Hewitt/Lyons/Suchocki/Yeh

Conceptual Integrated Science

Chapter 23

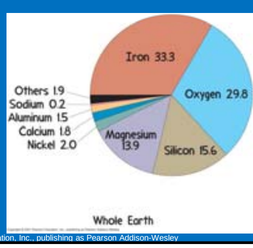
ROCKS AND MINERALS

This lecture will help you understand:

- Materials of the Earth
- Mineral Properties
- Formation of Minerals
- How Minerals Are Classified
- Silicate Minerals
- Nonsilicate Minerals
- Igneous Rocks
- Sedimentary Rocks
- Metamorphic Rocks

Materials of the Earth

- There are 112 naturally occurring chemical elements.
- Eight elements account for 98% of Earth's mass.

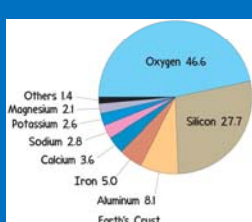


Earth's Chemical Elements Are Distributed Unevenly

- Earth's early molten (or nearly molten) state led to differentiation and formation of Earth's layered structure.
  - —Differentiation: the separation of materials of differing densities
  - —Heaviest elements were concentrated at Earth's core, which is composed of dense, iron-rich material
  - —Lighter elements migrated toward Earth's surface
- Crust is composed of lighter, silicon- and oxygen-rich material

Earth's Crust Is Composed of Lighter Elements

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



Five Characteristics of a Mineral

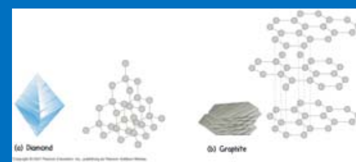
- A mineral is naturally occurring (formed naturally rather than manufactured).
- It is a crystalline solid.
- A mineral has a definite chemical composition, with slight variations.
- It is inorganic.
- It has definite physical properties, a consequence of the atoms and their arrangement.

Minerals Are Formed by the Process of 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.
  - —The combination of chemical composition and arrangement of atoms in an internal structure makes each mineral unique.

Minerals

- Some minerals can have the same composition but have a different crystal structure.
  - —Different arrangements of the same atoms result in different minerals.
    - Diamond and graphite are two examples
  - —Such minerals are called polymorphs.
  - —With a different crystal structure, the minerals will have different properties.



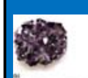
Mineral Properties

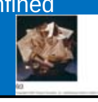
- Physical properties are an expression of chemical composition and internal crystal structure:
  - —Crystal form
  - —Hardness
  - —Cleavage and fracture
  - —Color & Streak
  - —Specific gravity

Crystal Form

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

- Internal atomic arrangement is determined by atom/ion charge, size, and packing.
- The conditions in which the crystal grows also affect crystal form.
  - —Temperature, pressure, space for growth
- Well-formed minerals are rare in nature—most minerals grow in cramped confined spaces.





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.
- Bond strength is determined by ionic charge, atom (or ion) size, and packing.
  - —Charge—the greater the attraction, the stronger the bond.
  - —Size and packing—small atoms pack more closely, resulting in a smaller distance between atoms, increasing the attractive forces and thus yielding a stronger bond.

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.
  - Minerals break along planes where bond strength is weakest.
- Fracture occurs in minerals where bond strength is generally the same in all directions.
  - Minerals that fracture do not exhibit cleavage.

Color

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

Color-Related Characteristics

- Streak is the color of a mineral in its powdered form.
  - —Powder produced by rubbing against an unglazed porcelain plate—a streak plate.
  - —Mineral color may vary, but streak color is generally constant.
- Luster describes the way a mineral's surface reflects light. There are two types of luster—metallic and nonmetallic.

http://www.championjewelery.us/

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).

Formation of Minerals

Minerals form by the process of crystallization.

- Minerals crystallize from two primary sources:
  - —Magma
  - —Water solutions

Crystallization in Magma

Magma is molten rock, which forms inside Earth.

- Minerals crystallize systematically based on their respective melting points.
  - —The first minerals to crystallize from a magma are those with the highest melting point.
  - —The last minerals to crystallize from a magma are those with lower melting points.

http://www.nuuanu.k12.hi.us/g-1/public_html/websites/lance/index.html

Crystallization in Water Solutions

- Water solutions contain many dissolved mineral constituents.
- As water solutions become chemically saturated, minerals precipitate.
- Water solutions associated with later stages of crystallization from a magma account for many important ore deposits.
  - —Ore deposits can be deposited into cracks or into the matrix of the rock itself.

Crystallization in Water Solutions

- Water solutions can precipitate chemical sediments such as carbonates and evaporites.
- For chemical sediments, solubility rather than melting point determines which minerals will form first.
  - —Low-solubility minerals precipitate first.
    - Minerals that are not easily dissolved
  - —High-solubility minerals precipitate last.
    - Minerals that dissolve easily

Minerals Are Classified by Chemical Composition

- There are two classifications of minerals:
  - —Silicate minerals
  - —Nonsilicate minerals

Silicate Minerals

- Silicate minerals are made up of silicon (Si) and oxygen (O) atoms, along with other elements (Al, Mg, Fe, Mn, and Ti).
- 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.
  - —Oxygen is the most abundant element.
  - —Silicon is the second most abundant element.

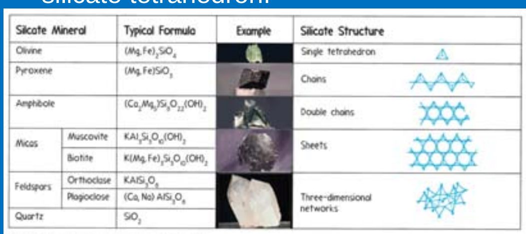
Silicate Minerals

The Silicates are divided into two groups:

- Ferromagnesian silicates
  - —Contain iron and/or magnesium
  - —Tend to have high density and are darkly colored
- Nonferromagnesian silicates
  - —No iron or magnesium
  - —Tend to have low density and are light in color

Silicate Minerals

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

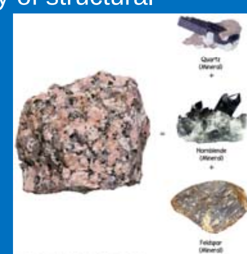


Silicate Mineral		Typical Formula	Example	Silicate Structure
Olivine		$(Mg,Fe)_2SiO_4$		Single tetrahedron
Pyroxene		$(Mg,Fe)SiO_3$		Chains
Amphibole		$(Ca_2Mg_5)Si_8O_{22}(OH)_2$		Double chains
Micas	Muscovite	$KAl_3Si_3O_{10}(OH)_2$		Sheets
	Biotite	$K(Mg,Fe)_3Si_3O_{10}(OH)_2$		
Feldspars	Orthoclase	$KAlSi_3O_8$		Three-dimensional networks
	Plagioclase	$(Ca,Na)AlSi_3O_8$		
Quartz		SiO_2		

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
  - Ore minerals—hematite, magnetite, chromite
- Sulfide minerals
  - Ore minerals—pyrite, galena
- Sulfate minerals
  - Barite, anhydrate, gypsum
- Native elements
  - Gold, platinum, iron

Rocks

A rock is a coherent aggregate of minerals—a physical mixture.

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:
  - —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.
  - —Any additional heat (from rocks descending into the mantle or rising heat from the mantle) may help to induce melting.

Origin of Magma

- Role of pressure:
  - —Reduced pressure lowers the melting temperature of rock.
  - —When confining pressures drop, decompression melting occurs.
- Analogies and examples:
  - —The solid inner core
  - —A pressure cooker

Origin of Magma

- Role of fluids (volatiles)
  - —Fluids (primarily water) cause rocks to melt at lower temperatures.
  - —This is particularly important where oceanic lithosphere descends into the mantle.
- Analogies
  - —Salt on icy roads
  - —Antifreeze in a car's radiator

Summing Up: Three Factors of Magma Formation

- Temperature
  - —Added heat can cause melting—minor player
- Pressure increases with depth, but
  - —Convective motion in the mantle allows rock to rise upward, reducing the pressure enough to lower the melting point and induce melting.
- Addition of water to rock
  - —As rock is dragged downward during subduction, water-rich fluids are released and migrate upward.
  - —Fluids lower the melting point of overlying rock, allowing partial melting and magma generation.

Magma to Igneous Rock

The mineral makeup of igneous rock is dependent on the chemical composition of the magma from which it crystallizes.

- Three types of magma:
  - – Basaltic / Mafic
  - – Andesitic / Intermediate
  - – Granitic / Felsic

Igneous Rock

- Basaltic / Mafic rock
  - —Composed of dark silicate minerals
  - —Dense
  - —Comprise the ocean floor as well as many volcanic islands
  - —Of all igneous rocks at crust, 80% have basaltic origin.

Igneous Rock

- Andesitic / Intermediate rock
  - —Composed of dark and light silicate minerals
  - —Intermediate density
  - —Continental rock, gets its name from the Andes Mountains
  - —Of all igneous rocks at crust, 10% have andesitic origin.

Igneous Rock

- Granitic / Felsic rock
  - —Composed of light-colored silicates
  - —Designated as being felsic (feldspar and silica) in composition
  - —Major constituents of continental crust
  - —Of all igneous rocks in crust, 10% have granitic origin.

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).

Sedimentary Rocks

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

Sedimentary Rocks

- Weathering—the physical breakdown and chemical alteration of rock at or near Earth's surface.
- Two types of weathering:
  - —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.

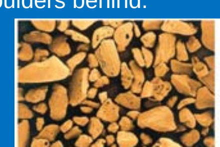
Chemical Weathering

- Main producer of sediment.
- Breaks down rock components and the internal structures of minerals.
- Most important agent involved in chemical weathering is water.
  - —responsible for transport of ions and molecules involved in chemical processes

Chemical Weathering

Spheroidal weathering (rock weathered into rounded shapes) results as rainwater chemically weathers the outer layers of rock. Once weathered, rainwater erodes the rock by washing away the weakened outer layers and leaving rounded boulders behind.

(a) Well-sorted sediments



(b) Poorly sorted sediments

Sedimentary Rocks

- Erosion—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.

Sedimentation

- During sedimentation, sediment particles are deposited horizontally layer by layer.
- As deposited sediment accumulates, it lithifies—changes into sedimentary rock.
- Lithification occurs in two steps:
  - —Compaction
  - —Cementation

Sedimentation

- Compaction—Weight of overlying material presses down upon deeper layers.
  - —Sediment particles compact and squeeze together.
- Cementation—Compaction releases "pore water" rich in dissolved minerals.
  - —This mineralized "pore water" acts as a glue to cement sediment particles together

Classifying Sedimentary Rock

- Rock types are based on the source of the material:
  - —Detrital rocks—transported sediment particles—bits and pieces of weathered rock
  - —Chemical rocks—sediments that were once in solution

Classifying Sedimentary Rock

Chief constituents of detrital rocks include:

- —Clay minerals
- —Quartz
- —Feldspars
- —Micas

- Particle size is used to distinguish among the various types of detrital rocks.

Common Detrital Sedimentary Rocks (in order of increasing particle size)

Shale
- Mud-sized particles in thin layers
- Most common sedimentary rock

Sandstone
- Composed of sand-sized particles
- Quartz is the predominant mineral

Conglomerates
- Composed of particles greater than 2 mm in diameter
- Consists largely of rounded gravels

Classifying Sedimentary Rock

Chemical sedimentary rocks consist of precipitated material that was once in solution.

- Precipitation of material occurs in two ways:
  - —Inorganic processes
  - —Organic processes (biochemical origin)

Chemical Sedimentary Rocks

Limestone:

- —Most abundant chemical rock.
- —Composed chiefly of the mineral calcite.
- —Marine biochemical limestones form as coral reefs, coquina (broken shells), and chalk (microscopic organisms).
- —Inorganic types of limestone include travertine
  - Found in caves, caverns, and hot springs

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

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

Agents of Metamorphism

- Heat is the most important agent.
  - —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
  - —Confining pressure applies forces equally in all directions
  - —Rocks may also be subjected to differential stress—unequal stress in different directions
    - Leads to foliation

Agents of Metamorphism

- Chemically active fluids (mainly water):
  - —Enhance migration of ions
  - —Aid in 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

- Metamorphism progresses from low grade to high grade.
  - —Grade refers to extent of metamorphism.
- During metamorphism, the rock remains essentially solid.
  - —Rocks do not melt (melting implies igneous activity).
  - —Rocks may undergo recrystallization or mechanical deformation.

Metamorphic Rocks

- Variations in the mineralogy and the textures of metamorphic rocks are related to the variations in the degree of metamorphism.
- Changes in mineralogy occur from regions of low-grade metamorphism to regions of high-grade metamorphism.

Metamorphic Texture

Texture refers to the size, shape, and arrangement of grains within a rock.

- *Foliation*—any planar arrangement of mineral grains or structural features within a rock.
  - —Parallel alignment of platy, layered minerals.
  - —Minerals get oriented perpendicular to applied stress.
  - —Examples of foliated rocks:
    - Schist
    - Gneiss

Metamorphic Texture

- Metamorphic rocks that lack foliation are referred to as nonfoliated.
  - —Develop in environments where deformation is minimal .
  - —Typically composed of one type of mineral.
  - —Examples of nonfoliated rocks:
    - Marble
    - Quartzite

Metamorphic Rocks

- Common metamorphic rocks from low grade to high grade:
  - —Slate
  - —Schist
  - —Gneiss
  - —Migmatite