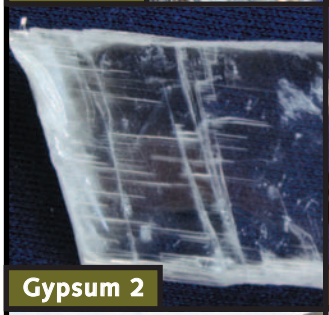

Biotite Mica


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
Glauconite	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:**

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

Examples of Crystal Forms:

Cube (Isometric class): Galena	
Octahedron (Isometric class): Magnetite	
Hexagonal pyramid (Hexagonal class): Nepheline	
Rhombohedron (Hexagonal class): Dolomite	
Scalenohedron (Tetragonal class): Chalcopyrite	

B. **Mining**

1. **Ore**: Useful metallic mineral found in large enough quantities to be profitable in mining
2. Variables in mining ores:
   a. **Amount of metal present** compared to total amount in Earth's crust; small amounts may not be worth mining
   b. **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
   c. **Value of the ore**: Depends on the demand; a more precious metal may be mined in smaller quantities if in demand

C. **Mineral Groups**

1. **Silicates**: Minerals with silicon and oxygen
   a. **Silica tetrahedron**: Silicon forms a pyramid-shaped structure with oxygen, basic building block for silicate minerals
   b. 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**
   a. **Carbonates**: Minerals with carbon and oxygen, including calcite, from which we procure limestone (roads) and marble (decorative slabs)
   b. **Oxides**: Oxygen-based solids; **example**: magnetite
   c. **Sulfides**: Contain sulfur; **example**: pyrite
   d. **Sulfates**: Contain sulfur and oxygen; **example**: gypsum
   e. **Halides**: Contain a halogen element and a metal, halite
   f. **Native metals**: Iron, zinc, gold, silver, nickel, copper

D. **Properties of Minerals**

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

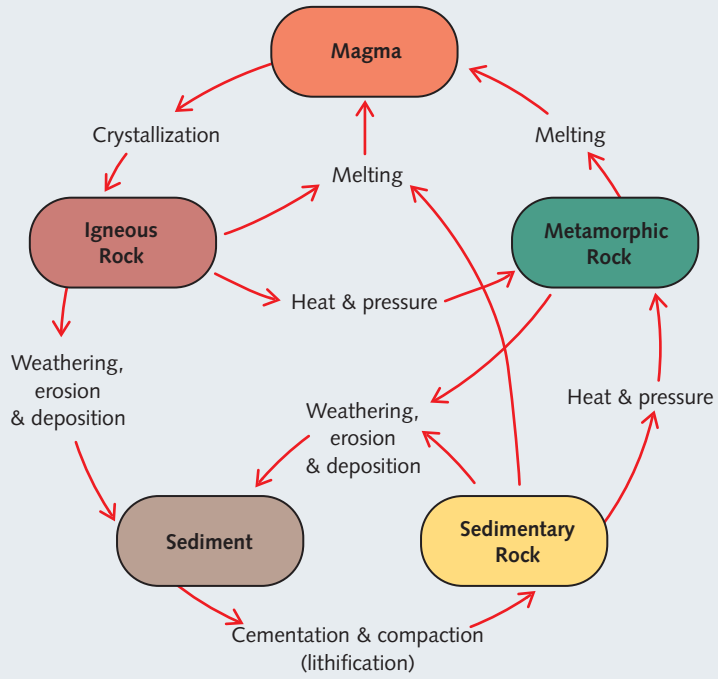
4. **Streak**: Color of mineral in powdered form
   a. Created by scratching mineral on streak plate or unglazed porcelain (applies to minerals with a hardness of 6 or less; if greater than 6, the powdered form of the mineral is the streak color)
   b. Color of streak may differ from surface color; **example**: hematite is metallic silver while the streak is red-brown
5. **Cleavage:** Tendency to break or separate along a flat surface due to a lack of or weakness in atomic structure; **example**: muscovite, biotite (mica)
   a. **Cleavage plane**: Flat surface created from cleavage breakage
   b. **Striation**: Thin, straight cuts on the cleavage plane
   c. **Fracture**: Surface created from breakage not related to atomic structure
      i. *Uneven*: Irregular, rough
      ii. *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**
   a. The ratio of the weight of a mineral to the weight of an equal volume of water
   b. **Density of water** = 1gm/cm3=1gm/ml i.e., lead = 7.7, or is 7.7 times heavier than an equal volume of water
   c. Useful in comparing relative weights between minerals
7. **Tenacity**: Ability to withstand breakage
   a. *Brittle*: Will shatter when struck
   b. *Malleable*: Can be shaped
   c. *Elastic*: Returns to initial form
   d. *Flexible*: Pliable
   e. *Splintery*: Similar to wood
8. **Special Properties**
   a. **Taste**: Some minerals can be identified by taste; **example**: halite (salty)
   b. **Smell**: May help identify a mineral; **example**: kaolinite smells moldy when moist; sulfur has a unique smell
   c. **Feel**: Texture can be determined
   d. **Reaction to Acid**: Carbonate minerals will react to hydrochloric acid or vinegar
   e. **Magnetic**: Will be drawn to a magnet; **example**: magnetite

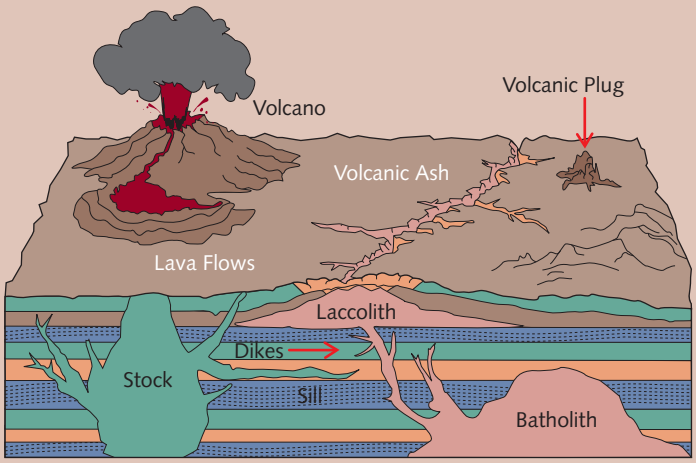
ROCK CYCLE



IGNEOUS ROCKS

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

Igneous Rock Formations



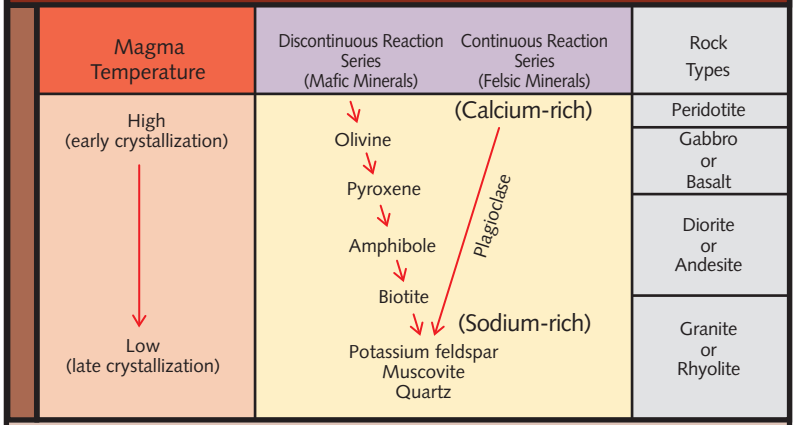
B. **Formations**
1. **Intrusive Igneous Rock**: Formed inside the Earth's crust in varying rock bodies
   a. **Batholith**: Largest intrusive igneous rock body, greater than 100 square miles, widens with depth (plutonic, very deep)
   b. **Stock**: Similar to but smaller than batholith, less than 100 square miles
   c. **Laccolith**: Bulge of magma parallel to bedding plane
   d. **Sill**: Thin sheet, runs parallel to bedding plane
   e. **Dike**: Cuts through formations, usually in fractures
2. **Extrusive Igneous Rock**: Formed on the surface of the Earth (volcanic)
   a. **Lava flows**: Lava seeping out of volcanoes
   b. **Pyroclasts**: Lava projected from volcanic explosions that quickly cools
      i. *Ash*, less than 2 mm in size
      ii. *Lapilli*, between 2 and 64 mm in size
      iii. *Blocks*, greater than 64 mm in size

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



1. **Continuous Reaction Series** (Right side of the Bowen Series)
   a. Calcium-rich parts of the magma form small crystals of feldspar
   b. These react with sodium in the magma to become more and more sodium rich
   c. Crystal structure does not change
2. **Discontinuous Reaction Series** (Left side of the Bowen Series)
   a. Minerals that form react with remaining magma to form new mineral
   b. New mineral is the result of a structural change of previous mineral
3. **End of Cooling**
   a. When everything is almost cool, remaining magma will have high silicone content, and quartz will form
   b. 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

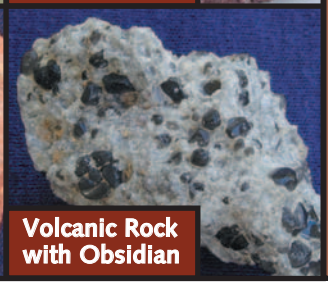
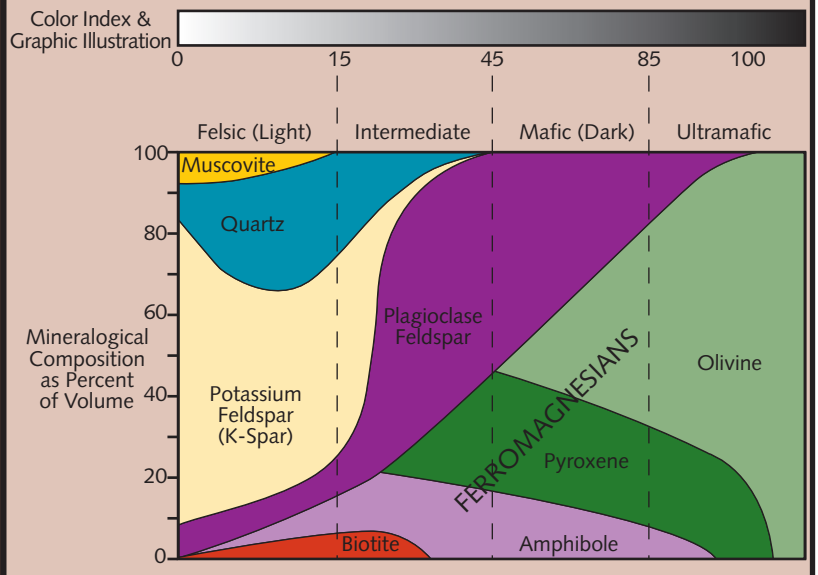

Volcanic Rock with Obsidian

TABLE OF IGNEOUS ROCK



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

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**
      i. Frost wedging
      ii. Unloading
      iii. Biological activity: Roots, burrows
   b. **Chemical weathering**
      i. Water to rust (oxidation)
      ii. CO_2 and water make carbonic acid
      iii. Granite reacts with water and gas to make clay minerals + potassium and silica
2. **Transport**: Method of moving sediments
   a. Running water, rivers
   b. Glaciers
   c. Wind
   d. Gravity
   e. Ground water
   f. Wave currents
3. **Depositional environment**: Places where the sediment is deposited
   a. *Continental* - deserts, lakes, river beds, swamps, caves
   b. *Continental and Marine* - deltas, sand bars, lagunes, estuaries
   c. *Marine* - the ocean floor
4. **Lithification**: Method of sediments becoming consolidated sedimentary rocks
   a. **Compaction**: Weight compresses deeper sediments
   b. **Cementation**: Materials are "cemented" together from precipitation of a mineral in spaces between sediment
   c. **Crystallization**: Sedimentary rock created from a solution

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

1. **Clastic rocks**: (detrital)
   a. Accumulated debris from weathering and transport
   b. Made up of mostly clay minerals and quartz
   c. Conglomerate: Made up of gravel-sized particles
2. **Chemical rocks**: Created from chemical precipitation
   a. Formed from materials in solution in bodies of water
   b. 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**
   a. Angular: Sediment has sharp corners and edges
   b. Rounded: Sediment has undergone abrasion and has rounded, smoothed edges
2. **Sizes**
   a. **Clay**: <1/256mm, creates mudstone
   b. **Silt**: Between 1/256 and 1/16 mm, creates siltstone
   c. **Sand**: Between 1/16 and 2 mm, creates sandstone
   d. **Pebble**: Between 2 and 64 mm, creates a conglomerate
   e. **Cobble**: Between 64 and 256 mm, creates a conglomerate
   f. **Boulder**: >256 mm, creates a conglomerate
3. **Sorting**
   a. Poorly-sorted: Particles of different sizes together, i.e., a glacier does not sort sediments
   b. Well-sorted: Particles of the same size together, i.e., a river sorts rocks from heaviest (upstream) to lightest (downstream)


Angular


Well-Rounded

D. **Properties of Sedimentary Rocks**

1. **Texture**
   a. **Clastic**: Made of transported sediments and deposition; observe particle size, shape of grain and how well-sorted
   b. **Bioclastic**: Remains of organic material
   c. **Crystalline**: Interlocking crystals of different sizes, considered dense if crystals are less than ¼ mm
   d. **Amorphous**: Dense, having no crystal structure
   e. **Oolitic**: Made of oolites, small round particles made of calcium carbonate
2. **Composition**: Possible matter found in sedimentary rocks
   a. *Carbonate*, test with HCl; **examples**: calcite and dolomite
   b. *Silica*; **examples**: quartz and chert
   c. *Clay minerals*; **examples**: kaolinite, silicate
   d. *Organic matter*; **examples**: plants, shells, bones
   e. *Evaporites*, minerals created from a solution; **example**: gypsum
   f. *Rock Particles*; **example**: conglomerates
   g. *Heavy Minerals*; **example**: garnet
   h. *Feldspar*, known as arkosic

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

1. **Stratification**: Distinct layers (strata or bed) formed from moving and depositing sediments
2. **Cross Bedding**: Stratification at an angle
3. **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
4. **Surface Impressions**: Impressions preserved in the bed
   a. ***Ripple Marks***: Marks preserved from flow in one direction (asymmetrical)
   b. ***Oscillation Marks***: Marks preserved from flow back and forth (symmetrical)
   c. ***Mud Cracks (Desiccation marks)***: Marks preserved from exposure to air
   d. ***Raindrop Impressions***: Marks preserved from rain
   e. ***Trace Fossils***: Marks preserved from the movement of animals


Poorly-Sorted


Well-Sorted


Sedimentary Rock: Durango, CO


Chert


Coquina


Dolomite


Shale


Sandstone


Limestone

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

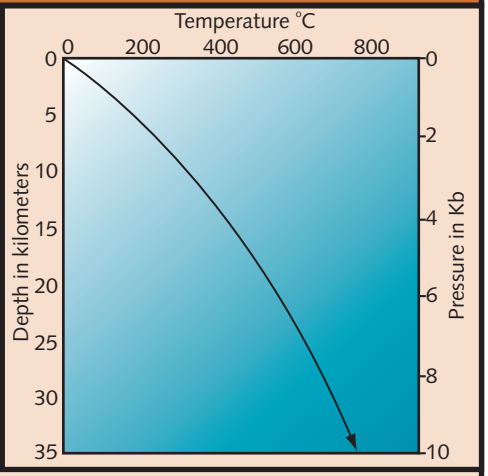
Name	Texture (of sediments)	General Description
Bituminous	coal bioclastic, dense	black, like soot
Chalk	bioclastic	white, will react w/HCl
Coquina	bioclastic	cemented shells
Diatomite	bioclastic	like chalk, no HCl reaction
Peat	bioclastic	plant material
Skeletal Limestone	bioclastic	shells, will react 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**
   a. Most important agent
   b. Provides energy for chemical reactions
   c. Created from igneous rock bodies movement through the existing rock
   d. Created from geothermal gradient, 25˚C increase in temperature with each kilometer increase in depth (geothermal gradient)
   e. For **example**, clay recrystallizes into feldspar and mica at high temperatures
2. **Pressure and Stresses**
   a. **Confining pressure**
      i. Equal pressure on all sides due to deep burial
      ii. Depth determines amount of pressure
      iii. 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
      iii. **Shear stress**: Stresses in opposite directions that cause the object to move parallel to the stress
3. **Chemical Activity**
   a. Change in atomic composition due to heat and/or pressure may cause crystal to recrystallize
   b. Water is the most common chemical agent

Geothermal Gradient

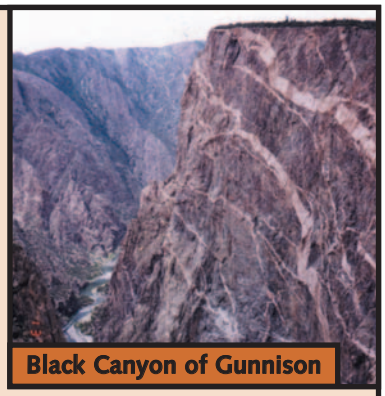


B. **Types of Metamorphism**
1. **Contact metamorphism**: Changes caused by proximity to magma or deep, hot rock
2. **Regional metamorphism**: Changes caused by intense stress and high temperatures
3. **Hydrothermal metamorphism**: Changes caused by hot liquids
4. **Fault Zone metamorphism**: Changes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

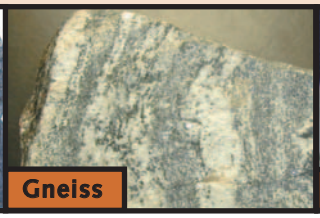
C. **Degrees of Metamorphism**
1. **Metamorphic grade**: Degree of metamorphism applied to rock
   a. **High-grade**: Very high amounts of heat and pressure; **example**: gneiss
   b. **Intermediate-grade**: Medium amounts of heat and pressure; **example**: schist
   c. **Low-grade**: Lower amounts of 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

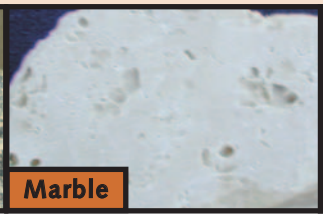
D. **Changes in Mineralogy**: Changes in texture or composition of the mineral due to heat and pressure
1. **Recrystallization**: Changed by smaller crystals joining to create larger crystals of the same mineral; common
2. **Neomorphism**: New minerals created from existing mineralogical compositions
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
   b. **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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