Chapter 1 Lecture Outline

Foundations of Earth Science
Seventh Edition

Matter and Minerals

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Focus Question 1.1

• What are the defining characteristics of a mineral?
Minerals: Building Blocks of Rocks

- **Minerals** are the building blocks of rocks
- **Minerals important in human history**
  - Flint and chert for weapons and tools
  - Gold, silver, and copper mined by Egyptians
  - Bronze developed by 2200 b.c.
  - Mining became common by the Middle Ages
- **Study of minerals is** **mineralogy**
Defining a Mineral

• Geologists’ definition:
  – Naturally occurring
  – Inorganic solid
  – Orderly crystalline structure
  – Definite chemical composition
Defining a Mineral

• Minerals are naturally occurring:
  – Form by natural geologic processes
  – Synthetic materials are not considered minerals
Defining a Mineral

- Minerals are generally inorganic
- Crystalline solids from organic sources are generally not considered minerals
- Some organisms secrete inorganic compounds like calcium carbonate
  - Considered a mineral when they become part of the rock record
Defining a Mineral

• Minerals are solid substances:
  – Exception: mercury occurs naturally as a liquid
Defining a Mineral

• Minerals have an orderly crystalline structure:
  – Atoms are arranged in an organized, repetitive manner
  – Organization is reflected in the crystal shape
Defining a Mineral

• Minerals have a chemical composition that allows for some variation:
  – Most minerals are compounds
  – Can be expressed as a chemical formula
    • Example: quartz = SiO$_2$
  – Composition may vary slightly if certain elements substitute for others
    • Substituting elements about the same size will not change the crystalline structure of the mineral
Defining a Mineral

• Are the following materials considered a mineral or not? Why or why not?
  – Ice
  – Cubic zirconia
  – Chocolate
  – Gold nugget
  – Glass
  – Salt
What is a rock?

• A rock is a naturally occurring solid aggregate mass of mineral, or mineral-like matter
• Most are aggregates of several different minerals
  – Individual properties of the minerals are retained
  – Some rocks are composed of a single mineral
    • Example: limestone is an impure mass of the mineral calcite
  – Some rocks are made of non-mineral matter
    • Examples: obsidian and pumice (volcanic glass), coal (organic)
What is a rock?

Granite
(Rock)

Quartz
(Mineral)

Hornblende
(Mineral)

Feldspar
(Mineral)
What is a rock?

• What is the relationship between atoms, minerals, and rocks?
Focus Question 1.1

• What are the defining characteristics of a mineral?

  – Naturally occurring
  – Inorganic
  – Solid
  – Crystalline structure
  – Definite chemical composition
Focus Question 1.2

- What are the particles that make up an atom?
Atoms: Building Blocks of Minerals

• All matter — including minerals — is composed of atoms
• All atoms (excluding H and He) formed inside massive stars by nuclear fusion
• An atom is the smallest particle that cannot be chemically split
• Atoms contain even smaller particles:
  – Protons
  – Neutrons
  – Electrons
• Protons, Neutrons, and Electrons:
  – **Protons** and **neutrons** have almost identical masses
  – **Electrons** are much smaller (1/2000) than protons and neutrons
  – Protons have a charge of +1
  – Neutrons have no charge
  – Electrons have a charge of -1
  – Most matter is neutral, because the charges of protons and electrons cancel each other out
Atoms: Building Blocks of Minerals

- Electrons are sometimes shown orbiting the **nucleus** like planets in a solar system.
- Electrons actually surround the nucleus like a cloud.
• Electrons:
  – Move around the nucleus in a cloud with different regions called principle shells
  – Each principle shell has an energy level and a specific number of electrons
  – The outer shell contains **valence electrons**
    • Interact with valence electrons of other atoms to form chemical bonds
Elements: Defined by Their Number of Protons

• The number of protons in the nucleus of an atom gives its **atomic number**
  – Determines chemical nature of atom
  – All atoms with the same atomic number are known as an **element**

• Approximately 90 naturally occurring elements
  – Elements are arranged in the **periodic table**
    • Elements with similar properties line up in columns
Elements: Defined by Their Number of Protons

- Vertical columns contain elements with similar properties.
- Tendency to lose outermost electrons to uncover full outer shell.
- Tendency to fill outer shell by sharing electrons.
- Tendency to gain electrons to make full outer shell.
- Noble gases are inert because outer shell is full.

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Elements: Defined by Their Number of Protons

- Most minerals are **chemical compounds**
  - Two or more elements joined together
- A few minerals are made up of single elements
  - Native minerals

A. Gold on quartz  
B. Sulfur  
C. Copper
Focus Question 1.2

• What are atomic particles?
  – Protons
    • Found in the nucleus
    • Have a positive charge
  – Electrons
    • Surround the nucleus like a cloud
    • Have a negative charge
    • Valence electrons interact to form bonds
  – Neutrons
    • Found in the nucleus
    • Have no charge
Focus Question 1.3

• Why and how do atoms bond?

A. The transfer of an electron from a sodium (Na) to a chlorine (Cl) atom leads to the formation of a Na\(^+\) ion and a Cl\(^-\) ion.

B. The arrangement of the Na\(^+\) and Cl\(^-\) in the solid ionic compound sodium chloride (NaCl), table salt.
Why Atoms Bond

• Elements (excluding noble gasses) form bonds under the temperature and pressure conditions that occur on Earth

• Bonds lower the total energy of the atoms and make them more stable
The Octet Rule and Chemical Bonds

• **Eight** valence electrons is a stable arrangement and a full valence shell
  – The noble gasses all have full valence shells so they lack chemical reactivity

• Elements gain, lose, or share electrons during chemical reactions
  – Producing stable electron arrangements
• **The Octet Rule**
  – Atoms tend to gain, lose, or share electrons until they have eight valence electrons
The Octet Rule and Chemical Bonds

• A chemical bond is the transfer or sharing of electrons that results in a full valence shell
  – Ionic bonds: electrons are transferred
  – Covalent bonds: electrons are shared
  – Metallic bonds: electrons move around
Ionic Bonds: Electrons Transferred

• When one atom loses or gains valence electron(s), ions are formed
  – Electrons are lost: becomes a positive ion
  – Electrons are gained: becomes a negative ion

• Ionic bonds form when ions with opposite charges are attracted
  – Creates ionic compounds
Ionic Bonds: Electrons Transferred

- NaCl is an ionic compound
  - Na loses a valence electron (becomes positive)
  - Cl gains a valence electron (becomes negative)
Ionic Bonds: Electrons Transferred

- Ionic compounds have very different properties than the bonded elements that make them up

- Example: Sodium Chloride
  - Sodium
    - Soft, silver, toxic metal that reacts explosively when exposed to water
  - Chlorine
    - Poisonous green gas used as a chemical weapon during World War I
  - Sodium Chloride is table salt!
A covalent bond forms when electrons are shared between atoms.

Two hydrogen atoms combine to form a hydrogen molecule, held together by the attraction of oppositely charged particles—positively charged protons in each nuclei and negatively charged electrons that surround these nuclei.

\[ H \cdot + H \cdot \rightarrow H : H \]
Metallic Bonds: Electrons Free to Move

• **Metallic bonds** form when valence electrons are free to move from one atom to another
  – All atoms share available valence electrons
  – Movement of valence electrons between atoms results in:
    • High electrical conductivity
    • Malleability
    • Other unique properties of metals
Focus Question 1.3

• Why and how do atoms bond?
  – The most stable configuration is eight valence electrons
  – Ionic bonds form when electrons are transferred from one atom to another
    • Produces negatively and positively charged ions, which are attracted to each other
  – Covalent bonds form when valence electrons are shared between two atoms
  – Metallic bonds form when valence electrons flow freely between atoms
Focus Question 1.4

• What physical properties can be used to identify a mineral?

Although the color of a mineral is not always helpful in identification, the streak, which is the color of the powdered mineral, can be very useful.
Physical Properties of Minerals

• Minerals have a **definite crystalline structure** and **chemical composition**
  – Gives them unique physical and chemical properties
• These properties can be used in identification
Physical Properties of Minerals

- **Luster** is the quality of light reflected from the surface of a mineral
  - Minerals that look like shiny metal have a metallic luster
    - A submetallic luster appears slightly dull
  - Nonmetallic luster includes:
    - Vitreous or glassy, dull, earthy, pearly, silky, and greasy
Physical Properties of Minerals

• Ability to transmit light
  – Minerals that do not transmit light are **opaque**
  – Minerals that transmit some light, but not an image, are **translucent**
  – Minerals that transmit both light and images are **transparent**
Physical Properties of Minerals

• **Color** may be one of the most obvious properties of a mineral, but it is *only a diagnostic property for a few minerals*.

• Slight variations in the chemical composition of a mineral can change the color dramatically.
Physical Properties of Minerals

• **Streak** is the color of a mineral in powdered form
  – Obtained by rubbing the sample on an unglazed porcelain tile known as a streak plate
  – Streak, unlike color, is generally consistent

• Metallic minerals generally have a dense, dark streak

• Nonmetallic minerals generally have a light streak

• Not all minerals produce a streak
Crystal Shape or Habit

• **Crystal shape** or **habit** is the characteristic shape of individual mineral crystals
• Most minerals grow in one common shape, but some have two or more characteristic shapes
Crystal Shape or Habit

A. Fibrous

B. Bladed

C. Banded

D. Cubic crystals
Mineral Strength

- The strength of a mineral is determined by the strength of its chemical bonds.
- Mineral strength determines how minerals break or deform under stress.
Mineral Strength

- **Tenacity** is a mineral’s resistance to breaking or deforming
  - Minerals with ionic bonds tend to be brittle
    - They will shatter
  - Minerals with metallic bonds are malleable
    - They can be deformed into shapes and thin sheets
  - Sectile minerals can be cut into thin shavings
  - Elastic minerals will return to their original shape after being bent
Mineral Strength

• **Hardness** is a mineral’s resistance to abrasion or scratching

• Hardness is measured on a scale of 1 to 10 (Moh's Scale)
  – Can be determined by rubbing the mineral against a material of known hardness
    • Fingernail (hardness = 2.5)
    • Copper penny (hardness = 3.5)
    • Glass (hardness = 5.5)
A. Mohs scale (Relative hardness)

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Hardness</th>
<th>Common Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond</td>
<td>10</td>
<td>Streak plate (6.5)</td>
</tr>
<tr>
<td>Corundum</td>
<td>9</td>
<td>Glass &amp; knife blade (5.5)</td>
</tr>
<tr>
<td>Topaz</td>
<td>8</td>
<td>Wire nail (4.5)</td>
</tr>
<tr>
<td>Quartz</td>
<td>7</td>
<td>Copper penny (3.5)</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>6</td>
<td>Fingernail (2.5)</td>
</tr>
<tr>
<td>Apatite</td>
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<tr>
<td>Fluorite</td>
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<td>Calcite</td>
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<td>Gypsum</td>
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<td></td>
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<tr>
<td>Talc</td>
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</table>
B. Comparison of Mohs scale and an absolute scale

MOHS SCALE

Talc  Gypsum  Calcite  Fluorite  Apatite  Orthoclase  Quartz  Topaz  Corundum

Diamond

Absolute Hardness Values

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Mineral Strength

• **Cleavage** is the tendency of a mineral to break along planes of weak bonding
  – This produces smooth, flat surfaces where the mineral is broken
  – Not all minerals have cleavage
  – Cleavage can be easily confused with crystal shape
    • Remember that cleavage is visible when a mineral is broken
Mineral Strength
Mineral Strength

A. Cleavage in one direction. Example: Muscovite

B. Cleavage in two directions at 90° angles. Example: Feldspar

C. Cleavage in two directions not at 90° angles. Example: Hornblende

D. Cleavage in three directions at 90° angles. Example: Halite

E. Cleavage in three directions not at 90° angles. Example: Calcite

F. Cleavage in four directions. Example: Fluorite
Mineral Strength

• **Fracture** is a property resulting from chemical bonds that are approximately equal in strength
  – *Irregular fracture*: uneven broken surface
  – *Conchoidal fracture*: smooth, curved broken surface

• Some minerals exhibit *splintery or fibrous* broken surfaces
Mineral Strength

A. Irregular fracture

B. Conchoidal fracture
Density and Specific Gravity

• **Specific gravity** describes the **density** of a mineral
  – Ratio of a mineral’s weight to an equal volume of water

• Most minerals have a specific gravity between 2 and 3
  – Many of the metallic minerals have a much higher specific gravity (20 for gold)

• Can be estimated by hefting a mineral in your hand
Other Properties of Minerals

• Some minerals have distinctive properties:
  – *Taste* (halite is salty)
  – *Feel* (talc is soapy; graphite is greasy)
  – *Smell* (sulfur smells like rotten eggs)
  – *Magnetism* (some can be picked up by a magnet and some can pick up iron objects)
  – *Optical properties* (calcite refracts light)
  – *Effervescence* (carbonate minerals fizz when exposed to dilute acid)
Focus Question 1.5

• What are the different mineral groups?
Mineral Groups

- There are over 4000 named minerals, but only a few dozen are abundant in Earth’s crust
  - Known as **rock-forming minerals**

- **Economic minerals** are less common than rock-forming minerals, but are used extensively in the manufacture of products
Mineral Groups

- The majority of rock-forming minerals are made up of only eight elements.
Mineral Groups

- Silica and oxygen combine to form the basic building block for the **silicates**
  - The most common minerals
  - More than 800 silicate minerals
  - Make up 90% of the Earth’s crust
Mineral Groups

• The remaining mineral groups are often referred to as the **nonsilicates**
  – Far less abundant in Earth’s crust
  – Some are very important economic minerals
Silicate Minerals

- The **silicon-oxygen tetrahedron** is the building block of all silicates
  - Four oxygen atoms surround a much smaller silicon atom
  - Tetrahedra can be joined into chains, sheets, or three-dimensional networks by sharing oxygen atoms
Silicate Minerals

• Feldspars are the most plentiful silicates
  – Over 50% of Earth’s crust
• Quartz is second-most-abundant mineral in continental crust
  – Only common mineral composed completely of Si and O
• Silicate minerals tend to cleave between the strong silicon-oxygen structures
Silicate Minerals

• Most silicate minerals crystallize from molten rock as it cools
  – Environment and chemical composition determines which minerals are produced
• Some silicate minerals form at Earth’s surface as other silicates are weathered
• Some silicate minerals form at extreme pressures during mountain building
Silicate Minerals

• How do the minerals present in a rock tell a story about how that rock formed?
Silicate Minerals

• Common **light silicate minerals** include:
  – Feldspars
  – Quartz
  – Muscovite
  – Clay minerals

• Contain varying amounts of aluminum, potassium, calcium, and sodium
Feldspars are the most abundant
- Found in igneous, sedimentary and metamorphic rocks
- Have two directions of cleavage at 90°
- 6 on Mohs hardness scale
- Potassium feldspar contains potassium ions
- Plagioclase feldspar contains calcium and/or sodium ions, and has striated cleavage surfaces
Silicate Minerals

- Quartz is common in igneous, sedimentary, and metamorphic rocks
  - Impurities cause a variety of colors
  - 7 on Mohs hardness scale
  - Forms hexagonal crystals with pyramid-shaped ends
Silicate Minerals

- Muscovite is a member of the mica family
  - Excellent cleavage in one direction
  - 2.5 on Mohs hardness scale
- Clay minerals are commonly the weathering product of other silicates
  - Common part of soil
  - Nearly half of the volume of sedimentary rocks is clay minerals
Silicate Minerals

Kaolinite

Knife blade

Weak bonds

Strong bonds
Silicate Minerals

• **Dark silicate minerals** contain iron and magnesium
  – Pyroxenes
  – Amphiboles
  – Olivine
  – Biotite
  – Garnet

• Dark color and high specific gravity from iron content
Silicate Minerals

- **Olivine** is a major constituent of dark igneous rocks
  - Abundant in Earth’s upper mantle
  - Black to olive green color, glassy luster, and granular

- **Pyroxenes** are an important component of dark-colored igneous rocks
  - Augite is black and, opaque and has two directions of cleavage at nearly 90º

- **The amphibole group** includes minerals that commonly make up the dark portion of light-colored rocks
  - Hornblende is a dark black mineral with two cleavage planes at 60º and 120º
Silicate Minerals

Olivine-rich peridotite (variety dunite)
Silicate Minerals

• Biotite is a dark, iron-rich member of the mica family
  – Excellent cleavage in one direction
  – Common in light-colored rocks

• Garnet is a dark silicate
  – Glassy luster, no cleavage, conchoidal fracture
  – Color varies, but commonly deep red
Nonsilicate minerals are divided into groups based on the negatively charged ion common to the group.

Nonsilicates make up only about 8% of Earth’s crust.

- Some occur in significant amounts in sedimentary rocks.
- Some are economically important.
Nonsilicate Minerals

A. Calcite
B. Dolomite
C. Halite
D. Gypsum
E. Hematite
F. Magnetite
G. Galena
H. Chalcopyrite
I. Fluorite
Nonsilicate Minerals

- Carbonates contain a carbonate ion
  - $\text{CO}_3^{2-}$
  - Calcite and dolomite
    - Used as road aggregate, building stone, and cement
- Halite and gypsum are common evaporites
  - Halite (a *halide*) is table salt
  - Gypsum (a *sulfate*) is used in plaster
- Oxides are important iron ores
Nonsilicate Minerals

• Other economically important nonsilicate minerals include:
  – Sulfides (galena, sphalerite)
  – Native elements (gold, silver, copper)
  – Fluorite
  – Corundum (ruby, sapphire)
  – Uraninite
Focus Question 1.5

• What are the different mineral groups?
  – Silicates (the most common) are based on the silicon-oxygen tetrahedron
    • Subdivided into light and dark groups
  – Nonsilicates include negatively charged ions
    • Common in sedimentary rocks
    • Many are economically important
Why does Earth’s crust contain a diverse array of minerals?