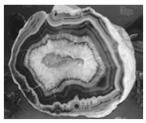
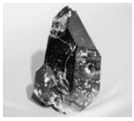
# Chapter 23

# Rocks and Minerals

## Five Characteristics of a Mineral

- A mineral is naturally occurring
- It is inorganic
- It is a crystalline solid
- A mineral has a definite chemical composition, with slight variations
- It has characteristic physical properties

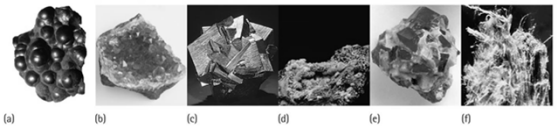




## Minerals

Some minerals can have *the same composition but a different crystal structure* (diamond and graphite).

- Such minerals are called polymorphs.
- A different crystal structure = different properties.



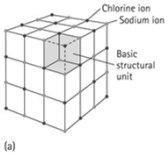

## Mineral Properties

Physical properties are an expression of chemical composition and internal crystal structure:

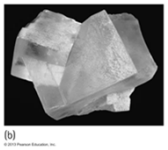
- Crystal form
- Hardness
- Cleavage and fracture
- Color / Streak / Luster
- Specific gravity

## Minerals Formed by Crystallization

Crystallization is the formation and growth of a solid from a liquid or gas.



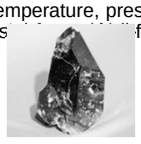

Atoms come together in specific chemical compositions and geometric arrangements.




## Mineral Properties: Crystal Form

Crystal form—crystal shape—is the outward expression of a mineral's internal arrangement of atoms.

- Internal atomic arrangement determined by atom (or ion) charge, size, and packing
- The conditions (temperature, pressure, space for growth) affect crys[illegible]formed minerals are rare in nature



## Mineral Properties: Hardness

- Hardness is the resistance of a mineral to scratching.
- Hardness is dependent on the strength of a mineral's chemical bonds - the stronger the bonds, the harder the mineral.

## Mineral Properties: Hardness

| Mineral | Hardness | Objects with Similar Hardness |
|---|---|---|
| Talc | 1 | |
| Gypsum | 2 | Fingernail = 2.5 |
| Calcite | 3 | Copper wire = 3.5 |
| Fluorite | 4 | |
| Apatite | 5 | Glass Plate = 5.5 |
| Orthoclase Feldspar | 6 | Knife or Steel File =6.5 |
| Quartz | 7 | |
| Topaz | 8 | |
| Corundum | 9 | |
| Diamond | 10 | |

## Mineral Properties: Cleavage and Fracture

Cleavage is the property of a mineral to break along planes of weakness.

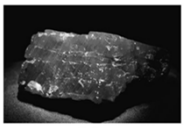
- Planes of weakness are determined by crystal structure and bond strength.

Fracture occurs in minerals where the bond strength is generally the same in all directions.

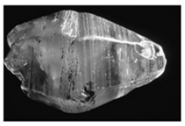
(b)

## Mineral Properties: Color

- Color is an obvious feature of many minerals, but it is *not reliable for mineral identification*.
- Color results from the interaction of light waves with the mineral.
- Very slight variations in composition or minor impurities can change a mineral's color.



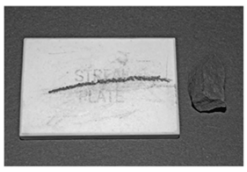
Ruby



Sapphire

## Mineral Properties: Color-Related Characteristics

- Streak is the color of a mineral in its powdered form.
- Mineral color may vary, but *streak color is generally constant*.

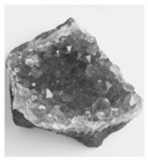


## Mineral Properties: Color-Related Characteristics

- Luster describes the way a mineral's surface reflects light.

(c)

Metallic

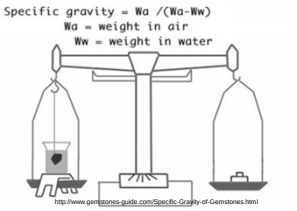


(b)

Nonmetallic

## Mineral Properties: Specific Gravity

- Specific gravity is the ratio of the weight of a substance to the weight of an equal volume of water.
- In simple terms, it is how heavy a mineral feels for its size (volume).



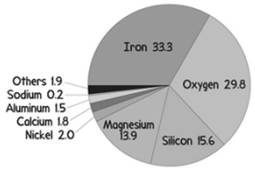

## Earth's Chemical Elements Are Distributed Unevenly

Earth's early molten (or nearly molten) state led to the differentiation and formation of Earth's layered structure.

- Differentiation is the separation of materials of differing densities.
- Earth's core concentrated heavier elements (iron & nickel).
- Earth's crust has lighter, silicon- and oxygen-rich material.

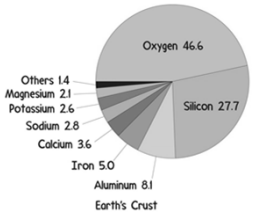
## Materials of the Earth

- There are over 100 chemical elements but only eight elements account for 98% of Earth's mass!

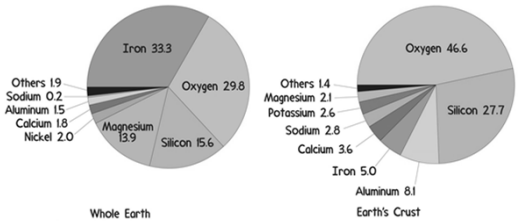



## Earth's Crust Is Composed of Lighter Elements

- Oxygen and silicon make up 75% of Earth's crust.



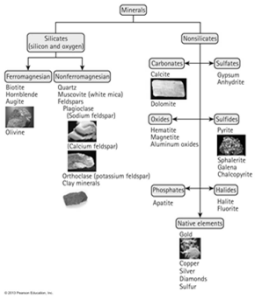

## Materials of the Earth




## Minerals Are Classified by Chemical Composition

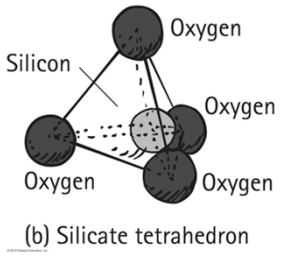
There are two major classes of minerals:

- Silicate minerals
- Nonsilicate minerals



## Silicate Minerals

All silicate minerals have the same fundamental structure of atoms—the silicate tetrahedron.



(b) Silicate tetrahedron

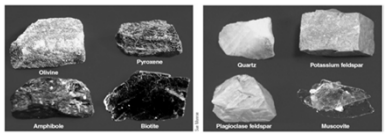
## Silicate Minerals

- Silicate minerals are the most common mineral group; they account for over 90% of Earth's crust.
- The abundance of silicate minerals is due to the abundance of oxygen and silicon.
- Silicate minerals are made up of silicon (Si) and oxygen (O) atoms, possibly along with other elements (Al, Na, Ca, K, Mg, Fe, Mn, and Ti).

## Silicate Minerals

The silicates are divided into two groups:

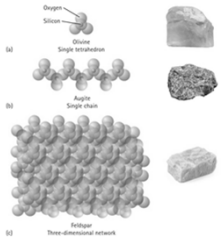
- Ferromagnesian silicates (darker, denser, contain iron and/or magnesium)
- Nonferromagnesian silicates (lighter, less dense, contain no iron or magnesium)




## Silicate Minerals

Tetrahedra can form as single units or as links with a variety of structural configurations:

- Single chains
- Double chains
- Sheets



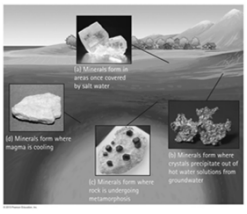

## Nonsilicate Minerals

Nonsilicate minerals make up about 8% of Earth's crust.

- Carbonate minerals (calcite, dolomite)
- Oxide minerals (hematite, magnetite, chromite)
- Sulfide minerals (pyrite, galena)
- Sulfate minerals (barite, anhydrate, gypsum)
- Native elements (gold, platinum, iron)

## Formation of Minerals

- Crystallization from cooling magma
- Precipitation from hydrothermal solutions
- Evaporation of surface water
- Recrystallization of preexisting minerals



## Crystallization in Magma

Minerals crystallize systematically based on their respective melting points.

- The first minerals to crystallize from magma are those with the highest melting point.
- The last minerals to crystallize from magma are those with lower melting points.

## Precipitation from Water Solutions

- Water solutions contain many dissolved mineral constituents.
- As water solutions become chemically saturated, minerals precipitate.
- Water solutions account for many important ore deposits that are deposited into cracks or into the matrix of the rock itself.

## Minerals from Evaporation and Temperature/Pressure Changes

- Evaporite minerals, including halite, are formed by the evaporation of surface water containing dissolved substances.
- Minerals such as diamond are formed by the recrystallization of preexisting minerals caused by temperature and/or pressure changes.


## Rocks

A rock is an aggregate of minerals. There are three categories of rock:

- Igneous: formed from cooling and crystallization of magma or lava
- Sedimentary: formed from preexisting rocks subjected to weathering and erosion
- Metamorphic: formed from preexisting rock transformed by heat, pressure, or chemical fluids

## Igneous Rock

Igneous rocks are formed from the cooling and crystallization of magma or lava.

- Magma is molten rock that forms inside Earth.
- Lava is molten rock (magma) erupted at Earth's surface.

## Origin of Magma

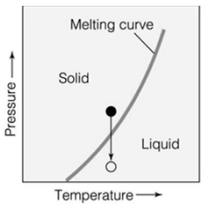
Role of heat

- The temperature increases within Earth's upper crust—the geothermal gradient—at an average of 30°C per kilometer.
- Rocks in the lower crust and upper mantle are near their melting points, so any additional heat may help to induce melting.

## Origin of Magma

Role of pressure

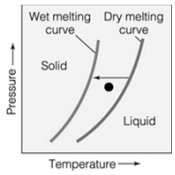
- Reduced pressure lowers the melting temperature of rock causing decompression melting occurs.
- Analogies and examples: A pressure cooker




## Origin of Magma

Role of fluids

- Fluids (primarily water) cause rocks to melt at lower temperatures; particularly important where oceanic lithosphere descends into the mantle.
- Analogies: Salt on icy roads




## Summing Up: Three Factors of Magma Formation

- Temperature: added heat can cause melting
- Pressure: decreases in pressure can induce melting
- Addition of fluids: release of fluids from water-rich minerals lower the melting point

## Magma to Igneous Rock

- The mineral makeup of igneous rock is dependent on the chemical composition of the magma from which it crystallizes.
- There are three types of magma:
  - Basaltic = “mafic”
  - Andesitic = “intermediate”
  - Granitic = “felsic”

## Igneous Rock

Basaltic / Mafic rock

- Composed of dark, dense silicate minerals
- Comprises the ocean floor as well as many volcanic islands
- Makes up 80% of igneous rocks in crust

## Igneous Rock

Andesitic / Intermediate rock

- Composed of dark and light silicate minerals with intermediate density
- Continental rock gets its name from the Andes Mountains
- Makes up 10% of igneous rocks in the crust

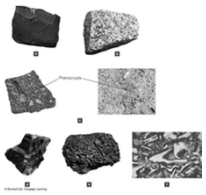
## Igneous Rock

Granitic / Felsic rock

- Composed of light-colored silicates
- Major constituents of continental crust
- Makes up 10% of igneous rocks in the crust


## Igneous Rock

- Rocks formed from magma that crystallizes at depth are termed intrusive, or plutonic, rocks.
- Rocks formed from lava at the surface are classified as extrusive, or volcanic, rocks.



## Igneous Rocks Are Classified by Their Texture

Rate of cooling determines crystal size.

- Slow rate promotes the growth of fewer but larger crystals (coarse-grained).
- Fast rate forms many small crystals (fine-grained).
- Very fast rate forms glass (i.e., no crystals).


Slow


Fast

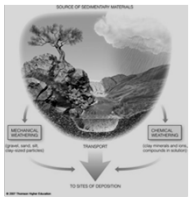

Very Fast

## Sedimentary Rocks

- Sedimentary rocks are products of mechanical and chemical weathering and erosion.
- They blanket about 75% of Earth's surface and account for 5% (by volume) of Earth's crust.
- They contain evidence of past environments and often contain fossils.

## Formation of Sedimentary Rocks

- Weathering is the physical breakdown and chemical alteration of rock at or near Earth's surface.
  - Mechanical weathering—breaking and disintegration of rocks into smaller pieces
  - Chemical weathering—chemical decomposition and transformation of rock into one or more new compounds




## Mechanical Weathering

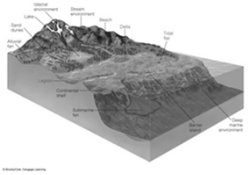
- Frost wedging—alternate freezing and thawing of water in fractures and cracks promotes the disintegration of rocks.
- Thermal expansion—alternate expansion and contraction due to heating and cooling.
- Biological activity—disintegration resulting from plants and animals.


## Chemical Weathering

- Breaks down rock components and the internal structures of minerals.
- Most important agent involved in chemical weathering is **water**, which is responsible for transport of ions and molecules

## Formation of Sedimentary Rocks

- Erosion is the physical removal of material by mobile agents such as water, wind, ice, or gravity.
- Transportation: As sediment is transported, it continues to weather and erode. Particle size decreases and edges are rounded off.
- Deposition occurs when eroded sediment comes to rest.



## Formation of Sedimentary Rocks

- Sediment particles are deposited horizontally layer by layer, turning into rock as it accumulates.
- Lithification occurs in two steps:
  - Compaction
  - Cementation

## Formation of Sedimentary Rocks

- Compaction—Weight of the overlying material presses down on deeper layers
- Cementation—Compaction releases "pore water" rich in dissolved minerals that act as a cement to hold particles together

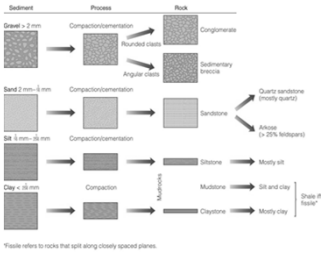
## Classifying Sedimentary Rock

Rock types are based on the source of the material:

- Clastic or "detrital" rocks are formed from transported sediment particles (bits and pieces of weathered rock).
- Chemical rocks are formed by sediments that were once in solution.

## Classifying Sedimentary Rock

- Chief constituents of clastic rocks are clay minerals, quartz, feldspars, and micas
- Particle size is used to name detrital (clastic) rocks.



## Classifying Sedimentary Rock

- Chemical sedimentary rocks consist of precipitated material that was once in solution.
- Precipitation of material occurs in two ways: Inorganic or organic processes (biochemical origin)

## Chemical Sedimentary Rocks

Limestone

- is the most abundant chemical rock and is composed chiefly of the mineral calcite.
- marine biochemical varieties form from coral reefs, broken shells (coquina), and layers of microscopic organisms (chalk)
- inorganic limestone include travertine

## Chemical Sedimentary Rocks

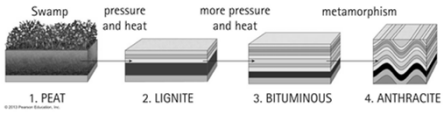
Evaporites

- Evaporation triggers the deposition of chemical precipitates
- Examples include rock salt and rock gypsum.

## Chemical Sedimentary Rock

Coal: different from other rocks because it is composed of *organic material*.

- Stages in coal formation (in order): plant material, peat, lignite, bituminous coal, anthracite coal




## Metamorphic Rocks

- Metamorphism is the transition of one rock into another by temperatures or pressures different from those in which it formed.
- Metamorphic rocks are produced from:
  - Igneous rocks
  - Sedimentary rocks
  - Other metamorphic rocks

## Agents of Metamorphism

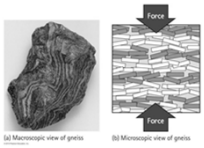
Heat is the most important agent, producing recrystallization results in new, stable minerals.

- Two sources of heat:
  - Heat from magma (contact metamorphism)
  - An increase in temperature with depth due to the geothermal gradient (burial metamorphism)

## Agents of Metamorphism

Pressure (stress) increases with depth

- Two types of pressure:
  - Confining pressure applies forces equally in all directions.
  - Differential pressure applies unequal forces in different directions (leads to foliation)



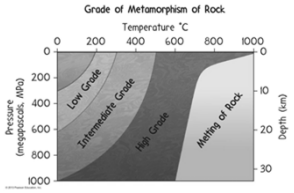

## Agents of Metamorphism

Chemically active fluids (mainly water) enhance the migration of ions and aid in the recrystallization of existing minerals.

- Sources of fluids:
  - Pore spaces of sedimentary rocks
  - Fractures in igneous rocks
  - Hydrated minerals such as clays and micas

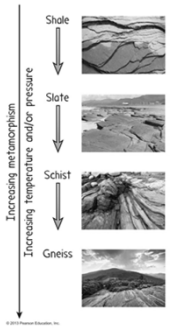
## Metamorphic Rocks

- During metamorphism, the rock remains solid but undergo recrystallization or deformation
- Metamorphism progresses from low grade to high grade (grade refers to the extent of metamorphism)



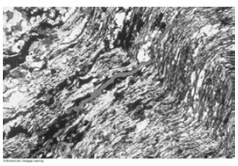

## Metamorphic Rocks

- Variations in the mineralogy and the textures = variations in the degree of metamorphism.
- Changes in mineralogy occur between low-grade metamorphism to high-grade metamorphism.




## Metamorphic Texture

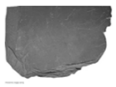
- Texture refers to the size, shape, and arrangement of grains within a rock.
- *Foliation* is any planar arrangement of mineral grains or structural features within a rock.
  - Platy, layered minerals have a parallel alignment oriented perpendicular to applied stress.

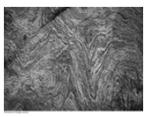
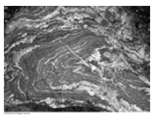


## Metamorphic Rocks

Common foliated metamorphic rocks (from low grade to high grade):

- Slate
- Schist
- Gneiss
- Migmatite

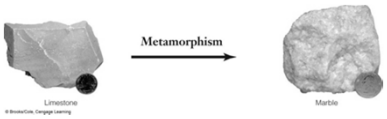


## Metamorphic Texture

Metamorphic rocks that lack foliation are referred to as nonfoliated

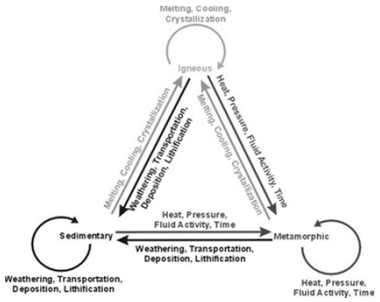
- Develop in environments where deformation is minimal and are typically composed of one type of mineral




## The Rock Cycle

- The rock cycle is one among many cycles in nature.
- Rock forms from preexisting rock.
- Any type of rock can become different types, even a new rock of the same type!
- There are many different paths around the rock cycle.

## The Rock Cycle




## Reading the Rock Record

- Radiometric dating and fossils reveal ages of rock.
- Sedimentary rock type reveals much about geologic events that occurred where and when the rock formed.