Chapter 2: Earth Materials

Point Lake, NW Territories, Canada, diamond mine discovered in 1991. Diamonds from the mine are shown below.
Learning Objectives

Elements and compounds
- Describe atoms, molecules, and four kinds of chemical bonds.

What is a mineral?
- Define minerals and their properties.

Mineral families
- Identify some common chemical elements and mineral families.

Rock: A first look
- Describe the three major families of rocks.
Elements and Compounds

Elements, Atoms, and Ions

Element

- The most fundamental substance into which matter can be separated using chemical means.

Atom

- The smallest individual particle that retains the distinct chemical properties of an element.

Three Materials Made of Carbon

- Diamond
- Coal
- Graphite

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Elements and Compounds
Elements, Atoms, and Ions

Proton (positively charged)
Neutron (uncharged)
Electron (negatively charged)

Electrons orbiting the nucleus

Nucleus containing 6 protons and 6 neutrons
First energy-level shell (2 electrons)
Second energy-level shell (4 electrons that are available for chemical bonding)

Figure 2.1 part 1
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Elements and Compounds
Elements, Atoms, and Ions

Ions
• Atoms that have either gained or lost electrons, leaving them with a negative (anion) or positive charge (cation)

Isotopes
• Atoms with the same atomic number but different mass numbers

Figure 2.1 part 2
(top) Eric Nathan/Alamy; (bottom) James P. Blair/NG Image Collection; (right) Mark A. Schneider/Photo Researchers, Inc.
Compound: A combination of atoms of one or more elements in a specific ratio

Molecule: The smallest chemical unit that has all properties of a particular compound

Figure 2.2
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Elements and Compounds
Compounds, Molecules, and Bonding

Bond: The force that holds together the atoms in a chemical compound

- Ionic bonding
- Covalent bonding
- Metallic bonding
- Van der Waals bonding
Ionic Bonding

Crystal structure

In table salt (sodium chloride, NaCl), each sodium cation is surrounded by chlorine anions.

Occurrence

Crystals of sodium chloride are rectangular, with straight edges.

Uses

Salt is a moderately hard solid that dissolves easily in water.
# Covalent Bonding

<table>
<thead>
<tr>
<th>Crystal structure</th>
<th>Occurrence</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Diamond structure diagram" /></td>
<td>Diamond crystals appear in a rock called kimberlite. Covalent compounds are often strong and hard; diamond is one of the hardest substances known.</td>
<td>Cut and polished diamonds are prized gems. Tiny diamonds are used in industry for cutting and grinding instruments.</td>
</tr>
</tbody>
</table>

Diamond consists of carbon atoms connected in a network of covalent bonds. Each atom is connected to four others.

*Figure 2.3 part 2*

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**Metallic bonding:**

**Crystal structure**  
Atoms of gold are packed in the densest possible manner. Each atom is surrounded by, and in contact with, 12 other gold atoms.

**Occurrence**  
This 2.3-kg nugget of gold was once embedded in rock, but weathering and erosion have removed most of the rock.

**Uses**  
Gold is durable as well as malleable; it has been used as currency since ancient times.
<table>
<thead>
<tr>
<th>Crystal structure</th>
<th>Occurrence</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>In graphite, carbon atoms form layers connected by covalent bonds. The layers are weakly held together by Van der Waals bonds.</td>
<td>Graphite is not a strong material and can be easily crumbled into small particles.</td>
<td>The “lead” in pencils is not lead, it’s really graphite. When you write, the pressure of your hand breaks off a trail of carbon particles.</td>
</tr>
</tbody>
</table>
Ionic Bonding

- One atom transfers electron to another, which creates bond
- Table salt (sodium chloride)
- Cubic lattice
- Moderate strength and hardness

Figure 2.3 part 1
© 2012 John Wiley & Sons, Inc. All rights reserved. Photos: (left) C.D. Winters/Photo Researchers, Inc.; (right) Corbis Digital Stock
Elements and Compounds
Compounds, Molecules, and Bonding

Covalent Bond

• Electrons from different atoms “pair up,” which creates a bond
• Does NOT produce ions
• Strongest of chemical bonds
Metallic Bond

- Electrons shared among several atoms
- Outer electrons may drift between each other
- Typically good conductors of electricity

Metallic bonding:

Crystal structure  Occurrence  Uses

Figure 2.3 part 3
© 2012 John Wiley & Sons, Inc. All rights reserved. Photos: (left) ITAR-TASS Photo Agency/Alamy; (right) Bill Curtsinger/NG Image Collection
Van der Waals Bond

- Attraction between electrically neutral molecules with asymmetrical charge
- Form sheets
  - Considered weak between sheets
  - May feel slippery between sheets
What Is a Mineral?

Mineral
- A naturally formed, solid, inorganic substance with a characteristic crystal structure and a specific chemical composition

http://en.wikipedia.org/wiki/Malachite
Ice is a mineral, though you may not usually think of it that way. It occurs in nature in the form of hexagonal crystals and has a specific chemical formula (H₂O).

Water is not a mineral, because it is not a solid. This criterion also means that such naturally occurring substances such as oil and natural gas cannot be considered minerals.

Bones are a tricky case. They do contain the same chemical compound found in a common mineral called apatite, but they are not minerals because they form by organic processes. Thus the bone in this modern crocodile skull is not a mineral. Bones and other solids formed by organic processes are often called biominerals.

This fossil, a crocodile skull in the Kenyan National Museum, was once made of bone but is now composed of minerals. During fossilization, the materials of the original bone were replaced in an inorganic process called mineralization.
What Is a Mineral?
What a Geologist Sees

Coal fails the second of the four tests for a mineral because it is derived from the remains of plant material and was formed as a result of organic processes. Coal also fails the composition test because it is not a single compound; rather, it is composed of many different compounds.

Steel (being produced in the background) fails the first of the four tests for a mineral because it does not occur naturally. It is formed by extensive human processing of naturally occurring ores, which are minerals.

Quartz is an easily recognizable mineral. Its chemical formula is SiO$_2$. Note that some minerals have very complex formulas. For example, phlogopite, a form of mica, is KMg$_3$AlSi$_3$O$_{10}$(OH)$_2$. The important thing is that the elements combine in specific ratios. Phlogopite is a mineral even though its chemical formula is complicated.

Opal, a gemstone, is typically included in books about minerals, but it is not a true mineral. Opals do not have a specific composition, and they lack a crystalline structure (they are amorphous). Opal is an example of a mineraloid.
Composition of Minerals

- **Crystal structure:** An arrangement of atoms or molecules into regular geometric lattice.
- **Materials that possess a crystal structure** are said to be crystalline.
What Is a Mineral?  
Telling Minerals Apart

Luster
• The quality and intensity of light reflection:
  • Metallic
  • Vitreous
  • Resinous
  • Pearly
Crystal Form and Habit

- **Crystal Form**
  - Flat or planar surface that forms during the growth of minerals
  - Crystal faces
  - Formed by crystallization or precipitation

- **Habit**
  - The distinctive shape of a particular mineral

- **Cleavage**
  - The manner in which a mineral breaks
What Is a Mineral?
Telling Minerals Apart

Figure 2.6 Crystal faces and angles, interfacial angles are always the same.
What Is a Mineral?
Telling Minerals Apart

Figure 2.7 Fibers of asbestos, an example of habit
### What Is a Mineral?

**Telling Minerals Apart**

**Hardness**

- A mineral’s resistance to scratching

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#### The Mohs scale* of relative hardness of minerals

<table>
<thead>
<tr>
<th>Relative Hardness</th>
<th>Number</th>
<th>Reference Mineral</th>
<th>Hardness of Common Objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softest</td>
<td>1</td>
<td>Talc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Gypsum</td>
<td>Fingernail</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Calcite</td>
<td>Copper penny</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Fluorite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Apatite</td>
<td>Pocketknife; glass</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Potassium feldspar</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Quartz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Topaz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Corundum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Diamond</td>
<td></td>
</tr>
</tbody>
</table>

*Named for Friedrich Mohs, a German mineralogist, who chose the 10 minerals of the scale.

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What Is a Mineral?
Telling Minerals Apart

Figure 2.8 Mineral cleavage, (a) Muscovite, one perfect plane of cleavage; (b) potassium feldspar, two planes of cleavage at right angles; and (c) Halite, three planes of cleavage at right angles
What Is a Mineral?  
Telling Minerals Apart

Color and Streak

- The thin layer of powder made by rubbing a specimen on an unglazed fragment of porcelain

Density

- Reflection of compactness of atoms
Figure 2.10 Streak of hematite is always reddish brown, even if the mineral sample is metallic and silver.
What Is a Mineral?

Other Mineral Properties

Birefringent (Double Refraction): When you look at an object though them, you can see a double image.

Magnetic: They are attracted by a magnet

Luminescence or fluorescence: They glow when exposed to an ultraviolet light.
Mineral Families
Minerals of the Earth’s Crust

- Silicate minerals: A strongly bonded, complex anion that contains both silicon and oxygen
- Oxide minerals: Contains the simple oxide anion $\text{O}^{2-}$
Elements of the Earth’s Crust

Figure 2.11 Elements of the continental crust

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Mineral Families
Minerals of the Earth’s Crust

Figure 2.12  Silicate links

The four oxygen atoms of a silicate ion form a regular tetrahedron.

An exploded view shows the smaller silicon atom in the center.

Two tetrahedra can link together by sharing an oxygen atom.

Exploded view of the same configuration.

Figure 2.12  Silicate links

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Mineral Families
Minerals of the Earth’s Crust

Rock-forming minerals
- Polymerization
- The formation of a complex molecule by the joining of repeated simpler units

Accessory minerals
- Less common minerals
<table>
<thead>
<tr>
<th>Silicate structure</th>
<th>Mineral/Formula</th>
<th>Cleavage</th>
<th>Example of a specimen</th>
</tr>
</thead>
</table>
| Single tetrahedron | Olivine  
Mg$_2$SiO$_4$ | None     | ![Image](image1.jpg) |
| Hexagonal ring      | Beryl (Gem form is emerald)  
Be$_3$Al$_2$Si$_6$O$_{18}$ | One direction | ![Image](image2.jpg) |
| Single chain        | Pyroxene group  
CaMg(SiO$_3$)$_2$ (variety: diopside) | Two directions at 90° | ![Image](image3.jpg) |

Figure 2.13 part 1
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Figure 2.13 Polymerization of silicate minerals
<table>
<thead>
<tr>
<th>Silicate structure</th>
<th>Mineral/Formula</th>
<th>Cleavage</th>
<th>Example of a specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double chain</td>
<td>Amphibole group</td>
<td>Two directions at 120°</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td>$\text{Ca}_2\text{Mg}_5(\text{Si}<em>4\text{O}</em>{11})_2(\text{OH})_2$ (variety: tremolite)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheet</td>
<td>Mica</td>
<td>One direction</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td>$\text{KAl}_2(\text{AlSi}<em>3\text{O}</em>{10})(\text{OH})_2$ (variety: muscovite)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\text{K(Mg,Fe)}_3(\text{AlSi}<em>3\text{O}</em>{10})(\text{OH})_2$ (variety: biotite)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>See Figure 2.15</td>
<td>Feldspar</td>
<td>Two directions at 90°</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td>$\text{KA}\text{Si}_3\text{O}_8$ (variety: orthoclase)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quartz</td>
<td>None</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td>$\text{SiO}_2$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2.13 Polymerization of silicate minerals**
Mineral Families
Minerals of the Earth’s Crust

Other mineral families

- Carbonate
- Sulfates
- Sulfides
- Phosphates
Ore deposits
• A localized concentration that can be extracted profitably

Mining
– Disturbs Earth’s surface
– Damages environment

Figure 2.15 Mining and destruction of the environment
Rock: A First Look
Igneous, Sedimentary, and Metamorphic

Rock
• A naturally formed coherent aggregate of minerals and possibly other nonmineral matter
• Records history of Earth processes

Igneous rock
• Formed by cooling and solidifying molten rock
• Magma: molten rock

Figure 2.16 Igneous rock example
Rock: A First Look
Igneous, Sedimentary, and Metamorphic

Sedimentary rock
• Forms under conditions of low pressure and low temperature near the surface

Metamorphic rock
• Altered by exposure to high temperature, high pressure, or both

Figure 2.16 Sedimentary rock example (top), metamorphic rock example (bottom)
Rock: A First Look
What Holds Rock Together?

- Partly mechanical, partly chemical
- Igneous and metamorphic rocks most cohesive
- Rocks held together by:
  - Compaction
  - Solution
  - Recrystallization

Figure 2.17 Recrystallization of snow
Critical Thinking

Which of the following materials are minerals, and why (or why not)?

- Water, beach sand, diamond, wood, vitamin pill, gold nugget, fishbone

Rock samples, taken from the Moon, contain many of the same minerals as those found on Earth. Why might this be the case?
Are there valuable ores being mined locally? If so, what are the rocks and minerals of interest?