1 **Matter and Minerals**

<u>Earth</u>
Chapter 3

2 ***Chapter 3 – Matter & Minerals***

3 **Figure 3.1**

4 **Minerals: Building Blocks of Rocks**

- Geologic Definition of a Mineral:
  - Naturally occurring
  - Generally inorganic
  - Solid substance
  - Orderly crystalline structure
  - Definite chemical composition
    - (that allows for some variation)
- Definition of a Rock:
  - A solid mass of minerals or mineral-like matter that occurs naturally
    - Minerals are joined together in such a way that their individual properties are retained.

5 **Atoms: Building Blocks of Minerals**

- Atoms
  - Smallest particles of matter that cannot be chemically split
  - Composed of:
    - Protons: charge of +1
    - Neutrons: charge of 0
    - Surrounded by electrons: charge of –1
  - Electrons exist as a cloud of negative charges surrounding the nucleus of protons and neutrons, occurring in regions called *principal shells.*
  - The outermost shell contains valence electrons, which interact with other atoms to form chemical bonds.

6 **The Atom**

7 **Atoms: Building Blocks of Minerals**

- Atomic Number
  - The number of protons in the nucleus of an atom
  - Determines the atom's chemical nature
- Element
  - A group of the same kind of atoms
  - Approximately 90 natural elements and several synthesized in a laboratory
  - Organized in the periodic table so that those with similar properties line up
  - Most elements join with other elements to form chemical compounds

8 **The Periodic Table**

9 **The Periodic Table (updated)**

10 **Why Atoms Bond**

- Chemical Bonding
  - Transferring or sharing electrons allows atoms to attain a full valence shell of electrons
    - Lowers total energy of bonded atoms
    - Makes them more stable
  - Octet Rule
    - Atoms tend to gain, lose, or share electrons until they are surrounded by eight valence electrons
  - Most minerals are chemical compounds of composed of atoms of two or more elements.
    -

11 **Ionic Bonding**

- Ionic Bonding

- Atoms gain or lose outermost (valence) electrons to form ions (positively and negatively charged atoms).
- Ionic compounds consist of an orderly arrangement of oppositely charged ions.
- Ionic bond: the attraction of oppositely charged ions to one another
- Example:
  - Halite (table salt)—NaCl
  -
  -

12 **Halite (NaCl)—An Example of Ionic Bonding**

13 **Covalent Bonding**

- Covalent Bonding
  - Atoms share one or more valence electrons
  - Attraction between oppositely charged particles:
    - Positively charged protons
    - Negatively charged electrons

14 **Covalent Bonding**

15 **Other Types of Bonding**

- Metallic Bonding
  - Valence electrons are free to migrate among atoms
  - Accounts for the high electrical conductivity of metals
  -
- Hybrid Bonds
  - Many chemical bonds are actually hybrids that exhibit some degree of electron sharing and some degree of electron transfer.
  - Silicate minerals are comprised of hybrid bonds

16 **How Do Minerals Form?**

- Precipitation of Mineral Matter
  - Ions dissolved in an aqueous solution reach saturation and start forming crystalline solids
    - Drop in temperature or water lost through evaporation brings solution closer to saturation
    - Once saturation is reached, ions begin to bond, forming crystalline solids
    - *Evaporite deposits* (salts)
  - Minerals can precipitate from slowly moving groundwater filling fractures and voids.
    - *Geodes*

17 **How Do Minerals Form?**

18 **How Do Minerals Form?**

- Crystallization of Molten Rock
  - Similar to water freezing
  - When the magma is hot, the atoms are mobile, when the magma cools, the atoms slow and begin to chemically combine.
  - Generates a mosaic of intergrown crystals
- Deposition as a Result of Biological Processes
  - Marine organisms use calcium or silica from seawater and secrete external skeletons composed of calcium carbonate ($CaCO_3$) or silica.
    - Corals and mollusks use Ca
    - Diatoms and radiolarians use Si

19 **How Do Minerals Form?**

20 **How Do Minerals Form?**

21 **Properties of Minerals**

- Definite crystalline structure and chemical composition of minerals give them unique physical and chemical properties.
- Primary diagnostic properties
  - Determined by observation or performing a simple test
  - Several physical properties are used to identify hand samples of minerals.

22 **Properties of Minerals**

- Optical Properties
  - Luster
    - Appearance of a mineral in reflected light
  - Two basic categories:
    - Metallic
    - Nonmetallic
      - Vitreous or glassy luster
      - Dull or earthy luster
      - Pearly luster
      - Silky luster
      - Greasy luster

23 **Submetallic and Metallic Luster of Galena (PbS)**

24 **Properties of Minerals**

- Optical Properties
  - Ability to Transmit Light
    - Opaque – no light is transmitted
    - Translucent – light, but no image is transmitted
    - Transparent – light and an image are visible through the sample
  - Color
    - Generally unreliable for mineral identification
    - Often highly variable due to impurities or slight changes in mineral chemistry

25 **Color Variations in Minerals**

26 **Properties of Minerals**

- Optical Properties
  - Streak
    - Color of a mineral in its powdered form
    - Obtained by rubbing mineral across a porcelain *streak plate.*
    - Not every mineral produces a streak when rubbed across a streak plate.
    - Although a mineral’s color may vary, its streak is usually consistent in color.

27 **Streak Is Obtained on an Unglazed Porcelain Plate**

28 **Properties of Minerals**

- Crystal Shape, or Habit
  - Characteristic shape of a crystal or aggregate of crystals
  - Minerals tend to have one common crystal shape, but a few have two or more characteristic shapes.

29 **Common Crystal Habits**

30 **Properties of Minerals**

- Mineral Strength
  - How easily minerals break or deform under stress
  - Hardness
    - Resistance of a mineral to abrasion or scratching
    - All minerals are compared to a standard scale called the Mohs scale of hardness.

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32 **Properties of Minerals**

- Mineral Strength
  - Cleavage
    - Tendency to break (cleave) along planes of weak bonding
    - Produces smooth, flat surfaces
    - Described by:
      - Number of planes
      - Angles between adjacent planes
      - Resulting geometric shapes
  - Fracture
    - Minerals with equally strong bonds have an absence of cleavage
      - *Irregular fractures*
      - *Conchoidal fractures*
      - *Splintery fractures*
      - *Fibrous fractures*

33 **Properties of Minerals**

34 **Properties of Minerals**

35 **Properties of Minerals**

36 **Properties of Minerals**

- Mineral Strength
  - Tenacity
    - The mineral's resistance to breaking or deforming
      - *Brittle* minerals (such as those with ionic bonds) will shatter into small pieces.
      - *Malleable* minerals (such as those with metallic bonds) are easily hammered into different shapes.
      - *Sectile* minerals, such as gypsum and talc, can be cut into thin shavings.
      - *Elastic* minerals, such as the micas, will bend and snap back to their original shape.

37 **Properties of Minerals**

- Density and Specific Gravity
  - Density is defined as mass per unit volume
  - Specific gravity is a related measure and more frequently used by mineralogists
    - *The ratio of the weight of a mineral to the weight of an equal volume of water*
    - Most have a specific gravity between 2 and 3
    - Metallic minerals can have more than twice that specific gravity
      - The specific gravity of galena (PbS) is 7.5 and 24 karat gold is 20!

38 **Properties of Minerals**

- Other Properties of Minerals:
  - Taste
    - Halite tastes like salt
  - Feel
    - Talc feels soapy, graphite feels greasy
  - Stinky streak
    - Sulfur-bearing minerals have streaks that smell like rotten eggs
  - Magnetism
    - Magnets pick up magnetite, lodestone is a natural magnet
  - *Double refraction*
    - Transparent calcite
  - Effervescence
    - Carbonates fizz in reaction to dilute hydrochloric acid
    -

39 **Rock Salt (halite, NaCl)**

40 **Properties of Minerals**

41 **Properties of Minerals**

42 **Mineral Structures and Compositions**

- All mineral samples are crystals or crystalline solids
  - Any natural solid with orderly, repeating internal structures.
- Mineral Structures
  - Atomic arrangement that results in the basic building blocks of a mineral crystal, called unit cells.

43 **Mineral Structures and Compositions**

44 **Mineral Structures and Compositions**

- Unit cells combine to form mineral crystals
  - Two minerals can be constructed of geometrically similar building blocks and exhibit different crystal forms.
  - Examples of minerals with cubic unit cells include:
    - Fluorite – crystals are cubes
    - Magnetite – crystals are octahedrons
    - Garnets – crystals are dodecahedrons
  -
-

45 **Cubic Unit Cells**

46 **Mineral Structures and Compositions**

- Steno's Law
  - Law of Constancy of Interfacial Angles
    - Regardless of crystal size, the angles between equivalent crystal faces of the same mineral are consistent.
    - Observation first made by Nicolas Steno in 1669

47 **Mineral Structures and Compositions**

- Compositional Variations in Minerals
  - Ions of similar size can substitute for one another without disrupting the mineral's internal framework.
  - Some minerals have substantially different chemical composition:
    - E.g. olivine: $(Mg, Fe)SiO_2$
  - Other minerals only have trace elements that differ in their chemical composition:
    - E.g. quartz (SiO_2) and Fluorite (CaF_2)
    - Trace elements can significantly influence mineral color

48 **Mineral Structures and Compositions**

- Structural Variations in Minerals
  - Polymorphs
    - Minerals with identical composition but different crystalline structures.
    - Examples include diamond and graphite made entirely of carbon atoms.
- Transforming one polymorph into another is called a phase change.

49 **Diamond Versus Graphite—Polymorphs of Carbon**

50 **Mineral Groups**

- Nearly 4000 minerals have been named
- Rock-forming minerals
  - Only a few dozen
  - Common minerals that make up most of the rocks of Earth's crust
  - Composed mainly of the eight elements that make up most of the continental crust
- Economic minerals
  - Less abundant
  - Minerals used extensively in the manufacture of products
- Not always mutually exclusive groups (e.g., Calcite)

51 **The Eight Most Abundant Elements in the Continental Crust**

- The eight elements that make up the vast majority of rock-forming minerals represent more than 98% (by weight) of the continental crust!

52 **Mineral Groups**

- Classifying Minerals
  - A collection of specimens that exhibit similar internal structure and chemical compositions are called mineral species.
  - Mineral species can be further divided into mineral varieties
    - For example, varieties of quartz
      - Smoky quartz: contains trace amounts of aluminum
      - Amethyst: contains trace amounts of iron
- Mineral species are assigned to mineral classes
  - Silicates, carbonates, halides, and sulfates are different mineral classes.

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54 **Mineral Groups**

- Silicate Versus Nonsilicate Minerals
  - Silicate minerals are the most common type of minerals (more than 800 known silicates).
    - Account for >90% of Earth's crust
    - Silicon and oxygen make up the basic building blocks of silicate minerals
  - Nonsilicate minerals are not as common as the silicates but important economically and include the.
    - Carbonates
    - Sulfates
    - Halides

55 **The Silicates**

- All silicate minerals contain oxygen and silicon: the two most abundant elements in Earth's crust.
- Silicate Structures
  - Silicon–oxygen tetrahedron
    - Fundamental building block
    - Four oxygen ions surrounding a much smaller silicon ion
  - Single tetrahedra are linked together to form various structures.

56 **The Silicates**

- Silicate minerals with independent tetrahedra
  - One of the simplest silicate structures
  - Oxygen ions are bonded with positive ions (such as Mg^{2+}, Fe^{2+}, Ca^{2+})
    - Olivine $(Mg, Fe)_2SiO_4$
    - Garnet
  - Form hard, dense equidimensional crystals that lack cleavage

57 **The Silicates**

- SiO_4 tetrahedra can link to one another in a variety of configurations.
  - Called polymerization
  - Accounts for the high variety of silicate minerals
  - Polymerization is achieved by sharing one, two, three or all four oxygen atoms with adjacent tetrahedra.
- Tetrahedra can then form single chains, double chains, sheet structures, or three-dimensional frameworks.

58

59 **The Silicates**

- Silicate minerals with three-dimensional framework
  - All oxygen ions are "shared" between tetrahedra
  - The most common silicate structure
  - Examples include:

- Quartz
- The feldspars

60 **The Silicates**

- Joining Silicate Structures
  - Most silicate structures have a net negative charge (except for quartz).
  - Positive metal ions are required to balance the charge.
  - These positive ions bond with unshared oxygen ions in the tetrahedra.
    - Most common ions are Fe^{2+}, Mg^{2+}, K^{+}, Na^{+}, Al^{3+}, Ca^{2+}

61 **The Silicates**

- Joining silicate structures
  - Covalent silicon–oxygen bonds are typically stronger than the ionic bonds of the silicate structure.
  - Controls the cleavage and hardness of minerals
    - Examples:
      - Quartz has a three-dimensional framework, is very hard, and lacks cleavage.
      - Talc has a sheet structure framework bonded with Mg ions and is a very soft mineral.

62 **Common Silicate Minerals**

- Most silicates form from molten rock cooling and crystallizing
  - The feldspars are the most common silicate group and make up more than 50% of Earth's crust.
  - Quartz is the second-most abundant mineral in the continental crust and the only common mineral made completely of silicon and oxygen.
- Silicates are subdivided into light (non-ferromagnesian) and dark (ferromagnesian) groups.

63 **Common Silicate Minerals**

64 **Common Silicate Minerals**

- Light (Nonferromagnesian) Silicates
  - Generally light in color
  - Specific gravity of approximately 2.7
  - Contain varying amounts of Al, K, Ca, and Na
  - Lack Fe and Mg
- Feldspar Group
  - Most common mineral group
  - Forms under a wide range of temperatures and pressures
  - Exhibit two directions of perfect cleavage at 90º
  - Two most common members:
    - Orthoclase (potassium feldspar)
    - Plagioclase (sodium and calcium feldspar)
  -
      -

65 **Common Silicate Minerals**

66 ***Potassium feldspar***

67 ***Plagioclase feldspar***

68 **Common Silicate Minerals**

69 **Common Silicate Minerals**

- The Light Silicates
  - Quartz
    - Only common silicate composed entirely of oxygen and silicon
    - Hard and resistant to weathering
    - Conchoidal fracture due to three-dimensional framework
    - Often forms hexagonal crystals
    - Colored by impurities (various ions)
  - Muscovite

    - Common member of the mica family
    - Excellent cleavage in one direction
    - Thin sheets are clear
      - Used as “glass” during the Middle Ages
    - Produces the “glimmering” brilliance often seen in beach sand
    -

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72 **Common Silicate Minerals**

- The Light Silicates
  - Clay minerals
    - “Clay” is a general term used to describe a variety of complex fine-grained minerals that have sheet structure.
    - Clay makes up a large percentage of soil
    - Most originate as products of chemical weathering
    - Kaolinite is common clay mineral used to manufacture fine china

73 **Common Silicate Minerals**

- Dark (Ferromagnesian) Silicates
  - Contain iron and/or magnesium in their structure
  - Generally dark in color
  - Specific gravity between 3.2 and 3.6
- Olivine Group
  - High-temperature silicates
  - Black to green in color
  - Glassy luster and conchoidal fracture
  - Forms small, rounded crystals
  - Common in oceanic crust and through to constitute 50% of the Earth’s mantle

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- The Dark Silicates
  - Pyroxene group
    - Important components of dark-colored igneous rocks
    - Augite is the most common mineral in the pyroxene group
      - Black in color
      - Two distinctive cleavages at nearly 90º
      - Dominant mineral in basalt
  - Amphibole group
    - Hornblende is the most common mineral in this group
      - Usually black to dark green
      - Very similar in appearance to augite
    - Two perfect cleavages exhibiting angles of 120º and 60º

76 **Augite and Hornblende**

77 ***Cleavage angles for augite and hornblende***

78 **Common Silicate Minerals**

- The Dark Silicates
  - Biotite
    - Iron-rich member of the mica family
    - Excellent cleavage in one direction (sheet structure)
  - Garnet
    - Composed of individual tetrahedra linked by metallic ions (similar to olivine)
    - Glassy luster, lacks cleavage, and has conchoidal fracture (also similar to olivine)
    - Color varies, most often brown-red

- Well-developed crystals have 12 diamond-shaped faces

79 **Common Silicate Minerals**

80 **Important Nonsilicate Minerals**

- Divided into groups based on the negatively charged ion or complex ion that the members have in common.
- Make up approximately 8% of Earth's crust
  - Carbonates
  - Halides
  - Oxides
  - Sulfides
  - Sulfates
  - Native elements

81 **Common Nonsilicate Mineral Groups**

82 **Important Nonsilicate Minerals**

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86 ***Native copper***

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90 **Important Nonsilicate Minerals**

- Carbonates
  - Composed of the carbonate ion (CO_3^{2-}) and a positive ion
  - Two most common carbonates are calcite ($CaCO_3$) and dolomite $CaMg(CO_3)_2$
  - Primary constituents in limestone and dolostone
  - Used as road aggregate, building stone, and main ingredient in Portland cement.

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91 **Important Nonsilicate Minerals**

- Many nonsilicate minerals have economic value
  - Examples:
    - Halite (mined for salt)
    - Gypsum (used to make plaster and other building materials)
    - Hematite and magnetite (mined for iron ore)
    - Sulfides—compounds of sulfur and one or more metals (galena: lead, sphalerite: zinc, chalcopyrite: copper)
    - Native elements (gold, silver, and diamonds)

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92 **Important Nonsilicate Minerals**

93 **End of Chapter**