INSTRUCTOR'S MANUAL

for

Edward J. Tarbuck / Frederick K. Lutgens
Cameron J. Tsujita / Stephen R. Hicock

EARTH

An Introduction to Physical Geology

Fourth Canadian Edition

Prepared by

Deana Schwarz
University of Western Ontario

PEARSON
Toronto

CONTENTS

CHAPTER 1 An Introduction to Geology and Plate Tectonics 1-1

CHAPTER 2 Minerals: The Building Blocks of Rocks 2-1

CHAPTER 3 Igneous Rocks 3-1

CHAPTER 4 Volcanoes and Volcanic Processes 4-1

CHAPTER 5 Weathering and Soil 5-1

CHAPTER 6 Sedimentary Rocks 6-1

CHAPTER 7 Metamorphism and Metamorphic Rocks 7-1

CHAPTER 8 Geologic Time 8-1

CHAPTER 9 Crustal Deformation 9-1

CHAPTER 10 Earthquakes and Earth's Interior 10-1

CHAPTER 11 The Ocean Floor 11-1

CHAPTER 12 Plate Tectonics: The Framework for Modern Geology 12-1

CHAPTER 13 Mountain Building and Continental Frameworks 13-1

CHAPTER 14 Mass Wasting: The Work of Gravity 14-1

CHAPTER 15 Running Water 15-1

CHAPTER 16 Groundwater 16-1

CHAPTER 17 Glaciers and Glaciation 17-1

CHAPTER 18 Deserts and Winds 18-1

CHAPTER 19 Shorelines 19-1

CHAPTER 20 Mineral and Energy Resources 20-1

An Introduction to Geology and Plate Tectonics 1

Learning Objectives

After reading, studying, and discussing the chapter, students should be able to:

- Briefly define geology as a science.
- Explain the relationship between geology, people, and the environment.
- Discuss the history of geology, including the concepts of uniformitarianism and catastrophism.
- Briefly explain relative dating of geologic events and the development of the geologic time scale.
- Understand the magnitude and importance of the concept of geologic time.
- Briefly discuss the origin and early evolution of Earth.
- Briefly explain the theory of continental drift and its supporting evidence.
- Briefly describe the theory of plate tectonics, including the three major plate boundaries, and explain how this paradigm provides a mechanism for continental drift.
- Compare and contrast the layers of Earth that are defined by composition with those defined by physical properties.
- Define and briefly discuss the major "spheres" of the Earth.
- Briefly discuss the major features of continents and ocean basins.
- Discuss the Earth as a system.
- Explain the concept of the rock cycle.

Thinking inside the box:

□ 1.1 Understand the contribution of Sir William Logan to Earth Science in Canada.
□ 1.2 Briefly explain the mechanism underlying Earth's magnetic field.

Chapter Summary

- *Geology* means "the study of Earth." The two broad areas of the science of geology are (1) *physical geology*, which examines the materials composing Earth and the processes that operate beneath and upon its surface; and (2) *historical geology*, which seeks to understand the origin of Earth and its development through time.

- The relationship between people and the natural environment is an important focus of geology. This includes natural hazards, resources, and human influences on geologic processes.

- During the seventeenth and eighteenth centuries, *catastrophism* influenced the formulation of explanations about Earth. Catastrophism states that Earth's landscapes have been developed primarily by great catastrophes. By contrast, *uniformitarianism*, one of the fundamental principles of modern geology advanced by *James Hutton* in the late eighteenth century, states that the physical, chemical, and biological laws that operate today have also operated in the geologic past. The idea is often summarized as "the present is the key to the past." Hutton argued that processes that appear to be slow-acting could, over long spans of time, produce effects that were just as great as those resulting from sudden catastrophic events. The acceptance of uniformitarianism meant the understanding that Earth is very old.

- Using the principles of *relative dating*, the placing of events in their proper sequence or order without knowing their absolute age in years, scientists developed a geologic time scale during the nineteenth century. Relative dates can be established by applying such principles as the *law of superposition* and the *principle of fossil succession*.

- The *nebular hypothesis* describes the formation of the solar system. The Sun began forming about five billion years ago from a large cloud of dust and gases. As the cloud contracted, it began to rotate and assume a disk shape. Material that was gravitationally pulled toward the center became the *protosun*. Within the rotating disk, small centers, called *protoplanets*, swept up more and more of the cloud's debris forming the planets.

- The accumulation of material during the formation of Earth caused intense heating and melting. The heavy elements, iron and nickel, sank to the centre of Earth, forming the *core*. Lighter material rose to the surface, forming a primitive *crust*. The material between the crust and the core is called the *mantle*.

- In the early twentieth century, Alfred Wegener proposed the continental drift hypothesis. One of the major tenets was that a supercontinent called Pangaea began breaking apart into smaller continental fragments that “drifted” to their present positions. To support the claim that the now-separate continents were once joined, Wegener and others used the fit of the margins of South America and Africa, fossil evidence, rock types and structures, and evidence of ancient climates.

- The theory of *plate tectonics* provides a comprehensive model, or *paradigm*, of Earth's internal workings. It holds that Earth's rigid, outer lithosphere consists of several segments called *plates* that are slowly and continually in motion relative to each other. Most earthquakes, volcanic activity, and mountain building are associated with the movements of these plates.

- The three distinct types of plate boundaries are (1) *divergent boundaries*, where plates move apart, (2) *convergent boundaries*, where plates move together, causing one to go beneath the other or where plates collide, and (3) *transform fault boundaries*, at which plates slide past each other.

- Earth’s internal structure is divided into layers based on differences in chemical composition and on the basis of changes in physical properties. Compositionally, Earth is divided into a thin outer *crust*, a solid, rocky *mantle*, and a dense *core*. Based on physical properties, the layers of Earth are (1) the *lithosphere*, the cool, rigid outermost layer that averages about 100 kilometres thick, (2) the *asthenosphere*, a relatively weak layer located in the mantle beneath the lithosphere, (3) the more rigid *mesosphere*, where rocks are very hot and capable of gradual flow, (4) the liquid *outer core* where Earth’s magnetic field is generated, and (5) the solid *inner core*.

- Earth's physical environment is traditionally divided into four major parts, (1) the *hydrosphere*, (2) the *atmosphere*, (3) the *biosphere*, and (4) the *geosphere*. Although each of Earth’s four spheres can be studied separately, they are all related in a complex and continuously-interacting whole that we call the *Earth system*. Changing one part of the Earth system can produce changes in any or all the other parts.

- Two principal divisions of the Earth's surface are the *continents* and *ocean basins*. The boundary between the *continental shelf* and the *continental slope* marks the continent-ocean basin transition. Major continental features include *mountains* and *shields*. Important zones on the ocean floor are *trenches* and the extensive *oceanic ridge system*.

• The two sources of energy that power the Earth system are (1) the Sun, which drives the external processes that occur in the atmosphere, in the hydrosphere, and at Earth's surface, and (2) heat from Earth's interior which powers the internal processes that produce volcanoes, earthquakes, and mountains.

• The *rock cycle* is one of many cycles of the Earth system in which matter is recycled. It illustrates the origin of the three rock types (*sedimentary, igneous and metamorphic*) and the role of various geologic processes in transforming one rock type into another.

Chapter Outline

I. The Science of Geology
  A. Geology is the science that pursues an understanding of planet Earth
    1. Two broad areas of geology
      a. Physical geology - examines the materials composing Earth and seeks to understand the many processes that operate beneath and upon its surface
      b. Historical geology - seeks an understanding of the origin of Earth and its development through time
    2. Understanding Earth is challenging because it is a dynamic body with many interacting parts
  B. Geology, people, and the environment
    1. There are many important relationships between people and the natural environment
    2. Some of the problems and issues addressed by geology involve, among others
      a. Natural hazards
      b. Resources
      c. World population growth
      d. Environmental issues
  C. Some historical notes about geology
    1. The nature of Earth has been a focus of study for centuries
      a. Early Greeks wrote about such topics as fossils, gems, earthquakes, and volcanoes more than 2300 years ago
    2. Catastrophism
      a. Archbishop James Ussher
        1. Constructed a chronology of human and Earth history in the mid-1600s
        2. Chronology of human and Earth history based on Scripture
        3. Calculated age of the Earth was only a few thousand years (created in 4004 B.C.)
      b. During the seventeenth and eighteenth century, the doctrine of catastrophism strongly influenced people's thinking about Earth
        1. Catastrophists believed that Earth's landscape had been shaped primarily by great catastrophes
        2. Features such as mountains and canyons were produced by sudden and often worldwide disasters
    3. Uniformitarianism
      a. Modern geology began in the late 1700s; James Hutton's *Theory of the Earth*
      b. Uniformitarianism is the fundamental principle of geology
        1. The physical, chemical, and biological laws that operate today have also operated in the geologic past- "the present is the key to the past"
        2. Premised on the acceptance of a very long history for Earth

3. Prior to Hutton, no one effectively demonstrated that geological processes occur over extremely long periods of time

II. Geologic Time
   A. Geologists are now able to assign fairly accurate dates to events in Earth history
   B. Relative dating and the geologic time scale
      1. Relative dating means that Earth materials or events are placed in their proper sequence or order without knowing their age in years
      2. Principles of relative dating include
         a. Law of superposition
         b. Principle of fossil succession
   C. The magnitude of geologic time
      1. Involves vast times – millions or billions of years
      2. An appreciation for the magnitude of geologic time is important because many processes are very gradual

III. Early Evolution of Earth
   A. Origin of planet Earth
      1. Most researchers believe that Earth and the other planets formed at essentially the same time from the same primordial material as the Sun
      2. Nebular hypothesis
         a. Solar system evolved from an enormous rotating cloud called the solar nebula
         b. Nebula was composed mostly of hydrogen and helium
         c. About 5 billion years ago the nebula began to contract
         d. Assumes a flat, disk shape with the protosun (pre-Sun) at the center
         e. Inner planets begin to form from metallic and rocky clumps of substances with high melting points
   B. Formation of Earth's layered structure
      1. As Earth formed, high-velocity impacts caused the temperature to increase, and iron and nickel began to melt and sink toward the center
      2. Buoyant masses of molten rock rose to the surface to produce a primitive crust
      3. Early chemical segregation established the three basis divisions of Earth's interior
         a. An iron-rich core
         b. A thin primitive crust, and
         c. The mantle between the core and crust
      4. A primitive atmosphere evolved as gaseous materials escaped from Earth's interior

IV. Plate Tectonics: a Geologic Paradigm
   A. To explain the ever-changing surface of Earth, Alfred Wegener proposed the notion of drifting continents
   B. Continental drift: an idea before its time
      1. Alfred Wegener, a German meteorologist and geophysicist published *The Origin of Continents and Oceans* (1915)
      2. Fragments "drifted" apart to modern continental locations
      3. Numerous lines of evidence
         a. Fit of continents
            1. Africa and South America
            2. Continental shelves
         b. Fossil evidence
            1. *Glossopteris*

            2. *Mesosaurus*
        c. Rock type and structural similarities
        d. Paleoclimatic evidence
            1. Glacial rocks in now-tropics
            2. Coal beds now in now temperate regions
    4. Fifty years until widely-accepted

V. Planet of Shifting Plates
  A. The theory of plate tectonics
    1. Involves understanding the workings of our dynamic planet
    2. Mechanism for continental drift
    3. Comprehensive theory (*paradigm*) that provides geologists with the first comprehensive model of Earth's internal workings
      a. Earth's rigid outer shell (lithosphere) is divided into numerous slabs called plates
      b. The lithospheric plates move relative to each other at a very slow but continuous rate that averages about 5 centimetres a year
      c. The grinding movements of the plates
        1. Generates earthquakes
        2. Creates volcanoes, and
        3. Deforms large masses of rock into mountains
  B. Plate boundaries
    1. All major interactions among individual plates occurs along their boundaries
    2. Types of plate boundaries
      a. Divergent boundary – two plates move apart, resulting in upwelling of material from the mantle to create new seafloor
        1. Occurs mainly at the mid-ocean ridge
        2. Mechanism, called seafloor spreading, has created the floor of the Atlantic Ocean during the past 160 million years
        3. Along divergent boundaries the oceanic lithosphere is elevated and forms a ridge because it is hot and occupies more volume than cooler rocks
      b. Convergent boundary – two plates move together
        1. Older oceanic plates return to the mantle along these boundaries
        2. Descending plates produce ocean trenches
          1. Subduction zones are plate margins where oceanic crust is being consumed
          2. Whenever continental lithosphere moves toward an adjacent slab of oceanic lithosphere, the less dense continental plate remains "floating" while the denser oceanic lithosphere sinks into the asthenosphere
      c. Transform fault boundaries
        1. Located where plates grind past each other without either generating new lithosphere or consuming old lithosphere
        2. Most are located along mid-ocean ridges
    3. Movement along one boundary requires adjustments at others

VI. Earth's Internal Structure
  A. Earth's internal layers can be defined by
    1. Chemical composition, and/or
    2. Physical properties
  B. Layers defined by composition
    1. Crust
      a. Thin, rocky outer skin
      b. Two divisions

1. Oceanic crust
    a. Seven kilometres thick
    b. Composed of dark igneous rocks called basalt
2. Continental crust
    a. Averages 35-40 kilometres thick
    b. Composition consists of many rock types
        1. Upper crust has an average composition of a granite
        2. Lower crust is more akin to basalt
    c. Continental crust rocks are less dense and older than oceanic crust rocks

2. Mantle
    a. Over 82% of Earth's volume
    b. Solid, rocky shell
    c. Extends to a depth of 2900 kilometres
    d. Dominant rock in the uppermost mantle is peridotite
3. Core
    a. Thought to be composed of an iron-nickel alloy with minor amounts of oxygen, silicon, and sulphur
    b. Due to the extreme pressure found in the core, the density is nearly 11 g/cm^3

C. Layers defined by physical properties
1. Temperature, pressure, and density gradually increase with depth in Earth's interior
2. Changes in temperature and pressure affect the physical properties and
3. Hence, the mechanical behaviour of Earth materials
4. Five main layers of Earth based on physical properties and hence mechanical strength
    a. Lithosphere
        1. Consists of
            a. The crust and
            b. Uppermost mantle
        2. Relatively cool, rigid shell
        3. Averages about 100 kilometres in thickness, but may be 250 kilometres or more thick below the older portions of the continents
        4. Within the ocean basins it is only a few kilometres thick
    b. Asthenosphere ("weak sphere")
        1. Beneath the lithosphere, in the upper mantle
        2. Small amount of melting in the top portion
        3. Lithosphere is mechanically detached and is able to move independently of the asthenosphere
    c. Mesosphere (or lower mantle)
        1. Between 660 and 2900 kilometres
        2. Rocks are rigid but capable of very gradual flow
    d. Outer core
        1. A liquid layer
            a. Convective flow of metallic iron generates Earth's magnetic field
    e. Inner core
        1. Strong due to immense pressure
        2. Solid

VII. Earth's Spheres

A. Planet Earth is small, self-contained, and somewhat fragile

B. Earth's four interacting spheres
1. Hydrosphere
    a. Water makes Earth unique

b. Global ocean - the most prominent feature of the hydrosphere
   1. Nearly 71% of Earth's surface
   2. About 97% of Earth's water
c. Also includes the water found in streams, lakes, and glaciers
   1. Sources of fresh water
   2. Responsible for sculpting and creating many of Earth's varied landforms

2. Atmosphere
   a. Gaseous envelope that surrounds Earth
   b. Without an atmosphere many of the processes that shape Earth's surface could not operate
3. Biosphere
   a. Includes all life on Earth
   b. Influences the makeup and nature of the other three spheres
4. Geosphere

VIII. The Face of Earth

A. Earth's surface
   1. Two principal divisions
      a. Continents
      b. Ocean basins
   2. Significant difference between the continents and ocean basins is their relative density, and hence levels
   3. Shoreline is not the boundary between continents and ocean basin
      a. Continental shelf, a gently sloping platform of continental material, extends seaward from the shore
      b. Continental slope, a steep drop-off at the outer edge of the continental shelf, marks the boundary between the continents and the deep-ocean basin

B. Continents
   1. Most prominent features are linear mountain belts
      a. Not randomly distributed
      b. Two zones
         1. Circum-Pacific belt surrounding the Pacific Ocean
         2. The area that extends eastward from the Alps through Iran and the Himalayas, and then dips southward into Indonesia
   2. Shields

C. Ocean basins
   1. Ocean ridge system – the most prominent topographic feature on Earth
      a. Continuous belt that winds for more than 70,000 kilometres around the globe
      b. Composed of igneous rock that has been fractured and uplifted
   2. Deep-ocean trenches
      a. Extremely deep - occasionally more than 11,000 meters deep
      b. Relatively narrow
      c. Some are located adjacent to young mountains that flank the continents
      d. Other trenches parallel linear island chains called volcanic arcs

IX. Earth as a System

A. Earth is a dynamic planet with many interacting parts or spheres
   1. This complex and continuously interacting whole is referred to as the Earth system
   2. System – a group of interacting, or independent parts that form a complex whole

B. Parts of the Earth system are linked so that a change in one part can produce changes in any or all other parts

C. Characterized by processes that

1. Vary on spatial scales from fractions of millimetre to thousands of kilometres
2. Have time scales that range from milliseconds to billions of years

D. The Earth system is powered by
1. Sun – drives external processes that occur in the
   a. Atmosphere
   b. Hydrosphere, and
   c. At Earth's surface
2. Earth's interior – heat remaining from the formation and heat that is continuously generated by radioactive decay powers the internal processes that produce
   a. Volcanoes
   b. Earthquakes, and
   c. Mountains

E. Humans are "a part" of the Earth system, not "apart"

F. The rock cycle: part of the Earth system
1. The loop that involves the processes by which one rock changes to another
2. Basic cycle: ( ) denotes processes
   a. Magma
   b. (Cooling and solidification- crystallization)
   c. Igneous rock
   d. (Weathering)
   e. (Transportation and deposition- erosion)
   f. Sediment
   g. (cementation and compaction- lithification)
   h. Sedimentary rock
   i. (Heat and pressure- metamorphism)
   j. Metamorphic rock
   k. (Melting)
   l. Magma
3. Alternative paths

Answers to the Review Questions

1. **Uniformitarianism** states that rational observations and analyses of modern geologic processes and events give an accurate representation of geologic workings in the past. For example, seemingly inconsequential and barely recognizable stream erosion can cut a Grand Canyon, given enough time. Lateral movements of a centimetre per year can build oceans and move continents hundreds of miles, given enough time. In addition to the slow day-to-day processes, occasional, large-scale, powerful events (volcanic eruptions, earthquakes, meteorite impacts, etc.) occur as part of the very long, evolutionary history of Earth. Acceptance of the uniformitarian concept logically forces one to accept a very old age for Earth.

2. Earth's compositional boundaries include (from the surface inward): (1) the **crust**, (2) the **mantle**, and (3) the **core**. The crust is the thin, rocky outer skin divided into a thin **basaltic oceanic crust** (density ~3.0 g/cm^3) and a thicker, less homogeneous **continental crust** that essentially has the composition of a **granite** (density ~2.7 g/cm^3). The mantle is thick (~82% of Earth's volume, and dominantly composed of peridotite (density ~3.3 g/cm^3). Consideration of the density and electrical properties of the core suggest that its composition is mainly iron alloyed with nickel and a small percentage of other elements. The layers of Earth based on physical properties and mechanical behaviour as pressure and temperature increase with depth are: (1) **lithosphere-** the cool, rigid, brittle outer shell, (2) **asthenosphere-** a

comparatively weak zone with a small amount of melting at the contact with the lithosphere above, allowing the rigid plates to move independently of the asthenosphere, (3) **mesosphere** or **lower mantle**, a stronger, more rigid layer, but capable of very gradual flow (4) **outer core**, a liquid layer where the magnetic field is generated by convective flow of iron-nickel alloy, and (5) **inner core** of solid iron-nickel alloy.

3. The four major spheres of our living environment are 1) the **atmosphere**, the gaseous envelope surrounding our planet, 2) the **hydrosphere**, those environments (oceans, rivers, lakes, ice, groundwater and water vapour in the atmosphere) that are involved in the *hydrologic cycle*, 3) the **biosphere**, the diverse, surficial and near-surface environments that include all living organisms and their habitats, and 4) the **geosphere**, the soils, regolith, and crustal bedrock layers of Earth. The geosphere hosts most of the hydrosphere, forms the inorganic substrate for the biosphere, and interacts extensively with the atmosphere.

4. The evidence that Wegener and his followers gathered in support of their continental drift hypothesis included (1) the fit of the continents, which is even more convincing once continental shelves are considered, (2) fossil evidence of plants (*Glossopteris*) and animals (*Mesosaurus*) existing on continents that are now separated by vast expanses of ocean, (3) rock type and structural similarities which, like the fossil evidence, appear to be continuous from one previously-joined continent to another, and (4) paleoclimatic evidence which suggests that now-tropical and subtropical regions experienced periods of glaciation, and the existence of significant coal beds (suggesting a tropical paleoclimate) in now-temperate regions.

5. A **paradigm** is a comprehensive theory that provides a framework into which observations can be placed and understood as part of a coherent whole. The theory of plate tectonics not only provided a plausible mechanism to explain observational evidence of continental drift, but it allows us to understand the distribution of Earth's major features and processes. It is thus an important **scientific revolution**.

6. **Igneous rocks** form by cooling and crystallization of magmas, which form by melting of other igneous, sedimentary, or metamorphic rocks. **Sedimentary rocks** are composed of constituents derived from the disintegration and decomposition of other rocks (igneous, metamorphic, or sedimentary). **Metamorphic rocks** were once igneous, sedimentary, or metamorphic rocks that have since changed in texture and/or mineral composition in response to elevated temperatures and/or elevated pressures (deep burial). Therefore, all rocks are the result of various processes acting upon pre-existing rocks.

Suggested Quiz Questions

1. What was one thing that Sir William Logan and James Hutton had in common?
   a. A belief that the Earth was about 6,000 years old
   b. Scientific foundations in medicine
   c. German fathers

Questions 2 – 4: Match the term with the appropriate phrase

a. asthenosphere b. outcrop c. convection

2. ____ the circulation of hot and cool materials within the mantle

3. ____ a part of the upper mantle that is mechanically-detached from the layer beneath

4. ____ where bedrock is exposed at surface

5. Which of the following responses accurately states the basic differences between the disciplines of physical and historical geology?
   a. physical geology is the study of fossils and sequences of rock strata; historical geology is the study of how rocks and minerals were used in the past
   b. historical geology involves the study of rock strata, fossils, and geologic events, utilizing the geologic time scale as a reference; physical geology includes the study of how rocks form and of how erosion shapes the land surface

6. Which one of the following observations and conclusions is not consistent with the concept of uniformitarianism?
   a. sand rolling along a stream bottom shows that sediment is moving downstream
   b. an erupting volcano proves that burning subterranean coal beds provide the heat
   c. along a coastline, wave-cut erosional features now well above sea level indicate that the land was uplifted

7. _____________ was a Scottish physician and farmer who published *Theory of the Earth*.
   a. James Ussher b. Isaac Asteroid c. Charles Lyell d. James Hutton

8. Which of the following best describes the fundamental concept of superposition?
   a. older strata generally are deposited directly on younger strata without intervening, intermediate age strata
   b. all sedimentary deposits accumulate on older rock or sediment layers

9. _____________ forms the relatively cool, brittle plates of plate tectonics.
   a. Asthenosphere b. Lithosphere c. Mantle d. Eosphere

10. Which of the following describes a divergent plate boundary?
    a. both plates move toward the boundary; one plate sinks beneath the other
    b. both plates move away from the boundary; the gap is filled by new volcanic rock

11. Mount St. Helens and the other Cascade Range volcanoes are associated with which type of plate boundary?
    a. stable b. dipolar c. transverse d. convergent

12. _____________ form by crystallization and consolidation of molten magma.
    a. planetary nebula b. sedimentary rocks c. primary fossils d. igneous rocks

13. _____________ rocks always originate at the surface of the geosphere.
    a. secondary b. igneous c. sedimentary d. metamorphic

14. If the current trend in the polarity of the Earth's magnetic field holds, when will the use of a traditional compass become more or less obsolete?
    a. never b. 11 years c. 22 years d. about 1,500 years

15. Which of the following lists the Earth's internal layers in correct order from the center outward?
    a. outer core, inner mantle, crust
    b. inner core, crust, mantle, hydrosphere
    c. inner core, outer core, mantle, crust
    d. core, crust, mantle, hydrosphere

16. Which concept is often paraphrased as "the present is the key to the past"?
    a. biblical prophesy
    b. uniformitarianism
    c. Aristotelian logic
    d. catastrophism

17. Which natural philosophy of the 17th and early 18th centuries was based on a firm belief in a very short geologic history for the Earth?
    a. revelationism
    b. ethnocentrism
    c. uniformitarianism
    d. catastrophism

18. The _____________ layer of the Earth is molten and metallic in composition.
    a. inner core
    b. lithosphere
    c. mantle
    d. outer core

19. The famous San Andreas Fault in California is a _____________ plate boundary.
    a. convergent
    b. emergent
    c. divergent
    d. transform

20. At a _____________ plate boundary, new seafloor is created at the edges of two plates.
    a. convergent
    b. divergent
    c. transform
    d. emergent

Answers to Quiz Questions

1. b	2. c	3. a	4. b	5. b	6. b	7. d
8. b	9. b	10. b	11. d	12. d	13. c	14. d
15. c	16. b	17. d	18. d	19. d	20. b	

Minerals: The Building Blocks of Rocks 2

Learning Objectives

After reading, studying, and discussing the chapter, students should be able to:

- List the definitive characteristics that qualify certain Earth materials as minerals.
- Explain the difference between a mineral and a rock.
- Discuss the basic concepts of atomic structure as it relates to minerals.
- Compare and contrast the different types of chemical bonding.
- Discuss the internal structures of minerals.
- Explain why polymorphs, such as diamond and graphite, have such different physical properties.
- List and discuss the various physical properties of minerals.
- Explain the structure and importance of silicate minerals.
- List the common rock-forming silicate minerals and relate their physical properties, such as cleavage and fracture, to their silicate structure.
- Discuss other mineral classes and give an example from each class.
- List several of the important nonsilicate minerals and their economic uses.

Thinking inside the box:

□ 2.1 Understand the nature of kryptonite in fact and fiction, and the relationship of the new mineral jadarite to the description of kryptonite in the 2006 movie *Superman Returns*.
□ 2.2 Understand what constitutes a “gemstone”.

Chapter Summary

- A *mineral* is a naturally-occurring, inorganic solid that possesses a definite chemical composition and a definitive molecular structure that gives it a unique set of physical properties. Most *rocks* are aggregates composed of two or more minerals.

- The building blocks of minerals are *elements*. An *atom* is the smallest particle of matter that still retains the characteristics of an element. Each atom has a *nucleus*, which contains *protons* (particles with positive electrical charges) and *neutrons* (particles with no electrical charge). Orbiting the nucleus of an atom in regions called *energy levels*, or *shells*, are *electrons*, which have negative electrical charges. The number of protons in an atom's nucleus determines its *atomic number* and the name of the element.

- Atoms combine with each other to form more complex substances called *compounds*. Atoms bond together by gaining, losing, or sharing electrons with other atoms. In *ionic bonding*, one or more electrons are transferred from one atom to another, giving the atoms a net positive or negative charge. The resulting electrically-charged atoms are called *ions*. Ionic compounds consist of oppositely charged ions assembled in a regular, crystalline structure that allows for the maximum attraction of ions, given their sizes. NaCl, table salt (the mineral halite) is a good example (Figure 2.5). Another type of bond, the *covalent bond*, is produced when atoms share electrons. The silica (silicon-oxygen) tetrahedron, building bock of the common rock-forming minerals, is covalently bonded (Figure 2.7).

- The properties of minerals include *crystal habit*, *lustre*, *colour*, *streak*, *hardness*, *cleavage*, *fracture*, and *specific gravity*. In addition, a number of special physical and chemical properties (*taste*, *smell*, *elasticity*, *malleability*, *feel*, *magnetism*, *double refraction*, and *chemical reaction to hydrochloric acid*) are useful in identifying certain minerals. Each mineral has a unique set of properties that can be used for identification.

- Of the over 4600 minerals, no more than a few dozen make up most of the rocks of Earth's crust and these are classified as *rock-forming minerals*. Eight elements (oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium) make up the bulk of these minerals and represent over 98 percent (by weight) of Earth's continental crust.

- The most common mineral class is the *silicates*. All silicate minerals have the negatively charged *silicon-oxygen tetrahedron* as their fundamental building block. In some silicate minerals the tetrahedra are joined in chains (the pyroxene and amphibole groups); in others, the tetrahedra are arranged into sheets (the micas, biotite, and muscovite), or three-dimensional networks (the feldspars and quartz). The tetrahedra and various silicate structures are often bonded together by the positive ions of iron, magnesium, potassium, sodium, aluminum, and calcium.

- The *nonsilicate* mineral classes, which contain several economically important minerals, include the *oxides* (e.g., hematite, mined for iron), *sulphides* (e.g., sphalerite, mined for zinc, and galena, mined for lead), *sulphates* (e.g., gypsum), *halides* (e.g., halite and sylvite), and *native elements* (e.g., gold and silver). The more common nonsilicate rock-forming minerals include the *carbonate minerals*, calcite and dolomite, as well as halite, sylvite, and gypsum that formed when lakes and seas evaporated.

Chapter Outline

I. Minerals
   A. Mineral: definition
      1. Naturally occurring
      2. Inorganic
      3. Solid
      5. Orderly internal structure
      4. Definite chemical structure
   B. Rock: a solid, naturally-occurring mass of mineral, or mineral-like, matter

II. The Composition of Minerals
   A. Elements
      1. 118 known, 90 naturally occurring
      2. Most minerals are a combination of two or more elements joined to form a chemically stable and electrically-neutral compound
   B. Atomic structure
      1. Nucleus, which contains
         a. Protons - positive electrical charges
         b. Neutrons – no electrical charge
      2. Electrons
         a. Surround nucleus
         b. Negatively charged zones called energy levels, or shells