

The Islamia University of Bahawalpur

University College of Agriculture and Environmental Sciences

ES-302

Introduction to Earth Science

3(2-1)

Class: B. S Environmental Sciences
2nd Semester, (session: Fall 2019-23)

Semester: Spring - 2020

Instructor: Dr. Zaffar Malik

Class Room: R. 7 # Environmental undergraduate Lab

Class days and timings: Practical: Tuesday (1:00 pm-2:00 pm)
Theory : Tuesday (08:30 am-09:20 pm) & Thursday (01:00 pm-02:00 pm)

Contact No. zafar_agrarian@yahoo.com

Course Objective: This course aims to provide knowledge about the basic concepts of geology and geography. This will help the student to get the knowledge about different types of rocks and minerals, the process of their formation, different earth processes like mountain buildings, earth quakes, weathering and erosion. The student will also be introduced to work with different types of maps and GPS system.

Teaching Methodology:

1. The class will be conducted in a lecture and discussion environment, where the class teacher will lead discussion and students will be encouraged to participate and ask question at the end of each class session. The theory part will be well supported by practical accordingly.
2. Students will be expected to read assignments in advance and these will be tested through quizzes and presentations in the class.
3. Teacher will be available for meeting class students immediately

Books Prescribed

1. Earth evolving system: The history of plant earth by Ronald martin, Jones & Bartlett, Learning: LLC an Ascend Learning Company USA 2013.
2. Earth: An Introduction of physical geology, Tarbuck, E. J. lutgens, F. K., abd Tasa, D. 9th Edition, Prentice Hall; 2007
3. Historical Geology: Evolution of Earth and Life through Time, Wicander, R., and Monroe, J., 5th Edition, Brooks/Cole, 2007
4. Earth Scieces, Tarbuck, E.J., Lutgens, F.K., and Tasa, D., 11th Edition, Prentice hall, 2005

COURSE CONTENTS (Theory):

Session 1	Major components of earth system and their characteristics
Session 2	Geological time and processes
Session 3	Geology as historical science, scientific method and study of earth evolving systems
Session 4	Processes and interaction of earth solid systems
Session 5	Rock cycle: Igneous rocks, metamorphic and sedimentary rocks
Session 6	The hydrosphere and hydrological cycles
Sessions 7 & 8	Ocean circulation, biosphere-biogeography, energy relationship, biogeo-chemical cycles
Session 9	<i>Mid term Examination</i>

Session 10	Sedimentary rocks and fossils, processes of weathering, biogenic sedimentary rocks
Session 11	Marine environment, coral reefs, continental shelves
Session 12	Terrestrial environment: forests, deserts, glaciers, lakes
Session 13	Time and Stratigraphy: relative ages, absolute ages, evolution of geological time scale
Session 14	Plate Tectonics, structure of earth, hypothesis of continental drifts
Session 15	The dynamic earth and natural hazards: earth quack and volcanos, land instability
Session 16	Weather hazards, fires and coastal hazards, humans and environment
Sessions 17-18	Introduction to Holocene, sea level rise, climate change at millennial time scale, continental time scale and at multidecadal time scale
Session 19	<i>Final term examination</i>

Practical:

- Study of earth relief features with the help of topographical models and thematic maps
- Introduction of samples of rocks and minerals
- Use of Brunton compass and GPS
- One study tour in the field.

Testing and Grading:

1. Learning will be accomplished through lectures, class exercises, and student participation in classroom discussion and presentations.
2. Grading will tend to focus on your overall performance rather than one or two aspects. A midterm examination and a comprehensive final examination will be given.
3. Another portion of the course grade will include the discussion/attendance grade, quizzes, and/or other assignments.
4. The mid-term examination will be graded for 30% marks and final examination will have a weightage of 50% marks. 20% marks are allocated as sessional both in theory and practical separately. These will be awarded on the basis of attendance, class and practical participation, quizzes, presentations and conduct during the semester etc.
5. Attendance in classes is compulsory as per university rules. Students not meeting the required attendance will not be allowed to take the final examination.
6. Test questions may be taken from textbook readings, additional material discussed in class, questions/ answers covered in the class and practical and/or other assigned readings.

Please Note:

In the unlikely event of an unplanned absence by the instructor, the material to have been covered during that class meeting will be shifted to the next meeting. If a test was scheduled for that class meeting, the test will be given during the next class meeting. In the event of any necessary planned absences, information on schedule changes will be provided in advance.

Appointment with Instructor:

Instructor will be available for meeting class students immediately after each class, and/ or in the office by appointment made in advance.

Introduction to Earth Science



- There are four major areas in Earth Science. Astronomy is the study of space. Meteorolgy is the study of the Earth's atmosphere. Oceanography is the study of the Earth's oceans. The study of Earth's surface, materials, and processes is Geology.

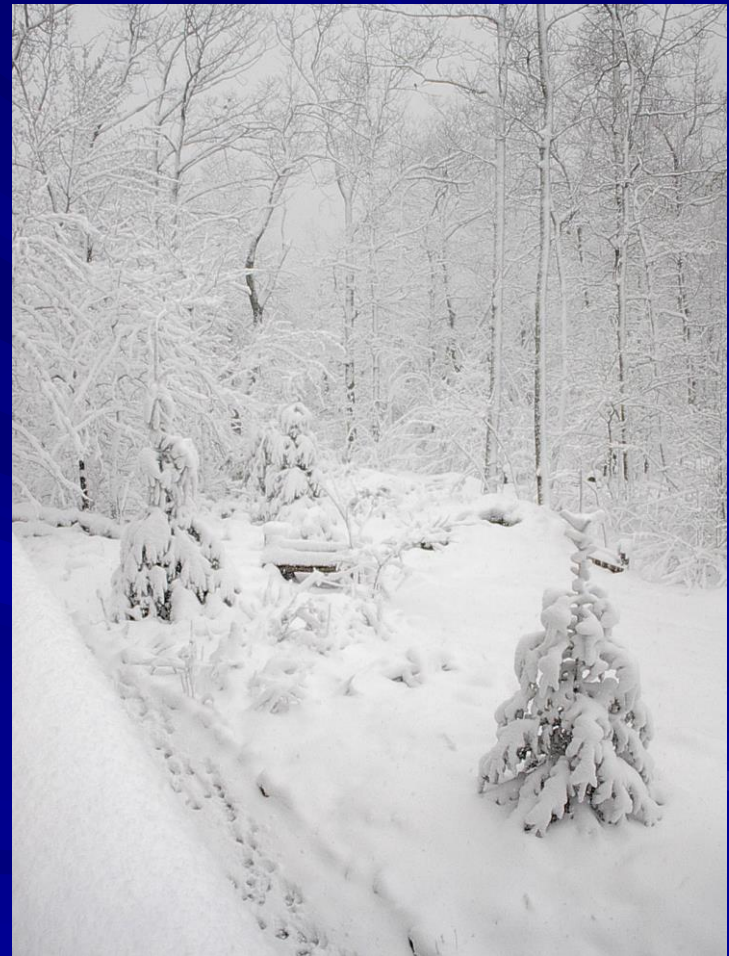
Astronomy

- In astronomy we will study such topics as the sun and other stars, planets and other objects in our solar system, lunar phases, tides, and eclipses.



Meteorology

- Here we will take a look at cloud and precipitation types, storms such as hurricanes and tornadoes, and fronts, pressure systems, and weather maps.



Oceanography

- We will explore our four major oceans, the properties of seawater, ocean floor and coastline features, ocean sediments, and major ocean currents.



Geology

- Here we tackle a variety of topics including minerals and rocks, volcanoes, earthquakes, faults and folds, soils, erosion, mountains, plate tectonics, and geologic history.



Earth Systems

- Although we study four branches of earth science, there are many interactions between earth's systems. You are standing on the litho sphere. You are breathing in part of the atmo sphere. If you went to the beach or canoed down the James you where visiting the hydro sphere. And you and all the other living things on earth make up the bio sphere.

Scientific Method

- When solving problems scientifically we follow a series of steps to avoid wasting time, effort, and resources. These steps include:
- 1. Defining the **problem** (may include research or observation)
- 2. Stating a **hypothesis** (explanation of observation; must be able to be tested)
- 3. **Testing** the hypothesis (involves measurement of one variable at a time)
- 4. Analyzing the **results** (data organized in graphs, tables, and charts)
- 5. Drawing **conclusions** (returning to step #2 as needed)

This is not a rigid, step-by-step outline.

Additional Chapter 1 Vocabulary

- Control - the standard for comparison in an experiment
- Constants - all the variables we are not testing and trying to keep the same
- Dependent Variable - factor in an experiment that may change if the independent variable changes
- Independent Variable - factor that the experimenter changes
- Metric Units - also known as SI units; uses a decimal base 10 system; such units as liters, meters, and grams.
- Scientific Notation - shorthand where a number is expressed as a multiplier and a power of 10
- Theory - explanation that is consistent with repeated observations, can be tested and make predictions, and is as simple as possible
- Law - basic fact describing behavior of a natural phenomenon

Chapter 1 Introduction to Earth Science

Summary

1.1 What Is Earth Science?

➡ Earth science is the name for the group of sciences that deals with Earth and its neighbors in space.

- **Geology** means “study of Earth.” Geology is divided into physical geology and historical geology.
- **Oceanography** is the study of the Earth’s oceans, as well as coastal processes, seafloor topography, and marine life.
- **Meteorology** is the study of atmosphere and the processes that produce weather and climate.
- **Astronomy** is the study of the universe.

➡ The nebular hypothesis suggests that the bodies of our solar system evolved from an enormous rotating cloud called the solar nebula. It was made up mostly of hydrogen and helium, with a small percentage of heavier elements.

- Shortly after the Earth formed, melting occurred in the Earth’s interior. Gravity caused denser elements to sink to Earth’s center. Less dense elements floated toward the surface. As a result, Earth is made up of layers of materials that have different properties.

1.2 A View of Earth

➡ Earth can be thought of as consisting of four major spheres: the hydrosphere, atmosphere, geosphere, and biosphere.

- The **hydrosphere** is the water portion of Earth.
- The **atmosphere** is an envelope of gases that surrounds Earth.
- The **geosphere** is the layer of Earth under both the atmosphere and the oceans. It includes the core, the mantle, and the crust.
- The **biosphere** is made up of all life on Earth.

➡ Because the geosphere is not uniform, it is divided into three main parts based on differences in composition—the core, the mantle, and the crust.

- The **core**, Earth’s innermost layer, is located just below the mantle.
- The **mantle** is 2890 kilometers thick. It is located below the Earth’s crust and above the Earth’s core.
- The **crust** is the thin, rocky, outer layer of Earth.

➡ The theory of plate tectonics provided geologists with a model to explain how earthquakes and volcanic eruptions occur and how continents move.

- Destructive forces wear away Earth’s surface.
- Constructive forces build up the Earth’s surface.
- Tectonic plates move constantly over the Earth’s mantle.

Chapter 1 Introduction to Earth Science**1.3 Representing Earth's Surface**

☛ **Latitude** is the distance north or south of the equator, measured in degrees. **Longitude** is the distance east or west of the prime meridian, measured in degrees.

- The equator divides Earth into two hemispheres—the northern and the southern.
- The prime meridian and the 180° meridian divide Earth into eastern and western hemispheres.

☛ **No matter what kind of map is made, some portion of the surface will always look either too small, too big, or out of place. Mapmakers have, however, found ways to limit the distortion of shape, size, distance, and direction.**

☛ **Topographic maps show elevation using contour lines.**

- A **topographic map** represents Earth's three-dimensional surface in two dimensions.
- A **contour line** indicates the elevation of the land.
- A **contour interval** tells the difference in elevation between adjacent contour lines.
- A scale helps to determine distances on a map.

☛ **A geologic map shows the type and age of exposed rocks.**

☛ **Today's technology provides us with the ability to more precisely analyze Earth's physical properties.**

- Satellites and computers provide more accurate maps.

1.4 Earth System Science

☛ **Earth system science aims to understand Earth as a system made up of interacting parts, or subsystems.**

☛ **A system can be any size group of interacting parts that form a complex whole.**

- In a closed system, matter does not enter or leave the system.
- In an open system, energy and matter flow into and out of the system.
- Most natural systems are open systems.
- The Earth system is powered by energy from two sources.

☛ **One source of energy for Earth systems is the sun, which drives external processes that occur in the atmosphere, hydrosphere, and at Earth's surface.**

- The sun's energy drives weather, climate, ocean circulation, and erosion.

Chapter 1 Introduction to Earth Science**☛ Earth's interior is the second source of energy for Earth systems.**

- Heat powers the internal processes that cause volcanoes, earthquakes, and mountains.
- The Earth system's processes are interlinked. A change in one part of the system can affect the whole system.

☛ Our actions produce changes in all of the other parts of the Earth system.

- Environment refers to things that surround and influence an organism.
- Environmental science focuses on the relationships between people and Earth.
- Resources include water, soil, metallic and nonmetallic minerals, and energy.

☛ Renewable resources can be replenished over relatively short time spans.

- Plants, animals, and energy such as water, wind, and the sun are some examples of renewable resources.

☛ Although these and other resources continue to form, the processes that create them are so slow that it takes millions of years for significant deposits to accumulate.

- Iron, aluminum, copper, oil, natural gas, and coal are examples of nonrenewable resources.
- Population growth equals an increase in demand for resources.

☛ Significant threats to the environment include air pollution, acid rain, ozone depletion, and global warming.

- Understanding Earth's environment and the impact of humans on limited resources is necessary for the survival and well-being of the planet.

1.5 What Is Scientific Inquiry?**☛ Once data have been gathered, scientists try to explain how or why things happen in the manner observed. Scientists do this by stating a possible explanation called a scientific hypothesis.**

- A hypothesis becomes a scientific theory if it survives tests and analyses.

☛ A scientific theory is well tested and widely accepted by the scientific community and best explains certain observable facts.

- Scientific investigations often have four steps—collecting facts; developing a hypothesis; observing and experimenting; and accepting, modifying, or rejecting the hypothesis.

Chapter 2 Minerals

Summary

2.1 Matter

➤ An element is a substance that cannot be broken down into simpler substances by chemical or physical means.

➤ An atom is the smallest particle of matter that contains the characteristics of an element.

- The central region of an atom is called the nucleus. The nucleus contains protons and neutrons.
- The number of protons in the nucleus of an atom is called the **atomic number**.
- Electrons are located in regions called **energy levels**.

➤ Atoms with the same number of protons but different numbers of neutrons are isotopes of an element.

- The **mass number** of an atom is the total mass of the atom expressed in atomic mass units.
- Many elements have atoms whose nuclei are unstable. These atoms disintegrate by radioactive decay.

➤ A compound is a substance that consists of two or more elements that are chemically combined in specific proportions.

➤ When an atom's outermost energy level does not contain the maximum number of electrons, the atom is likely to form a chemical bond with one or more other atoms.

- Chemical combinations of the atoms of elements are called **compounds**.
- **Chemical bonds** are the forces that hold atoms together in a compound. There are three principal types of chemical bonds: ionic, covalent, and metallic.
- An atom can gain or lose one or more electrons. The atom then has an electrical charge and is called an **ion**.

➤ Ionic bonds form between positive and negative ions.

➤ Covalent bonds form when atoms share electrons.

➤ Metallic bonds form when electrons are shared by metal ions.

Chapter 2 Minerals

2.2 Minerals

➡ **A mineral is a naturally occurring, inorganic solid with an orderly crystalline structure and a definite chemical composition.**

- Minerals form by natural processes.
- Minerals are solids in normal temperature ranges on Earth.
- Minerals are crystalline. Their atoms or ions are arranged in an orderly and repetitive way.
- Minerals have definite chemical composition. They usually are compounds formed of two or more elements.
- Most minerals are inorganic chemical compounds.

➡ **There are four major processes by which minerals form: crystallization from magma, precipitation, changes in pressure and temperature, and formation from hydrothermal solutions.**

- Magma is molten rock from deep in the Earth. As it cools, it forms minerals.
- Substances dissolved in water may react to form minerals.
- Changes in temperature and pressure can make new minerals form.
- When hot solutions touch existing minerals, chemical reactions take place and form new minerals.

➡ **Common minerals, together with the thousands of others that form on Earth, can be classified into groups based on their composition.**

➡ **Silicon and oxygen combine to form a structure called the silicon-oxygen tetrahedron.**

- **Silicates** are made of silicon and oxygen. They are the most common group of minerals on Earth.
- Most silicate minerals crystallize from cooling magma.

➡ **Carbonates are minerals that contain the elements carbon, oxygen, and one or more other metallic elements.**

➡ **Oxides are minerals that contain oxygen and one or more other elements, which are usually metals.**

➡ **Sulfates and sulfides are minerals that contain the element sulfur.**

➡ **Halides are minerals that contain a halogen ion plus one or more other elements.**

➡ **Native elements are minerals that only contain one element or type of atom.**

Chapter 2 Minerals

2.3 Properties of Minerals

- ➡ Small amounts of different elements can give the same mineral different colors.
- ➡ Streak is the color of a mineral in its powdered form.
- ➡ Luster is used to describe how light is reflected from the surface of a mineral.
- ➡ Crystal form is the visible expression of a mineral's internal arrangement of atoms.
- ➡ The Mohs scale consists of 10 minerals arranged from 10 (hardest) to 1 (softest).
 - **Hardness** is a measure of the resistance of a mineral to being scratched.
 - You can test hardness by rubbing a mineral against another mineral of known hardness. One will scratch the other, unless they have the same hardness.
- ➡ **Cleavage** is the tendency of a mineral to cleave, or break, along flat, even surfaces.
 - Minerals may have cleavage in one or more directions.
- ➡ Minerals that do not show cleavage when broken are said to fracture.
 - **Fracture** is the uneven breakage of a mineral.
- ➡ **Density** is a property of all matter that is the ratio of an object's mass to its volume.
- ➡ Some minerals can be recognized by other distinctive properties.

Chapter 3 Rocks

Summary

3.1 The Rock Cycle

➤ A rock is any solid mass of mineral or mineral-like matter that occurs naturally as part of our planet.

➤ The three major types of rocks are igneous rocks, sedimentary rocks, and metamorphic rocks.

➤ Interactions among Earth's water, air, and land can cause rocks to change from one type to another. The continuous processes that cause rocks to change make up the rock cycle.

➤ When magma cools and hardens beneath the surface or as the result of a volcanic eruption, igneous rock forms.

- **Magma** is molten material that forms deep beneath Earth's surface.
- **Lava** is magma that reaches the surface.
- **Weathering** is a process in which rocks are physically and chemically broken down by water, air, and living things.
- **Sediment** is made up of weathered pieces of earth materials.

➤ Eventually, sediment is compacted and cemented to form sedimentary rock.

- Sedimentary rocks buried deep within Earth's surface are subjected to great pressure and high temperatures.

➤ Under extreme pressure and temperature conditions, sedimentary rock will change in metamorphic rock.

➤ Processes driven by heat from Earth's interior are responsible for forming both igneous and metamorphic rocks. Weathering and the movement of weathered materials are external processes powered by energy from the sun and by gravity. Processes on and near Earth's surface produce sedimentary rocks.

3.2 Igneous Rocks

➤ Rocks that form when magma hardens beneath Earth's surface are called intrusive igneous rocks.

- The root word of *igneous* means "fire."

➤ When lava hardens, the rocks that form are called extrusive igneous rocks.

➤ Texture and composition are two characteristics used to classify igneous rocks.

Chapter 3 Rocks

- Texture is determined by the size, shape, and the arrangement of crystals.
 - Composition is determined by the proportions of light and dark minerals.
- ➡ **Slow cooling results in the formation of large crystals.**
- ➡ **Rapid cooling of magma or lava results in rocks with small, interconnected mineral grains.**
- **Porphyritic texture** occurs in rocks with different-size minerals that cool at different rates.
 - **Granitic composition** occurs when igneous rocks contain mostly quartz and feldspar.
 - **Basaltic composition** occurs when rocks contain many dark silicate materials.
 - **Andesitic composition** occurs in rocks with a combination of granitic and basaltic rocks.
 - **Ultramafic** rocks are composed almost entirely of dark silicate minerals.

3.3 Sedimentary Rocks

- ➡ **Erosion involves weathering and the removal of rock. When an agent of erosion—water, wind, ice, or gravity—loses energy, it drops the sediments. This process is called deposition.**
- Sediments form when solids settle out of a fluid, such as water or air.
 - **Compaction** and **cementation** change sediments into sedimentary rock.
- ➡ **Compaction is a process that squeezes, or compacts, sediments.**
- ➡ **Cementation takes place when dissolved minerals are deposited in the tiny spaces among the sediments.**
- ➡ **Just like igneous rocks, sedimentary rocks can be classified into two main groups according to the way they form.**
- **Clastic sedimentary rocks** are made of weathered bits of rocks and minerals.
 - The size of the sediments in clastic sedimentary rocks determines their grouping.
 - **Chemical sedimentary rocks** form when dissolved minerals separate from water solutions.
- ➡ **The many unique features of sedimentary rocks are clues to how, when, and where the rocks formed.**
- The oldest layers in sedimentary rock formations are at the bottom.
 - Fossils are found in sedimentary rocks and can provide much information about the rocks that contain them.

Chapter 3 Rocks

3.4 Metamorphic Rocks

➤ **Most metamorphic changes occur at elevated temperatures and pressures. These conditions are found a few kilometers below Earth's surface and extend into the upper mantle.**

- **Metamorphism** refers to the changes in mineral composition and texture of a rock subjected to high temperature and pressure within Earth.

➤ **During contact metamorphism, hot magma moves into rock.**

- This usually results in minor changes in rocks.

➤ **Regional metamorphism results in large-scale deformation and high-grade metamorphism.**

- This usually results in intense changes such as mountain building.

➤ **The agents of metamorphism are heat, pressure, and hydrothermal solutions.**

- **Hydrothermal solutions** occur when hot, water-based solutions escape from a mass of magma.

➤ **The texture of metamorphic rocks can be foliated or nonfoliated.**

- **Foliated metamorphic rocks** have a layered or banded appearance.
- **Nonfoliated metamorphic rocks** do not have a banded texture and usually contain only one mineral.

Chapter 4 Earth's Resources

Summary

4.1 Energy and Mineral Resources

☛ A renewable resource can be replenished over fairly short time spans such as months, years, or decades.

☛ By contrast, a nonrenewable resource takes millions of years to form and accumulate.

- Population growth and a higher standard of living are depleting existing resources.

☛ Fossil fuels include coal, oil, and natural gas.

- A fossil fuel is any hydrocarbon used as a source of energy.

☛ Some energy experts believe that fuels derived from tar sands and oil shales could become good substitutes for dwindling petroleum supplies.

- Mining tar sand has significant environmental drawbacks.
- Oil shale has less heat energy than crude oil and is costly to process.

☛ Some of the most important mineral deposits form through igneous processes and from hydrothermal solutions.

- Ore is a useful metallic mineral that can be mined at a profit.
- Gold, silver, copper, mercury, lead, platinum, and nickel are examples of metallic minerals produced by igneous processes.
- Most hydrothermal deposits are formed by hot, metal-rich fluids left by magma.
- Placer deposits are formed when eroded heavy minerals settle quickly from moving water.

☛ Nonmetallic mineral resources are extracted and processed either for the nonmetallic elements they contain or for their physical and chemical properties.

- Nonmetallic mineral resources are useful for building materials, industrial minerals, and manufacturing chemicals and fertilizers.

4.2 Alternate Energy Sources

☛ Solar energy has two advantages: the “fuel” is free, and it’s nonpolluting.

☛ In nuclear fission, the nuclei of heavy atoms such as uranium-235 are bombarded with neutrons. The uranium nuclei then split into smaller nuclei and emit neutrons and heat energy.

- About 7% of U.S. energy needs are met by nuclear power.

Chapter 4 Earth's Resources

- Although it was once believed that nuclear power would be a safe and clean energy source, cost and safety are obstacles to expanded nuclear power.
 - Fears about radioactive materials were realized in 1986, when a reactor at Chernobyl caused two explosions.
- ➡ **Some experts estimate that in the next 50 to 60 years, wind power could meet between 5 to 10 percent of the country's demand for electricity.**
- Wind energy is a promising source of energy, but technological advances are needed to fully realize its potential.
- ➡ **The water held in a reservoir behind a dam is a form of stored energy that can be released through the dam to produce electric power.**
- **Hydroelectric power**, which is generated by falling water, drives turbines that produce electricity.
 - About 5% of the country's electricity comes from hydroelectric power.
 - Limited usable sites and the finite lifetime of hydroelectric dams are both obstacles to further expansion.
- ➡ **Hot water is used directly for heating and to turn turbines to generate electric power.**
- **Geothermal energy** is harnessed by tapping natural underground reservoirs of steam and hot water.
 - Geothermal power is nonpolluting but reservoirs are easily depleted.
- ➡ **Tidal power is harnessed by constructing a dam across the mouth of a bay or an estuary in coastal areas with a large tidal range. The strong in-and-out flow that results drives turbines and electric generators.**

4.3 Water, Air, and Land Resources

- ➡ **Each day, people use fresh water for drinking, cooking, bathing, and growing food.**
- Less than one percent of Earth's water is usable fresh water.
 - **Point source pollution** is pollution that comes from a known and specific location.
 - **Nonpoint source pollution** is pollution that does not have a specific point of origin.
 - **Runoff** is the water that flows over the land rather than seeping into the ground. It often carries nonpoint pollution.
 - Water pollution can have serious health effects for humans.
- ➡ **The chemical composition of the atmosphere helps maintain life on Earth.**

Chapter 4 Earth's Resources

- Pollution can change the chemical composition of the atmosphere and disrupt its natural cycles and functions.
- **Global warming**, caused by increased carbon dioxide in the atmosphere, is the unnatural warming of the lower atmosphere.

➡ **Earth's land provides soil and forests, as well as mineral and energy resources.**

- Removing and using resources from Earth's crust can damage the environment.

4.4 Protecting Resources

➡ **Starting in the 1970s, the federal government passed several laws to prevent or decrease pollution and protect resources.**

- Although they comprise only 6% of the world's population, Americans use about one third of the world's resources.
- **Conservation** is the careful use of resources.

➡ **In 1970, Congress passed the Clean Air Act, the nation's most important air pollution law.**

- The Clean Air Act limited the amount of pollutants allowed in the air, resulting in improved air quality.

➡ **Protecting land resources involves preventing pollution and managing land resources wisely.**

- Farmers are using new soil conservation practices to prevent the loss of topsoil.
- Some farmers and gardeners use fewer pesticides and inorganic fertilizers.
- **Compost** is partly decomposed organic material that is used as fertilizer.
- Better landfill management and disposal techniques prevent waste seepage.
- **Recycling** is the collecting and processing of used items so they can be made into new products.

Chapter 5 Weathering, Soil, and Mass Movements

Summary

5.1 Weathering

➡ **Mechanical weathering occurs when physical forces break rock into smaller and smaller pieces without changing the rock's mineral composition.**

➡ **In nature, three physical processes are especially important causes of mechanical weathering: frost wedging, unloading, and biological activity.**

- In nature, water finds its way into cracks in a rock. When the water freezes, it expands. This enlarges the cracks in the rock. Over time, the rock breaks into pieces. This is called **frost wedging**.
- Sections of rock that are wedged loose may tumble into large piles of rock debris called **talus**, which typically form at the base of steep, rocky cliffs.
- Unloading is when large masses of igneous rock are exposed through uplift and erosion, reducing the pressure on the igneous rock. Slabs of the outer rock separate like the layers of an onion and break loose in a process called **exfoliation**.
- Plants, animals, and humans all cause mechanical weathering.

➡ **Chemical weathering is the transformation of rock into one or more new compounds.**

- The most important agent of chemical weathering is water.
- Chemical weathering changes the properties of rock.
- Spheroidal weathering is a type of chemical weathering that changes the physical shape of the rock as well as its chemical composition.
- Mechanical weathering increases the rate of chemical weathering.

➡ **Two other factors that affect the rate of weathering are rock characteristics and climate.**

- Different rock types weather at different rates.
- Temperature and moisture both affect the rate of weathering.

5.2 Soil

➡ **Soil is the part of the regolith that supports the growth of plants.**

- **Regolith** is the layer of rocks and mineral fragments that covers nearly all of Earth's land surface.
- Composition, texture, and structure are three important characteristics of soil.

Chapter 5 Weathering, Soil, and Mass Movements

☛ **Soil has four major components: mineral matter, or broken-down rock; organic matter, or humus, which is the decayed remains of organisms; water; and air.**

- The amount of these components in soil varies depending on the type of soil.
- Soil texture is the proportions of different particle sizes in soil. Texture strongly affects a soil's ability to support plant life.
- Plant cultivation, erosion, and water solubility are all affected by soil structure.

☛ **The most important factors in soil formation are parent material, time, climate, organisms, and slope.**

- Parent material is the source of the mineral matter in soil.
- Temperature and precipitation, or climate, has the greatest effect on soil formation.
- In the nitrogen cycle, bacteria convert nitrogen gas into nitrogen compounds that plants can use.

☛ **Soil varies in composition, texture, structure, and color at different depths.**

- These variations divide the soil into zones known as **soil horizons**.
- A vertical section through all of the soil horizons is called a **soil profile**.
- Mature soils often have three distinct soil horizons—the A horizon or topsoil, the B horizon or subsoil, and the C horizon, which contains partially weathered parent material.

☛ **Three common types of soil are pedalfer, pedocal, and laterite.**

- **Pedalfers** usually form in temperate areas that receive more than 63 cm of rain each year. They contain large amounts of iron oxide and aluminum-rich clay.
- **Pedocals** are found in the drier western United States in areas that have grasses and brush vegetation. They contain abundant calcite and are a light gray-brown.
- **Laterites** form in hot, wet tropical areas where chemical weathering is intense. These are rich in iron oxide and aluminum oxide. Laterites contains almost no organic matter and few nutrients.

☛ **Human activities that remove natural vegetation, such as farming, logging, and construction, have greatly accelerated soil erosion.**

- Soils are one of the most abused resources on Earth.
- Water, wind, and other forces such as climate, soil characteristics, and slope all affect the rate of erosion.
- Erosion can be controlled through planting windbreaks, terracing hillsides, plowing in contours, and rotating crops.

Chapter 5 Weathering, Soil, and Mass Movements

5.3 Mass Movements

➡ The transfer of rock and soil downslope due to gravity is called **mass movement**.

- Most landforms are caused by both weathering and mass movement.

➡ Among the factors that commonly trigger mass movements are **saturation of surface materials with water, oversteepening of slopes, removal of vegetation, and earthquakes**.

➡ Geologists classify mass movements based on the kind of material that moves, how it moves, and the speed of movement.

- A **rockfall** occurs when rocks or rock fragments fall freely through the air. This is common on steep slopes.
- In a **slide**, a block of material moves suddenly along a flat, inclined surface. Slides that include segments of bedrock are called **rockslides**.
- A **slump** is the downward movement of a block of material along a curved surface.
- A **mudflow** is a mass movement of soil and rock fragments containing a large amount of water, which moves quickly downslope.
- **Earthflows** are flows that move relatively slowly—from about a millimeter per day to several meters per day. They occur most often on hillsides in wet regions.
- The slowest type of mass movement is **creep**, which usually travels only a few millimeters or centimeters per year.

Chapter 6 Running Water and Groundwater

Summary

6.1 Running Water

☞ Water constantly moves among the oceans, the atmosphere, the solid Earth, and the biosphere. This unending circulation of Earth's water supply is the water cycle.

- Energy from the sun and gravity power the water cycle.
- **Infiltration** is the movement of surface water into rock or soil through cracks and pore spaces.
- Plants also absorb water and release it into the atmosphere through **transpiration**.

☞ Balance in the water cycle means the average annual precipitation over Earth equals the amount of water that evaporates.

☞ The ability of a stream to erode and transport materials depends largely on its velocity.

- **Gradient** is the slope or steepness of a stream channel.
- A **stream channel** is the course the water in a stream follows.
- The **discharge** of a stream is the volume of water flowing past a certain point in a given unit of time.

☞ While gradient decreases between a stream's headwaters and mouth, discharge increases.

- A **tributary** is a stream that empties into another stream.

☞ Base level is the lowest point to which a stream can erode its channel.

- There are two types of base level—ultimate base level and temporary base level. Sea level is the ultimate base level. Temporary base levels include lakes and main streams that act as base level for their tributaries.
- A stream in a broad, flat-bottomed valley that is near its base level often develops a course with many bends called **meanders**.

6.2 The Work of Streams

☞ Streams generally erode their channels lifting loose particles by abrasion, grinding, and by dissolving soluble material.

- Increased turbulence equals greater erosion.

☞ Streams transport sediment in three ways.

1. in solution (dissolved load)
2. in suspension (suspended load)
3. scooting or rolling along the bottom (bed load)

Chapter 6 Running Water and Groundwater

- **Bed load** is the sediment that is carried by a stream along the bottom of its channel.
 - The **capacity** of a stream is the maximum load it can carry.
- ➡ **Deposition occurs as streamflow drops below the critical settling velocity of a certain particle size. The sediment in that category begins to settle out.**
- The sorted material deposited by a stream is called **alluvium**.
 - A **delta** is an accumulation of sediment formed where a stream enters a lake or ocean.
 - A **natural levee** is a ridge made up mostly of coarse sediments that parallels some streams.
- ➡ **A narrow V-shaped valley shows that the stream's primary work has been downcutting toward base level.**
- A **floodplain** is the flat, low-lying portion of a stream valley subject to periodic flooding. It is caused by the side-to-side cutting of a stream close to base level.
- ➡ **Most floods are caused by rapid spring snow melt or storms that bring heavy rains over a large region.**
- A **flood** occurs when the discharge of a stream becomes so great that it exceeds the capacity of its channel and overflows its banks.
- ➡ **Measures to control flooding include artificial levees, flood control dams, and placing limits on floodplain development.**
- ➡ **A drainage basin is the land area that contributes water to a stream.**
- An imaginary line called a **divide** separates the drainage basins of one stream from another.

6.3 Water Beneath the Surface

- ➡ **Much of the water in soil seeps downward until it reaches the zone of saturation. The zone of saturation is the area where water fills all of the open spaces in sediment and rock. Groundwater is the water within this zone.**
- The upper limit of the zone of saturation is the **water table**.
- ➡ **Groundwater moves by twisting and turning through interconnected small openings. The groundwater moves more slowly when the pore spaces are smaller.**
- **Porosity** is the volume of open spaces in rock or soil.
 - The **permeability** of a material is its ability to release a fluid.
 - Permeable rock layers or sediments that transmit groundwater freely are **aquifers**. Aquifers are the source of well water.

Chapter 6 Running Water and Groundwater**🔑 A spring forms whenever the water table intersects the ground surface.**

- A **spring** is a flow of groundwater that emerges naturally at the ground surface.
- A **geyser** is a hot spring in which a column of water shoots up with great force at various intervals.
- A **well** is a hole bored into the zone of saturation.
- In an **artesian well**, groundwater rises on its own under pressure.

🔑 Overuse and contamination threatens groundwater supplies in some areas.

- Supplies of groundwater are finite.

🔑 Groundwater erosion forms most caverns at or below the water table in the zone of saturation.

- A **cavern** is a naturally formed underground chamber.
- **Travertine** is a type of limestone formed over great spans of time from dripping water containing calcium carbonate. The resulting cave deposits are known as dripstone.

🔑 Karst areas typically have irregular terrain, with many depressions called sinkholes.

- **Karst topography** an area that has been shaped largely by the dissolving power of groundwater, and has a land surface with numerous depressions called sinkholes.
- A **sinkhole** is a depression made in a region where groundwater has removed soluble rock.

Chapter 7 Glaciers, Deserts, and Wind

Summary

7.1 Glaciers

➡ A valley glacier is a stream of ice that flows between steep rock walls from a place near the top of the mountain valley.

- An **ice age** is a period of time when much of Earth's land is covered in glaciers.
- A **glacier** is a thick ice mass that moves slowly over the land surface.
- The **snowline** is the lowest elevation in a particular area that remains covered in snow all year.
- **Valley glaciers** are ice masses that slowly advance down valleys that were originally occupied by streams.

➡ Ice sheets are sometimes called continental ice sheets because they cover large regions where the climate is extremely cold. They are huge compared to valley glaciers.

- **Ice sheets** are enormous ice masses that flow in all directions and cover everything but the highest land.
- The Antarctic Ice Sheet holds nearly two-thirds of Earth's fresh water.

➡ The movement of glaciers is referred to as flow. Glacial flow happens two ways: plastic flow and basal slip.

- Plastic flow occurs when brittle ice begins to distort and change shape.
- Gravity causes basal slip, where the ice mass slips and slides downhill.

➡ The glacial budget is the balance or lack of balance between accumulation at the upper end of a glacier and loss, or wastage, at the lower end.

- When a glacier loses ice faster than it gains ice, it retreats.
- When a glacier gains ice faster than it loses ice, it advances.

➡ Many landscapes were changed by the widespread glaciers of the recent ice age.

- Glaciers erode the land by plucking and abrasion.

➡ Glaciers are responsible for a variety of erosional landscape features, such as glacial troughs, hanging valleys, cirques, arêtes, and horns.

- After glaciation, alpine valleys are no longer narrow.
- As a glacier moves down a valley once occupied by a stream, the glacier widens, deepens, and straightens the valley. The once narrow V-shaped valley is changed into a U-shaped **glacial trough**.
- A glacier carves cirques, arêtes, and horns by plucking and removing rocks.

Chapter 7 Glaciers, Deserts, and Wind

➡ **Glacial drift applies to all sediments of glacial origin, no matter how, where, or in what form they were deposited. There are two types of glacial drift: till and stratified drift.**

- **Till** is the material deposited directly by the glacier. It is deposited as the glacier melts and drops its load of rock debris.
- **Stratified drift** is sediment laid down by glacial meltwater.

➡ **Glaciers are responsible for a variety of depositional features, including moraines, outwash plains, kettles, drumlins, and eskers.**

- When glaciers melt, they leave layers or ridges of till called **moraines**.
- During the recent ice age, glaciers covered almost 30 percent of Earth's land. The ice sheets significantly changed drainage patterns over large regions, creating lakes and changing the directions of rivers.

7.2 Deserts

➡ **Much of the weathered debris in deserts has resulted from mechanical weathering.**

➡ **Though mechanical weathering is more significant in deserts, chemical weathering is not completely absent. Over long time spans, clays and thin soils do form.**

➡ **In the desert, most streams are ephemeral—they only carry water after it rains.**

- Ephemeral streams, also known as washes or arroyos, may flow for only a few hours or a few days.
- Because they are found in areas that lack much vegetation, ephemeral streams are susceptible to dangerous flash floods.

➡ **Most desert streams dry up long before long before they ever reach the ocean. The streams are quickly depleted by evaporation and soil infiltration.**

- An **alluvial fan** is a cone of debris left when an intermittent stream flows out of a canyon, loses speed, and quickly dumps its sediment.
- After heavy rain or snowmelt in the mountains, streams may flow across the alluvial fans to the center of the basin, converting the basin floor into a shallow **playa lake**. Playa lakes last only a few days or weeks.

➡ **Most desert erosion results from running water. Although wind erosion is more significant in deserts than elsewhere, water does most of the erosional work in deserts.**

- Although running water in the desert is infrequent, it is an important geological force.

Chapter 7 Glaciers, Deserts, and Wind

7.3 Landscapes Shaped by Wind

➡ **Wind erodes in the desert in two ways: deflation and abrasion.**

- Strong winds transport and deposit sediment.
- **Deflation** is the lifting and removal of loose particles such as clay and silt.
- Deflation creates a stony surface layer called **desert pavement** when it removes all the sand and silt and leaves only coarser particles.
- Abrasion happens when wind-blown sand cuts and polishes exposed rock surfaces.

➡ **The wind can create landforms when it deposits its sediments, especially in deserts and along coasts. Both layers of loess and sand dunes are landscape features deposited by wind.**

- Loess is windblown silt that blankets the landscape.

➡ **Unlike deposits of loess, which form blanket-like layers over broad areas, winds commonly deposit sand in mounds or ridges called dunes.**

- Whenever wind encounters an obstruction, no matter how small, dunes may form.

➡ **What form sand dunes assume depends on the wind direction and speed, how much sand is available, and the amount of vegetation.**

- Barchan dunes are solitary sand dunes shaped like crescents.
- Transverse dunes form in long ridges that are perpendicular to the direction of the wind.
- Barchanoid dunes form at right angles to the wind and look like several barchan dunes placed side by side.
- Longitudinal dunes form parallel to the wind.
- Parabolic dunes look like backwards barchan dunes. They often form along coasts and where there is some vegetation.
- Star dunes have three or four sharp ridges, and their bases look like stars.

Chapter 8 Earthquakes and Earth's Interior

Summary

8.1 What Is an Earthquake?

☛ **Faults are fractures in Earth where movement has occurred.**

- An **earthquake** is the vibration of Earth produced by the rapid release of energy within the lithosphere.
- Earthquakes are caused by slippage along a break in the lithosphere, called a **fault**.
- The point within Earth where an earthquake starts is called the **focus**.
- The energy released by an earthquake travels in all directions from the focus in the form of **seismic waves**.
- The movement that occurs along faults during earthquakes is a major factor in changing Earth's surface.
- The **epicenter** is the location on the surface directly above the focus.

☛ **According to the elastic rebound hypothesis, most earthquakes are produced by the rapid release of energy stored in rock that has been subjected to great forces. When the strength of the rock is exceeded, it suddenly breaks, releasing some of its stored energy as seismic waves.**

- Forces inside Earth slowly deform the rock that makes up Earth's crust, causing rock to bend.
- **Elastic rebound** is the tendency for the deformed rock along a fault to spring back after an earthquake.
- An **aftershock** is an earthquake that occurs sometime soon after a major earthquake.

8.2 Measuring Earthquakes

☛ **Earthquakes produce two main types of seismic waves—body waves and surface waves.**

- There are two types of body waves: P waves and S waves.
- **P waves** are push-pull waves that push (or compress) and pull (or expand) particles in the direction the waves travel.
- **S waves** shake particles at right angles to the waves' direction of travel.
- When body waves reach the surface, they produce **surface waves**. Surface waves are the most destructive seismic waves.

☛ **Scientists have developed an instrument to record seismic waves—the seismograph.**

- A seismograph produces a time record of ground motion during an earthquake called a **seismogram**. A seismogram shows all three types of seismic waves.

Chapter 8 Earthquakes and Earth's Interior

➡ **The Richter scale and the moment magnitude scale measure earthquake magnitude. The Modified Mercalli scale is based on earthquake intensity.**

- The **moment magnitude** is derived from the amount of displacement that occurs along a fault. Scientists today use the moment magnitude scale to measure earthquakes.

➡ **A travel-time graph, data from seismograms made at three or more locations, and a globe can be used to determine an earthquake's epicenter.**

8.3 Earthquake Hazards

➡ **Earthquake-related hazards include seismic shaking, liquefaction, landslides and mudflows, and tsunamis.**

- The ground vibrations caused by seismic waves are called seismic shaking.
- **Liquefaction** is a process earthquakes can cause in which soil and rock saturated with water turn into liquid and can no longer support buildings.
- A **tsunami** is a wave formed when the ocean floor shifts suddenly during an earthquake.
- Earthquakes can cause landslides and mudflows, two destructive events that can quickly bury entire towns under debris.

➡ **Earthquake damage and loss of life can be reduced by determining the earthquake risk for an area, building earthquake-resistant structures, and following earthquake safety precautions.**

- A **seismic gap** is an area along a fault where there has not been any earthquake activity for a long period of time.

8.4 Earth's Layered Structure

➡ **Earth's interior consists of three major layers defined by their chemical composition—the crust, mantle, and core.**

- The **crust**, the thin, rocky outer layer of Earth, is divided into oceanic and continental crust.
- Under the crust is the **mantle**—a solid, rocky shell that extends to a depth of 2890 kilometers.
- The **core** is the innermost layer of Earth. The core is divided into an outer core and an inner core.

➡ **Earth can be divided into layers based on physical properties—the lithosphere, the asthenosphere, the lower mantle, the outer core, and the inner core.**

- Earth's outermost layer consists of the crust and uppermost mantle and forms a relatively cool, rigid shell called the **lithosphere**.

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- Beneath the lithosphere lies a soft, comparatively weak layer known as the **asthenosphere**.
- Near the base of the mantle lies a more rigid layer called the lower mantle.
- The **outer core** is a liquid layer beneath the mantle that is 2260 kilometers thick. The outer core generates Earth's magnetic field.
- The **inner core** is the solid innermost layer of Earth, which has a radius of 1220 kilometers.

➤ During the twentieth century, studies of the paths of P and S waves through Earth helped scientists identify the boundaries of Earth's layers and determine that the outer core is liquid.

- The boundary that separates the crust from the underlying mantle is known as the **Moho**.

➤ To determine the composition of Earth's layers, scientists studied seismic data, rock samples from the crust and mantle, meteorites, and high-pressure experiments on Earth materials.

Chapter 9 Plate Tectonics

Summary

9.1 Continental Drift

➤ According to Wegener's hypothesis of continental drift, the continents had once been joined to form a single supercontinent.

- He called this supercontinent **Pangaea**, meaning *all land*.
- Wegener believed that about 200 million years ago Pangaea began breaking into smaller continents.

➤ Fossil evidence for continental drift includes several fossil organisms found on different landmasses.

- The distribution of Mesosaurus fossils supported the argument that South America and Africa had once been joined.

➤ Matching types of rock in several mountain belts that today are separated by oceans provide evidence for continental drift.

➤ Wegener found glacial deposits showing that between 220 million and 300 million years ago, ice sheets covered large areas of the Southern Hemisphere. Deposits of glacial till occurred at latitudes that today have temperate or even tropical climates: southern Africa, South America, India, and Australia.

➤ The main objection to Wegener's hypothesis was that he could not describe a mechanism capable of moving the continents.

- The theory of plate tectonics proved that Wegener was correct.

9.2 Sea-Floor Spreading

➤ Earth's mid-ocean ridge system forms the longest features on Earth's surface. The system winds more than 7,000 kilometers through all the major ocean basins like the seam on a baseball.

- **Sonar**, which stands for **s**ound **n**avigation and **r**anging, is a system that uses sound waves to calculate the distance to an object.
- As scientists mapped the ocean floor using sonar, they found long, curved valleys along the edges of some ocean basins called **deep-ocean trenches**.
- The **mid-ocean ridge** is a long chain of mountains extending the length of the ocean.
- A **rift valley** is a deep, central valley that runs down the center of a ridge.

➤ In the process of sea-floor spreading, new ocean floor forms along Earth's mid-ocean ridges, moves slowly outward across ocean basins, and finally sinks back into the mantle beneath deep-ocean trenches.

- In the process of **subduction**, ocean floor returns to the mantle as it sinks beneath a deep-ocean trench.

Chapter 9 Plate Tectonics

➡ Evidence for sea-floor spreading included magnetic stripes in ocean-floor rock, earthquake patterns, and measurements of the ages of ocean floor rocks.

- Earth's magnetic field occasionally reverses polarity. As certain rocks form, they acquire the polarity that Earth's magnetic field has at the time.
- **Paleomagnetism** is the study of changes in Earth's magnetic field, as shown by patterns of magnetism in rocks that have formed over time.

9.3 Theory of Plate Tectonics

➡ In the theory of plate tectonics, Earth's lithospheric plates move slowly relative to each other, driven by convection currents in the mantle.

- The lithosphere is broken into several huge pieces, called plates.
- Deep faults separate the different plates.
- There are three types of plate boundaries. Each plate contains a combination of each of the three types.
- **Divergent boundaries** are found where two of Earth's plates move apart.
- **Convergent boundaries** form where two plates move together.
- **Transform fault boundaries** occur where two plates grind past each other.

➡ Most divergent boundaries are spreading centers located along the crests of mid-ocean ridges. Some spreading centers, however, occur on the continents.

➡ At convergent boundaries, plates collide and interact, producing features including trenches, volcanoes, and mountain ranges.

- A **continental volcanic arc** is a range of volcanic mountains produced in part by the subduction of oceanic lithosphere.
- When two oceanic slabs converge, the resulting volcanic activity can build a chain of islands called a **volcanic island arc**.
- When two pieces of continental lithosphere collide, the two continents eventually merge, creating complex mountains.

➡ At a transform fault boundary, plates grind past each other without destroying the lithosphere.

Chapter 9 Plate Tectonics

9.4 Mechanisms of Plate Motions

➤ **Convection currents in the mantle provide the basic driving forces for plate motions.**

- A **convection current** is the continuous flow that occurs in a fluid because of differences in density.
- The hot, but solid rock of the mantle behaves in a plastic way—that is, it can flow slowly over geologic times.
- The heat sources for mantle convection include energy released by radioactive isotopes in the mantle and heat from the core itself.
- In the process called *whole mantle convection*, rock rises from the lower mantle toward the top of the mantle, then sinks back down. This process takes millions of years.

➤ **The sinking of cold ocean lithosphere directly drives the motions of mantle convection through slab-pull and ridge-push. Some scientists think mantle plumes are involved in the upward flow of rock in the mantle.**

- In **slab-pull**, the force of gravity pulls old ocean lithosphere, which is relatively cold and dense, down into the deep mantle.
- In **ridge push**, the stiff ocean lithosphere slides down the asthenosphere that is elevated near mid-ocean ridges.
- A **mantle plume** is a rising column of hot, solid mantle rock at a hot spot.

Chapter 10 Volcanoes and Other Igneous Activity

Summary

10.1 Volcanoes and Plate Tectonics

➡ Magma forms in the crust and upper mantle when solid rock partially melts. The formation of magma depends on several factors, including heat, pressure, and water content.

- When hot yet solid mantle rock is less dense than the surrounding rock, it rises, decreasing the pressure on the rock. This lowers the rock's melting point, allowing **decompression melting** to occur.

➡ Most volcanoes form along divergent and convergent plate boundaries. Some volcanoes form far from plate boundaries above “hot spots” in the crust.

- At divergent boundaries, volcanic activity occurs where the plates pull apart.
- The **Ring of Fire** is the long belt of volcanoes that circles much of the Pacific Ocean.
- Volcanic activity within a plate is called **intraplate volcanism**.
- A small volcanic region a few hundred kilometers across that forms above a mantle plume is called a **hot spot**.

10.2 The Nature of Volcanic Eruptions

➡ The primary factors that determine whether a volcano erupts explosively or quietly include characteristics of the magma and the amount of dissolved gases in the magma.

- **Viscosity** is a substance's resistance to flow.
- A **vent** is an opening to the Earth's surface. During explosive eruptions, the gases trapped in magma push the magma out.

➡ Depending on the type of eruption, volcanoes may produce lava flows or eject pyroclastic materials, or both. All volcanic eruptions also emit large amounts of gases.

- Particles from volcanic eruptions are called **pyroclastic materials**.
- The fragments ejected during eruptions range in size from very fine dust and ash to pieces that weigh several tons.

➡ The three main volcanic types are shield volcanoes, cinder cones, and composite cones.

- Repeated eruptions of lava or pyroclastic material eventually build a mountain called a **volcano**.

Chapter 10 Volcanoes and Other Igneous Activity

- Located at the summit of many volcanoes is a steep-walled depression called a **crater**.
- **Shield volcanoes** are produced by the accumulation of fluid basaltic lavas and have the shape of a broad, slightly domed structure.
- A **cinder cone** is a small volcano built primarily of pyroclastic material ejected from a single vent.
- A **composite cone** is a large, nearly symmetrical volcanic mountain composed of layers of both lava and pyroclastic deposits.

➤ **Volcanic landforms also include calderas, volcanic rocks, and lava plateaus.**

- A **caldera** is a depression in a volcanic mountain.
- A **volcanic neck** is a landform made of magma that hardened in a volcano's pipe and later was exposed by eruption.
- A **lava plateau** is a volcanic landform produced by repeated eruptions of very fluid, basaltic lava. Instead of building a core, the lava spreads out over a wide area.

➤ **Volcano hazards include lava flows, volcanic ash, pyroclastic flows, and mudflows.**

- A **lahar** occurs when water-soaked volcanic ash and rock slide rapidly downhill.

10.3 Intrusive Igneous Activity

➤ **Types of plutons include sills, laccoliths, and dikes. Geologists classify plutons and other bodies of intrusive igneous rock according to their size, shape, and relationship to surrounding rock layers.**

- The structures that result from the cooling and hardening of magma beneath Earth's surface are called **plutons**. Uplift and erosion can expose plutons at the surface.
- A **sill** is a pluton that forms where magma flows between parallel layers of sedimentary rock.
- A **laccolith** is a lens-shaped pluton that has pushed the overlying rock layers upward.
- A **dike** is a pluton that forms when magma moves into fractures that cut across rock layers.

➤ **A batholith is a body of intrusive rock that has a surface exposure of more than 100 square kilometers.**

- Batholiths are the largest bodies of intrusive igneous rocks.

Chapter 11 Mountain Building

Summary

11.1 Forces in Earth's Crust

☛ The factors that affect the deformation of rock include temperature, pressure, rock type, and time.

- **Deformation** is any change in the original shape and/or size of a rock body.
- **Stress** is the force per unit area acting on a solid. When rocks are under stresses greater than their own strength, they begin to deform.
- The change in shape or volume of a body of rock as a result of stress is called a strain.

☛ The three types of stress that cause deformation of rocks are tensional stress, compressional stress, and shear stress.

- When rocks are squeezed or shortened, the stress is compressional.
- When rocks are pulled in opposite directions, the stress is tensional.
- When a body of rock is distorted, the stress is shear.

☛ Because of isostasy, deformed and thickened crust will undergo regional uplift both during mountain building and for a long period afterward.

- The concept of a floating crust in gravitational balance is called **isostasy**.
- The process of establishing a new level of gravitational balance is called **isostatic adjustment**.

11.2 Folds, Faults, and Mountains

☛ The three main types of folds are anticlines, synclines, and monoclines.

- An **anticline** is formed by the upfolding, or arching, of rock layers.
- Often found in association with anticlines are downfolds, or troughs, called **synclines**.
- **Monoclines** are large, step-like folds in sedimentary strata.

☛ The major types of faults are normal faults, reverse faults, thrust faults, and strike-slip faults.

- The rock surface just above the fault is called the hanging wall, and the rock surface below the fault is called the footwall.
- In a **normal fault**, the hanging wall moves down relative to the footwall.
- In a **reverse fault**, the hanging wall moves up relative to the footwall.
- **Thrust faults** are reverse faults with dips of less than 45°.
- Faults in which the movement is horizontal and parallel to the trend, of the fault surface are called **strike-slip faults**.

Chapter 11 Mountain Building

➡ The major types of mountains include volcanic mountains, folded mountains, fault-block mountains, and dome mountains.

- Geologists refer to the collection of processes involved in mountain building as **orogenesis**.
- Mountains that are formed primarily by compressional stresses, which create folds in the rock layers are called **folded mountains**.
- Compressional stress is the major factor that forms **folded mountains**.
- **Fault-block mountains** form as large blocks of crust are uplifted and tilted along normal faults.
- As the crust is stretched along a normal fault, a block called a **graben**, which is bounded by normal faults, drops down.
- Grabens produce an elongated valley bordered by relatively uplifted structures called **horsts**.

➡ Up-and-down movements of the crust can produce a variety of landforms, including plateaus, domes, and basins.

11.3 Mountains and Plates

➡ The convergence of two oceanic plates mainly produces volcanic mountains.

- The result of this collision is the formation of a volcanic island arc.

➡ The convergence of an oceanic plate and a continental plate produces volcanic mountains and folded mountains.

- During subduction, sediment is scraped from the subducting plate. The sediment forms a large mass called an **accretionary wedge**, which becomes attached to the overriding crustal block.

➡ At a convergent boundary, a collision between two plates carrying continental crust will form folded mountains. This happens because the continental crust is not dense enough to be subducted.

➡ The mountains that form along ocean ridges at divergent plate boundaries are fault-block mountains made of volcanic rock.

- These mountains are elevated because of isostasy.

➡ Volcanic mountains at hot spots, as well as some upwarped mountains and fault-block mountains, can form far from plate boundaries.

➡ The process of accretion enlarges continental landmasses and forms mountains along the edges of continents.

- When fragments of crust collide with a continental plate they become stuck to or embedded into the continent through **accretion**.
- A **terrane** is any crustal fragment with a distinct geologic history.

Chapter 12 Geologic Time

Summary

12.1 Discovering Earth's History

➡ In studying Earth's history, geologists make use of three main ideas:

- the rock record provides evidence of geological events and life forms of the past;
- processes observed on Earth in the present also acted in the past;
- Earth is very old and has changed over geologic time.
- The principle of **uniformitarianism** states that the physical, chemical, and biological laws that operate today have also operated in the geologic past.

➡ In relative dating, geologists follow several principles: the law of superposition, the principle of original horizontality, and the principle of cross-cutting relationships.

- The method that geologists use to place rocks in chronological order is called **relative dating**.
- The **law of superposition** states that in an undeformed sequence of sedimentary rocks, each layer is older than the one above it and younger than the one below it.
- The **principle of original horizontality** states that layers of sediment are generally deposited in a horizontal position.
- The **principle of cross-cutting relationships** states that when a fault cuts through rock layers, or when magma intrudes other rocks and hardens, then the fault or intrusion is younger than the rocks around it.

➡ Methods that geologists use to interpret the rock record include the study of inclusions and unconformities. Geologists also correlate rock layers at different locations.

- Inclusions are pieces of one rock unit that are contained within another.
- A surface that represents a break in the rock record is termed an **unconformity**.
- Geologists use **correlation** to match rocks of similar age in different locations.

12.2 Fossils: Evidence of Past Life

➡ The different types of fossils include petrified fossils, molds and casts, carbon films, preserved remains, and trace fossils.

- An **extinct** organism is one that no longer exists on Earth.
- A **fossil** is the remains or traces of an organism preserved from the geologic past.

Chapter 12 Geologic Time

➡ Two conditions that favor preservation of an organism as a fossil are **rapid burial** and the **possession of hard parts**.

➡ Two major scientific developments helped scientists explain the fossil record: the **principle of fossil successions** and the **theory of evolution**.

- The **principle of fossil succession** states that fossil organisms succeed one another in a definite and determinable order.
- The **theory of evolution** states that life forms have changed over time, or evolved, from simpler to more complex forms.
- In **natural selection**, individuals that are better adapted to their environment are more likely to survive and reproduce than others of the same type.
- Organisms possess certain traits, called **adaptations**, that affect their ability to survive and reproduce.

➡ Geologists used fossils to improve the correlation of rock layers and **reconstruct past environments**.

- An **index fossil** is the fossil of an organism that was geographically widespread and abundant in the fossil record, but that existed for only a limited span of time.

12.3 Dating With Radioactivity

➡ During radioactive decay, **unstable atomic nuclei spontaneously break apart, or decay, releasing energy**.

- **Radioactivity** is the process by which atoms decay.
- A **half-life** is the amount of time necessary for one half of the nuclei in a sample to decay to its stable isotope.

➡ In **radiometric dating**, scientists measure the ratio between the **radioactive parent isotope** and the **daughter products** in a sample to be dated. The older the sample, the more daughter product it contains.

- **Radiometric dating** is a way of calculating the absolute ages of rocks and minerals that contain certain radioactive isotopes.
- **Radiocarbon dating** is a method to date organic materials using carbon-14.

➡ When an organism dies, the amount of **carbon-14** gradually decreases as it decays. By comparing the ratio of carbon-14 to carbon-12 in a sample, **radiocarbon dates** can be determined.

➡ To determine the age of **sedimentary rock**, geologists must relate the **sedimentary rock** to **datable masses of igneous rock**.

12.4 The Geologic Time Scale

➡ The **geologic time scale** is a record that includes both **geologic events** and **major developments in the evolution of life**.

Chapter 12 Geologic Time

- The **geologic time** scale is a timeline that divide Earth's history into units representing specific intervals of time.

 **Eons represent the longest intervals of geologic time. Eons are divided into eras. Each era is subdivided into periods. Finally, periods are divided into still smaller units called epochs.**

- Geologists divide Earth's history into four long units called **eons**.
- The first three eons when Earth formed, the atmosphere and oceans developed, and early life evolved are grouped together and called **Precambrian time**.
- There are three **eras** within the Phanerozoic eon: the Paleozoic, Mesozoic, and Cenozoic eras.
- Different geologic events, environmental conditions, and life forms characterize each **period**.
- We live in the Holocene epoch of the Quaternary (or Neogene) period.

Chapter 13 Earth's History

Summary

13.1 Precambrian Time

🔑 Earth formed about 4.56 billion years ago. During Precambrian time, the atmosphere and oceans formed and plate tectonics began to build up continental landmasses.

- There are large core areas of Precambrian rocks that make up the surface of some continents. These areas are called **shields** because they roughly resemble a warrior's shield in shape.
- 🔑 The earliest life probably evolved in the oceans. Later, one-celled organisms evolved that used light energy to produce food through photosynthesis. These organisms consisted of simple cells called prokaryotes. Slowly, more complex cells, called eukaryotes, evolved. Late in the Precambrian, multicelled organisms with soft bodies evolved.
 - In **photosynthesis**, organisms use carbon dioxide and the energy of sunlight to make food in the form of carbohydrates. Photosynthesis releases oxygen into the environment.
 - Cyanobacteria are one-celled organisms that make their own food through photosynthesis.
 - **Stromatolites** are layered mounds of calcium carbonate deposited by cyanobacteria.
 - A **prokaryote** is a cell that lacks a nucleus. Earth's earliest organisms were prokaryotes.
 - About 1.8 billion years ago, cells evolved that were larger and more complex than prokaryotes. These cells, called **eukaryotes**, had nuclei.

13.2 Paleozoic Era: Life Explodes

🔑 Environmental changes that have affected the course of evolution on Earth include the formation and breakup of continents, mountain building, volcanic activity, changes in climate, and changes in sea level.

- Rapid change can lead to the extinction of many groups of organisms in a relatively short time, in an event called **mass extinction**.
- 🔑 Many new groups of organisms evolved in a relatively short time in an event called the "Cambrian Explosion."
 - The breakup of the supercontinent Rodinia created new environments, which contributed to the Cambrian Explosion.

Chapter 13 Earth's History

➡ **During the Ordovician period, more complex communities of organisms developed in the oceans. The first land-dwelling plants evolved.**

- **Gondwana** is a late Paleozoic continent that formed the southern portion of Pangea.
- Parts of five of today's continents make up Gondwana—South America, Africa, Australia, Antarctica, and parts of Asia.

➡ **The Silurian Period was a time of reef-building and continued evolution of the fishes in the seas. By the end of the period, plants and animals were becoming widespread on land.**

➡ **During the Devonian period, jawed fishes and sharks evolved in the seas. Plants continued to colonize the land, along with insects and other small arthropods. Later, amphibians evolved with adaptations for life on land.**

- During the Devonian period there were two large continents.
- To the north, continental landmasses collided to form a new large continent, called **Laurasia**.
- Toward the end of the Devonian period, amphibians evolved from fishes.
- An **amphibian** is a four-legged animal with lungs for breathing, that lives on land but lays its eggs in water.

➡ **The Carboniferous period saw the development of great “coal swamp forests” in wet, tropical regions. Amphibians and winged insects became common, and the first reptiles evolved.**

- **Reptiles** evolved from amphibians and are animals that lay leathery-shelled eggs that can survive out of water. They were among the first animals that evolved during the Carboniferous period.

➡ **As the Permian period began, Earth's continents were joined in the supercontinent Pangaea. The evolution of life during the period continued trends that began during the Carboniferous. But the Permian ended with the greatest mass extinction in geologic history.**

- Nearly 250 million years ago, the Permian period ended with a mass extinction that killed 96 percent of life on Earth.

Chapter 13 Earth's History

13.3 Mesozoic Era: Age of Reptiles

➡ Pangaea continued as a single, large landmass through most of the Triassic period. After a slow recovery from the Permian extinction, many kinds of reptiles evolved. Late in the period, the first mammals appeared.

- **Mammals** are warm-blooded animals that nourish their young with milk.
- **Gymnosperms** are a group of plants with seeds that lack a protective outer coat.

➡ Pangaea continued to split apart during the Jurassic period. Many kinds of dinosaurs evolved and became widely distributed.

➡ A greater diversity of life forms evolved during the Cretaceous period. Dinosaurs, birds, flowering plants, and small mammals all flourished.

- **Angiosperms** are plants that produce flowers and seeds with an outer covering.
- ➡ Most scientists think that a large meteorite collided with Earth and caused the mass extinction at the end of the Cretaceous.

13.4 Cenozoic Era: Age of Mammals

➡ Mammals succeeded during the Cenozoic because of adaptations that enabled them to out-compete the surviving reptiles.

➡ During the Tertiary period, mountain building and climate changes accompanied the breakup of Pangaea. Mammals became widespread and diverse worldwide.

➡ Two factors have greatly affected life on Earth during the Quaternary period: the advance and retreat of continental glaciers, which have formed and melted about 30 times in the last 3 million years, and the migration of *Homo sapiens*—modern humans—to every corner of Earth.

- In the 1940s, astronomer Milutin Milankovitch proposed that three different cycles, related to Earth's movements, were the main cause of ice ages. These cycles are called **Milankovitch cycles**.

Chapter 14 The Ocean Floor

Summary

14.1 The Vast World Ocean

- Nearly 70 percent of Earth's surface is covered by global ocean.
 - **Oceanography** is a science that draws on the methods and knowledge of geology, chemistry, physics, and biology to study all aspects of the world ocean.
- The world ocean can be divided into four main ocean basins—the Pacific Ocean, the Atlantic Ocean, the Indian Ocean, and the Arctic Ocean.
- The topography of the ocean floor is as diverse as that of continents.
 - **Bathymetry** (*bathos* = depth, *metry* = measurement) is the measurement of ocean depths and the charting of the shape or topography of the ocean floor.
- Today's technology—particularly sonar, satellites, and submersibles—allows scientists to study the ocean floor in a more efficient and precise manner than ever before.
 - **Sonar** is an acronym for **sound navigation and ranging**. Sonar calculates ocean depth by recording the time it takes sound waves to reach the ocean floor and return.
 - A **submersible** is a small underwater craft used for deep-sea research. Submersibles are used to collect data about areas of the ocean that were previously unreachable by humans.

14.2 Ocean Floor Features

- The ocean floor regions are the continental margins, the ocean basin floor, and the mid-ocean ridge.
 - The zone of transition between a continent and the adjacent ocean basin floor is known as the **continental margin**.
- In the Atlantic Ocean, thick layers of undisturbed sediment cover the continental margin, an area with very little volcanic or earthquake activity.
- In the Pacific Ocean, oceanic crust is plunging beneath continental crust. This force results in a narrow continental margin that experiences both volcanic activity and earthquakes.
- Continental shelves contain important mineral deposits, large reservoirs of oil and natural gas, and huge sand and gravel deposits.
 - The **continental shelf** is the gently sloping submerged surface extending from the shoreline.

Chapter 14 The Ocean Floor

- Marking the seaward edge of the continental shelf is the **continental slope**, a steep gradient that leads to the deep-ocean floor.
- Deep, steep-sided valleys known as **submarine canyons** are cut into the continental slope.
- **Turbidity currents** are occasional movements of dense, sediment-rich water down the continental slope.
- In regions where trenches do not exist, the steep continental slope merges into a more gradual incline known as the **continental rise**.
- Between the continental margin and the mid-ocean ridge lies the **ocean basin floor**. This region includes deep-ocean trenches, abyssal plains, seamounts, and guyots.

➡ **Trenches form at sites of plate convergence where one moving plate descends beneath another and plunges back into the mantle.**

- Deep-ocean trenches are long, narrow creases in the ocean floor that form the deepest parts of the ocean.

➡ **The sediments that make up abyssal plains are carried there by turbidity currents or deposited as a result of suspended sediments settling.**

- **Abyssal plains** are deep, extremely flat features. These regions are possibly the most level places on Earth.
- Submerged volcanic peaks on the ocean floor are **seamounts**.

➡ **New ocean floor is formed at mid-ocean ridges as magma rises between the diverging plates and cools.**

- The **mid-ocean ridge** is an interconnected system of mountains that have developed on newly formed crust. The rifts at the crest of ridges represent divergent plate boundaries.
- **Seafloor spreading** occurs at divergent plate boundaries where two lithospheric plates are moving apart.

14.3 Seafloor Sediments

➡ **Ocean-floor sediments can be classified according to their origin into three broad categories: terrigenous sediments, biogenous sediments, and hydrogenous sediments.**

➡ **Terrigenous sediments consist primarily of mineral grains that were eroded from continental rocks and transported to the ocean.**

- **Terrigenous sediment** is sediment that originates on land.

➡ **Biogenous sediments consist of shells and skeletons of marine animals and algae.**

- **Biogenous sediment** is sediment that is biological in origin.
- **Calcareous ooze** is the most common biogenous sediment, and is produced from the calcium carbonate shells of organisms.

Chapter 14 The Ocean Floor

- **Siliceous ooze** is composed primarily of the shells of diatoms—single-celled algae—and radiolarians—single-celled animals that have shells made out of silica.

➡ **Hydrogenous sediment consists of minerals that crystallize directly from ocean water through various chemical reactions.**

- Hydrogenous sediments make up only a small portion of the overall sediment in the ocean.

14.4 Resources From the Seafloor

➡ **Oil and natural gas are the main energy products currently being obtained from the ocean floor.**

- Oil and natural gas are the ancient remains of microscopic organisms.

➡ **Most oceanic gas hydrates are created when bacteria break down organic matter trapped in ocean-floor sediments.**

- **Gas hydrates** are compact chemical structures made of water and natural gas.

➡ **Other major resources from the ocean floor include sand and gravel, evaporative salts, and manganese nodules.**

- **Manganese nodules** are hard lumps of manganese and other metals that precipitate around a smaller object.

Chapter 15 Ocean Water and Ocean Life

Summary

15.1 The Composition of Seawater

➡ Because the proportion of dissolved substances in seawater is such a small number, oceanographers typically express salinity in parts per thousand.

- **Salinity** (*salinus* = salt) is the total amount of solid material dissolved in water.

➡ Most of the salt in seawater is sodium chloride, common table salt.

➡ Chemical weathering of rocks on the continents is one source of elements found in seawater.

➡ The second major source of elements found in seawater is from Earth's interior.

- Some of the processes affecting the salinity of seawater are runoff and melting icebergs, which decrease salinity, and evaporation and the formation of sea ice, which increase salinity.

➡ The ocean's surface water temperature varies with the amount of solar radiation received, which is primarily a function of latitude.

- The **thermocline** (*thermo* = heat, *cline* = slope) is the layer of ocean water between about 300 meters and 1000 meters, where there is a rapid change of temperature with depth.

➡ Seawater density is influenced by two main factors: salinity and temperature.

- **Density** is defined as mass per unit volume. It can be thought of as a measure of how heavy something is for its size.
- The **pycnocline** (*pycno* = density, *cline* = slope) is the layer of ocean water between about 300 meters and 1000 meters where there is a rapid change of density with depth.

➡ Oceanographers generally recognize a three-layered structure in most parts of the open ocean: a shallow surface mixed zone, a transition zone, and a deep zone.

- The **mixed zone** is the area of the surface created by the mixing of water by waves, currents, and tides. The mixed zone has nearly uniform temperatures.
- The transition zone includes a thermocline and associated pycnocline.
- Sunlight never reaches the deep zone, which accounts for about 80 percent of ocean water.

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- In high latitudes, the three-layered structure of the open ocean does not exist because there is no rapid change in temperature or density with depth.

15.2 The Diversity of Ocean Life

🔑 Marine organisms can be classified according to where they live and how they move.

🔑 Plankton (*planktos* = wandering) include all organisms—algae, animals, and bacteria—that drift with ocean currents.

- Among plankton, the algae that undergo photosynthesis are called **phytoplankton**.
- Animal plankton are called **zooplankton** and include the larval stages of many marine organisms.

🔑 Nekton (*nektos* = swimming) include all animals capable of moving independently of the ocean currents, by swimming or other means of propulsion.

🔑 The term *benthos* (*benthos* = bottom) describes organisms living on or in the ocean bottom.

🔑 Three factors are used to divide the ocean into distinct marine life zones: the availability of sunlight, the distance from shore, and the water depth.

- The upper part of the ocean into which sunlight penetrates is called the **photic zone** (*photos* = light).
- The area where the land and ocean meet and overlap is the **intertidal zone**.
- Seaward from the low-tide line is the **neritic zone**, which covers the continental shelf.
- Beyond the continental shelf is the **oceanic zone**.
- Open ocean of any depth is called the **pelagic zone**.
- The **benthic zone** includes any sea-bottom surface regardless of its distance from shore and is mostly inhabited by benthos organisms.
- The **abyssal zone** is a subdivision of the benthic zone and includes the deep-ocean floor.
- At hydrothermal vents, super-heated and mineral-filled water escapes into the ocean through cracks in the crust. At some vents, high water temperatures support organisms found nowhere else in the world.

15.3 Oceanic Productivity

🔑 Two factors influence a region's photosynthetic productivity: the availability of nutrients and the amount of solar radiation, or sunlight.

- **Primary productivity** is the production of organic compounds from inorganic substances through photosynthesis or chemosynthesis.

Chapter 15 Ocean Water and Ocean Life

- **Photosynthesis** is the use of light energy to convert water and carbon dioxide into energy-rich glucose molecules.
 - **Chemosynthesis** is the process by which certain microorganisms create organic molecules from inorganic nutrients using chemical energy.
- ➡ The availability of solar energy is what limits photosynthetic productivity in polar areas.
- ➡ Photosynthetic productivity in tropical regions is limited by the lack of nutrients.
- ➡ In temperate regions, which are found at midlatitudes, a combination of two limiting factors, sunlight and nutrient supply, controls productivity.
- ➡ The transfer of energy between trophic levels is very inefficient.
- A **trophic level** is a feeding level in a food chain. Plants and algae make up the first level, followed by herbivores that eat the plants, and a series of carnivores that eat the herbivores.
- ➡ Animals that feed through a food web rather than a food chain are more likely to survive because they have alternative foods to eat should one of their food sources diminish or disappear.
- A **food chain** is a sequence of organisms through which energy is transferred, starting with the primary producer.
 - A **food web** is a group of interrelated food chains.

Chapter 16 The Dynamic Ocean

Summary

16.1 Ocean Circulation

➡ Surface currents develop from friction between the ocean and the wind that blows across its surface.

- **Ocean currents** are masses of ocean water that flow from one place to another.
- **Surface currents** are movements of water that flow horizontally in the upper part of the ocean's surface.

➡ Because of Earth's rotation, currents are deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

- **Gyres** are huge circular-moving current systems that dominate the surfaces of the oceans.
- The **Coriolis effect** is the deflection of currents away from their original course as a result of Earth's rotation.

➡ When currents from low-latitude regions move into higher latitudes, they transfer heat from warmer to cooler areas on Earth.

➡ As cold water currents travel toward the equator, they help moderate the warm temperatures of adjacent land areas.

➡ Upwelling brings greater concentrations of dissolved nutrients, such as nitrates and phosphates to the ocean surface.

- **Upwelling** is the rising of cold water from deeper layers to replace warmer surface water.

➡ An increase in seawater density can be caused by a decrease in temperature or an increase in salinity.

- **Density currents** are vertical currents of ocean water that are caused by density differences among water masses.
- Ocean circulation is similar to a conveyor belt, bringing warm water from the equator to the poles, and cold water from the poles back to the equator.

16.2 Waves and Tides

➡ Most ocean waves obtain their energy and motion from the wind.

- The tops of waves are the crests, which are separated by troughs. The vertical distance between trough and crest is called the **wave height**.
- The horizontal distance between two successive crests or two successive troughs is the **wavelength**.

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- The time it takes one full wave—one wave-length—to pass a fixed position is the **wave period**.
- **The height, length, and period that are eventually achieved by a wave depend on three factors: (1) wind speed; (2) length of time the wind has blown; and (3) fetch.**
 - **Fetch** is the distance that the wind has traveled across open water.
- **Circular orbital motion allows energy to move forward through the water while the individual water particles that transmit the wave move around in a circle.**
- **Ocean tides result from differences in the gravitational attraction exerted upon different parts of Earth's surface by the moon and, to a lesser extent, by the sun.**
 - **Tides** are regular changes in the elevation of the ocean surface.
 - The **tidal range** is the difference in height between successive high and low tides.
 - **Spring tides** are tides that have the greatest tidal range due to the alignment of the Earth-moon-sun system. Spring tides occur during new and full moons.
 - **Neap tides** are tides that have the lowest tidal range, occurring near the times of the first-quarter and third-quarter phases of the moon.
 - Each month there are two spring tides and two neap tides, each about one week apart.
- **Three main tidal patterns exist worldwide: diurnal tides, semidiurnal tides, and mixed tides.**
 - A diurnal tidal pattern has a single high tide and a single low tide each tidal day. A semidiurnal tidal pattern has two high tides and two low tides each tidal day. A mixed tidal pattern has two high and two low tides of different heights.

16.3 Shoreline Processes and Features

- **Waves along the shoreline are constantly eroding, transporting, and depositing sediment. Many types of shoreline features can result from this activity.**
 - A **beach** is the accumulation of sediment found along the shore of a lake or ocean.
- **Because of refraction, wave energy is concentrated against the sides and ends of headlands that project into the water, whereas wave action is weakened in bays.**
 - **Wave refraction** is the bending of waves, and it affects the distribution of energy along the shore.

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➡ **Turbulence allows longshore currents to easily move along the fine suspended sand and to roll larger sand and gravel particles along the bottom.**

- A **longshore current** is a current that flows parallel to the shore and moves large amounts of sediment along the shore.

➡ **Shoreline features that originate primarily from the work of erosion are called erosional features. Sediment that is transported along the shore and deposited in areas where energy is low produce depositional features.**

- Wave-cut cliffs, platforms, sea arches, and sea stacks are all examples of shoreline features that result from erosion.
- Spit, bars, tombolos, and barrier islands are all formed as a result of deposition.
- **Barrier islands** are narrow sandbars parallel to, but separated from, the coast at distances from 3 to 30 kilometers offshore.

➡ **Groins, breakwaters, and seawalls are some structures built to protect a coast from erosion or to prevent the movement of sand along a beach.**

➡ **Beach nourishment is the addition of large quantities of sand to the beach system.**

- Beach nourishment is an attempt to stabilize shoreline sands without building protective structures.

Chapter 17 The Atmosphere: Structure and Temperature

Summary

17.1 Atmosphere Characteristics

☛ Weather is constantly changing, and it refers to the state of the atmosphere at any given time and place. Climate, however, is based on observations of weather that have been collected over many years. Climate helps describe a place or region.

☛ Water vapor is the source of all clouds and precipitation. Like carbon dioxide, water vapor absorbs heat given off by Earth. It also absorbs some solar energy.

☛ If ozone did not filter most UV radiation and all of the sun's UV rays reached the surface of Earth, our planet would be uninhabitable for many living organisms.

- **Ozone** is a form of oxygen that combines three oxygen atoms into each molecule (O₃).

☛ The atmosphere thins as you travel away from Earth until there are too few gas molecules to detect.

☛ The atmosphere can be divided vertically into four layers based on temperature.

- The bottom layer, where temperature decreases with an increase in altitude, is the **troposphere**.
- The **stratosphere** is the layer of the atmosphere immediately above the troposphere. In the stratosphere, temperature increases with height, due to the concentration of ozone.
- In the third layer, the **mesosphere**, temperatures again decrease with height until the outer layer of the mesosphere, the mesopause.
- The fourth layer is the **thermosphere**, which extends outward from the mesopause, has no well-defined upper limit, and contains only a tiny fraction of the atmosphere's mass.

☛ Seasonal changes occur because Earth's position relative to the sun continually changes as it travels along its orbit.

- On June 21 or 22 each year the axis is such that the Northern Hemisphere is "leaning" 23.5 degrees toward the sun. This date is known as the **summer solstice**, or the first "official" day of summer.
- December 21 or 22 is the **winter solstice**, the first day of winter.
- September 22 or 23 is the date of the **autumnal equinox** and the start of autumn in the Northern Hemisphere.

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- March 21 or 22 is the date of the **spring equinox** and the start of spring for the Northern Hemisphere.

17.2 Heating the Atmosphere

➡ **Heat is the energy transferred from one object to another because of a difference in their temperatures.**

- **Temperature** is a measure of the average kinetic energy of the individual atoms or molecules in a substance.

➡ **Three mechanisms of energy transfer as heat are conduction, convection, and radiation.**

- **Conduction** is the transfer of heat through matter by molecular activity.
- **Convection** is the transfer of heat by mass movement or circulation within a substance.
- **Radiation** is the transfer of heat through space by electromagnetic waves.
- Electromagnetic energy is classified according to wavelength in the electromagnetic spectrum.

➡ **Unlike conduction and convection, which need material to travel through, radiant energy can travel through the vacuum of space.**

➡ **All objects, at any temperature, emit radiant energy.**

➡ **Hotter objects radiate more total energy per unit area than colder objects do.**

➡ **The hottest radiating bodies produce the shortest wavelengths of maximum radiation.**

➡ **Objects that are good absorbers of radiation are good emitters as well.**

➡ **When radiation strikes an object, there usually are three different results:**

1. **Some energy is absorbed by the object.**
 2. **Substances such as water and air are transparent to certain wavelengths of radiation.**
 3. **Some radiation may bounce off the object without being absorbed or transmitted.**
- **Reflection** occurs when an electromagnetic wave bounces off an object.
 - **Scattering** occurs when electromagnetic waves bounce off an object, producing a larger number of weaker rays that travel in different directions.
 - In the **greenhouse effect**, Earth's surface and atmosphere are heated by solar energy that is absorbed and emitted by the atmosphere.

Chapter 17 The Atmosphere: Structure and Temperature

17.3 Temperature Controls

➤ Factors other than latitude that exert a strong influence on temperature include heating of land and water, altitude, geographic position, cloud cover, and ocean currents.

➤ Land heats more rapidly and to higher temperatures than water. Land also cools more rapidly and to lower temperatures than water.

➤ Many clouds have a high albedo, and therefore reflect a significant portion of the sunlight that strikes them back to space.

- **Albedo** is the fraction of total radiation that is reflected by any surface.
- **Isotherms** are lines on a map that connect points that have the same temperature.

Chapter 18 Moisture, Clouds, and Precipitation

Summary

18.1 Water in the Atmosphere

☛ When it comes to understanding atmospheric processes, water vapor is the most important gas in the atmosphere.

- Water vapor is the source of all condensation and **precipitation**, which is any form of water that falls from a cloud.

☛ The process of changing state requires that energy is transferred in the form of heat.

- **Latent heat** is the energy absorbed or released during a change in state. Latent heat does not produce a temperature change.
- The process of changing a liquid to a gas is called **evaporation**.
- The process of changing water vapor to the liquid state is called **condensation**.
- **Sublimation** is the conversion of a solid directly to a gas, without passing through the liquid state.
- **Deposition** is the conversion of a vapor directly to a solid.

☛ When saturated, warm air contains more water vapor than saturated cold air.

- The general term for the amount of water vapor in air is **humidity**.
- **Saturated** is the state of air that contains the most water vapor that it can hold at any given temperature and pressure.

☛ Relative humidity is a ratio of the air's actual water-vapor content compared with the amount of water vapor air can hold at that temperature and pressure.

- Relative humidity indicates how near the air is to saturation, rather than the actual amount of water vapor in the air.

☛ When the water-vapor content of air remains constant, lowering air temperature causes an increase in relative humidity, and raising air temperature causes a decrease in relative humidity.

- The dew-point temperature or simply the **dew point** is the temperature to which a parcel of air would need to be cooled to reach saturation.
- Relative humidity is commonly measured by using a **hygrometer**.

Chapter 18 Moisture, Clouds, and Precipitation

18.2 Cloud Formation

➡ When air is allowed to expand, it cools, and when it is compressed, it warms.

- Temperature changes that happen even though heat isn't added or subtracted are called **adiabatic temperature changes**.
- The rate of adiabatic cooling or heating in unsaturated air and is called the **dry adiabatic rate**.
- The rate of adiabatic cooling in saturated air is called the **wet adiabatic rate** and it is always slower than the dry adiabatic rate.

➡ Four mechanisms that can cause air to rise are **orographic lifting, frontal wedging, convergence, and localized convective lifting**.

- **Orographic lifting** of air occurs when elevated terrains, such as mountains, act as barriers to air flow, forcing the air to ascend.
- A **front** is the boundary between colliding masses of warm and cold air. Frontal wedging is a process that occurs at a front in which cold, dense air acts as a barrier over which warmer, less dense air rises.
- **Convergence** is the lifting of air that results from air in the lower atmosphere flowing together.
- **Localized convection lifting** occurs when unequal heating of Earth's surface warms a pocket of air more than the surrounding air, lowering the air pocket's density.

➡ Stable air tends to remain in its original position, while unstable air tends to rise.

- The most stable conditions happen when air temperature actually increases with height, called a **temperature inversion**.

➡ For any form of condensation to occur, whether dew, fog, or clouds, the air must be saturated.

- When condensation occurs in the air above the ground, tiny bits of particulate matter, called **condensation nuclei**, serve as surfaces for water-vapor condensation.

18.3 Cloud Types and Precipitation

➡ Clouds are classified on the basis of their form and height.

- **Cirrus** (*cirrus* = a curl of hair) clouds are high, white, and thin. They can occur as patches or as delicate veil-like sheets or extended wispy fibers that often have a feathery appearance.
- **Cumulus** (*cumulus* = a pile) clouds consist of rounded individual cloud masses. Normally, they have a flat base and the appearance of rising domes or towers.

Chapter 18 Moisture, Clouds, and Precipitation

- **Stratus** (*stratum* = a layer) clouds are best described as sheets or layers that cover much or all of the sky. While there may be minor breaks, there are no distinct individual cloud units.
- ☛ **Fog is defined as a cloud with its base at or very near the ground.**
- ☛ **For precipitation to form, cloud droplets must grow in volume by roughly one million times.**
 - The **Bergeron process** is a theory that relates the formation of precipitation to supercooled clouds, freezing nuclei, and the different saturation levels of ice and liquid water.
 - Water in the liquid state below 0°C is said to be **supercooled**. Supercooled water will readily freeze if it touches a solid object.
 - When air is saturated (100% relative humidity) with respect to water, it is **supersaturated** with respect to ice (greater than 100% humidity).
 - The **collision-coalescence** process is a theory of raindrop formation in warm clouds in which large cloud droplets collide and join together with smaller droplets to form a raindrop.
- ☛ **The type of precipitation that reaches Earth's surface depends on the temperature profile in the lowest few kilometers of the atmosphere.**
 - Rain, snow, sleet, glaze, and hail are all types of precipitation.

Chapter 19 Air Pressure and Wind

Summary

19.1 Understanding Air Pressure

➡ Air pressure is exerted in all directions—down, up, and sideways. The air pressure pushing down on an object balances the air pressure pushing up on an object.

- Air pressure is simply the pressure exerted by the weight of air above.
- A **barometer** is a device used for measuring air pressure (*bar* = pressure, *metron* = measuring instrument).

➡ In a mercury barometer, a tube is filled with mercury, then turned upside down in a dish of mercury. When air pressure increases, the mercury in the tube rises. When air pressure decreases, so does the height of the mercury column.

➡ Wind is the result of horizontal differences in air pressure. Air flows from areas of higher pressure to areas of lower pressure.

➡ The unequal heating of Earth's surface generates pressure differences. Solar radiation is the ultimate energy source for most wind.

➡ Three factors combine to control wind: pressure differences, the Coriolis effect, and friction.

- **Pressure gradient** is the amount of pressure change occurring over a given distance.
- **Isobars** are lines on a map that connect places of equal air pressure.

➡ Closely spaced isobars indicate a steep pressure gradient and high winds. Widely spaced isobars indicate a weak gradient and light winds.

➡ The Coriolis effect describes how Earth's rotation affects moving objects. All free-moving objects or fluids, including the wind, are deflected to the right of their path of motion in the Northern Hemisphere. In the Southern Hemisphere, they are deflected to the left.

- **Jet streams** are fast-moving rivers of air near the tropopause that travel between 120 and 240 km per hour in a west-to-east direction.

19.2 Pressure Centers and Winds

➡ In cyclones, the pressure decreases from the outer isobars toward the center. In anticyclones, pressure increases from the outside toward the center.

- Lows, or **cyclones**, are centers of low pressure.
- Highs, or **anticyclones**, are centers of high pressure.

Chapter 19 Air Pressure and Wind

- ➡ When the pressure gradient and the Coriolis effect are applied to pressure centers in the Northern Hemisphere, winds blow counterclockwise around a low. Around a high, they blow clockwise.
- ➡ In either hemisphere, friction causes a net flow of air inward around a cyclone and a net flow of air outward around an anticyclone.
- ➡ The atmosphere balances the unequal heating of Earth's surface by acting as a giant heat-transfer system. This system moves warm air toward high latitudes and cool air toward the equator.
 - **Trade winds** are two belts of winds that blow almost constantly from easterly directions.
 - The **Westerlies** are winds that blow west to east of the poleward side of the subtropical highs.
 - The **polar easterlies** are winds that blow from the polar high toward the subpolar low. These winds are not constant winds like the trade winds.
 - The **polar front** is the stormy frontal zone in the middle latitudes separating cold polar air masses from warm tropical air masses.
 - A **monsoon** is a seasonal reversal of wind direction. In winter, wind blows from land to sea. In summer, the wind blows from sea to land.

19.3 Regional Wind Systems

- ➡ The local winds are caused either by topographic effects or by variations in surface composition—land and water—in the immediate area.
- ➡ In the United States, the westerlies consistently move weather from west to east across the continent.
 - When the wind consistently blows more often from one direction than from any other, it is called a **prevailing wind**.
 - A cup **anemometer** is often used to measure wind speed.
- ➡ At irregular intervals of three to seven years, a warm current that normally flows from Ecuador to Peru for only a short time, becomes unusually strong and replaces normally cold offshore waters with warm equatorial waters.
 - Scientists use the term **El Niño** for these episodes of ocean warming that affect the eastern tropical Pacific.
- ➡ Researchers have come to recognize that when surface temperatures in the eastern Pacific are colder than average, a **La Niña** event is triggered that has a distinctive set of weather patterns.

Chapter 20 Weather Patterns and Severe Storms

Summary

20.1 Air Masses

➤ An air mass is an immense body of air in the troposphere that is characterized by similar temperatures and amounts of moisture at any given altitude.

➤ As it moves, the characteristics of an air mass change and so does the weather in the area over which the air mass moves.

➤ In addition to their overall temperature, air masses are classified according to the surface over which they form.

- Continental (c) air masses form over land, and are likely to be dry. Maritime (m) air masses form over water, and are humid.
- Polar (P) air masses form at high altitudes and are cold. Tropical (T) air masses form at low latitudes and are warm.

➤ Much of the weather in North America, especially weather east of the Rocky Mountains, is influenced by continental polar (cP) and maritime tropical (mT) air masses.

➤ Only occasionally do continental tropical (cT) air masses affect the weather outside their source regions.

20.2 Fronts

➤ When two air masses meet, they form a front, which is a boundary that separates two air masses of different properties.

- Fronts are classified by the temperature of the advancing front. There are four types of fronts: warm, cold, stationary, and occluded fronts.

➤ A warm front forms when warm air moves into an area formerly covered by cooler air.

➤ A cold front forms when cold, dense air moves into a region occupied by warmer air.

➤ When the flow of air on either side of a front is almost parallel to the front, the surface position of the front does not move, and a stationary front forms.

➤ When a cold front overtakes a warm front, an occluded front forms.

Chapter 20 Weather Patterns and Severe Storms

➡ **Middle-latitude cyclones are large centers of low pressure that generally travel from west to east and cause stormy weather.**

➡ **More often than not, air high up in the atmosphere fuels a middle-latitude cyclone.**

20.3 Severe Storms

➡ **A thunderstorm is a storm that generates lightning and thunder. Thunderstorms frequently produce gusty winds, heavy rain, and hail.**

➡ **Thunderstorms form when warm, humid air rises in an unstable environment.**

- There are three stages in thunderstorm development: the cumulus stage, the mature stage, and the dissipating stage.

➡ **Tornadoes are violent windstorms that take the form of a rotating column of air called a vortex. The vortex extends downward from a cumulonimbus cloud all the way to the ground.**

➡ **Most tornadoes form in association with severe thunderstorms.**

➡ **Whirling tropical cyclones that produce sustained winds of at least 119 kilometers per hour are known in the United States as hurricanes.**

➡ **Hurricanes develop most often in the late summer when water temperatures are warm enough to provide the necessary heat and moisture to the air.**

- The doughnut-shaped wall that surrounds the center of a hurricane is the **eye wall**. Here the greatest wind speeds and heaviest rainfall occurs.
- At the very center of the storm is the **eye** of the hurricane, where precipitation ceases and winds subside.
- A **storm surge** is a dome of water about 65 to 80 kilometers wide that sweeps across the coast where a hurricane's eye moves onto land.

Chapter 21 Climate

Summary

21.1 Factors That Affect Climate

- As latitude increases, the average intensity of solar energy decreases.
 - The **tropical zones** are located where the sun's rays are most intense, between about 23.5° north and 23.5° south of the equator. These regions are warm year-round.
 - The **temperate zones** are located where the sun's energy strikes Earth at a smaller angle than near the equator, between about 23.5° and 66.5° north and south of the equator. These regions have hot summers and cold winters.
 - In the **polar zones**, which are between 66.5° north and south latitude and the poles, the energy strikes at an even smaller angle, resulting in cold temperatures year-round.
- The higher the elevation is, the colder the climate.
- Topographic features such as mountains play an important role in the amount of precipitation that falls over an area.
- Large bodies of water such as lakes and oceans have an important effect on the temperature of an area because the temperature of the water body influences the temperature of the air above it.
- Global winds are another factor that influences climate because they distribute heat and moisture around Earth.
- Vegetation can affect both temperature and precipitation patterns in an area.

21.2 World Climates

- The Köppen climate classification system uses mean monthly and annual values of temperature and precipitation to classify climates.
- Humid tropical climates are climates without winters. Every month in such a climate has a mean temperature above 18°C. The amount of precipitation can exceed 200 cm per year.
 - A **wet tropical climate** has high temperatures and much annual precipitation.
 - **Tropical wet and dry climates** have temperatures and total precipitation similar to those in the wet tropics, but experience distinct periods of low precipitation.

Chapter 21 Climate

☛ **Climates with mild winters have an average temperature in the coldest month that is below 18°C but above –3°C. Climates with severe winters have an average temperature in the coldest month that is below –3°C.**

- Located between about 25° and 40° latitude on the eastern sides of the continents are the **humid subtropical climates**. They are hot and sultry in the summer, and winters are generally mild, though frosts are common in higher-latitude areas.
- Coastal areas between about 40° and 65° north and south latitude have **marine west coast climates**. These climates have mild winters and cool summers with ample rainfall throughout the year.
- Regions between about 30° and 45° latitude are **dry-summer subtropical climates**. They are humid climates with strong winter rainfall.
- North of the humid continental climate and south of the tundra is an extensive **subarctic climate** region. Winters are long and bitterly cold; summers are warm but very short. This region has the highest annual temperature ranges on Earth.

☛ **A dry climate is one in which the yearly precipitation is not as great as the potential loss of water by evaporation.**

☛ **Polar climates are those in which the mean temperature of the warmest month is below 10°C.**

☛ **In general, highland climates are cooler and wetter than nearby areas at lower elevations.**

21.3 Climate Changes

☛ **Geologic changes in Earth's land and oceans due to plate tectonics cause changes in climate over very long time scales.**

☛ **Changes in the shape of Earth's orbit and the tilt of Earth's axis of rotation affect global climates over intermediate time scales.**

☛ **Changes in ocean circulation also can result in short-term climate fluctuations.**

☛ **Over short time scales, fluctuations in the amount of solar radiation can change global climates.**

☛ **Volcanic ash, dust, and sulfur-based aerosols in the air increase the amount of solar radiation that is reflected back into space. This causes Earth's lower atmosphere to cool.**

☛ **The greenhouse effect is a natural warming of both Earth's lower atmosphere and Earth's surface.**

Chapter 21 Climate

➡ **As a result of increases in carbon dioxide levels, as well as increases in other greenhouse gases, global temperatures have increased. This increase is called global warming.**

- Scientists predict that by the year 2100, Earth's average temperature could increase by more than 5° C.
- Scientists use complex computer programs called climate models to make predictions about global warming. Climate models cannot describe Earth's atmosphere completely, so their results are only an approximation.
- Some of the possible effects of global warming are higher temperatures that could melt sea ice, leading to increasing sea levels, which could lead to shoreline erosion and coastal flooding. The oceans could warm, further increasing global temperature and causing stronger storms. Weather patterns could change, leading to more extreme weather around the world.

Chapter 22 Origin of Modern Astronomy

Summary

22.1 Early Astronomy

- **Astronomy** is the science that studies the universe. It deals with the properties of objects in space and the laws governing the universe.
- ☛ **In the geocentric model, the moon, sun, and known planets—Mercury, Venus, Mars, and Jupiter—go around Earth.**
 - The Greeks believed in a **geocentric** universe, in which Earth was a sphere that stayed motionless at the center.
 - The path of an object around another object in space is called an **orbit**.
- ☛ **In the heliocentric model, Earth and other planets orbit the sun.**
 - Aristarchus (312–230 B.C.) was the first Greek to propose a sun-centered, or **heliocentric**, universe.
 - **Retrograde motion** is the apparent westward motion of the planets with respect to the stars.
- ☛ **Copernicus concluded that the Earth is a planet. He proposed a model of the solar system with the sun at the center.**
- ☛ **Tycho Brahe's observations, especially of Mars, were far more precise than any made previously.**
- ☛ **Kepler discovered three laws of planetary motion.**
 - The oval-shaped path created by the orbit of the planets around the sun is called an **ellipse**.
 - The **astronomical unit (AU)** is the average distance between Earth and the sun. It is about 150 million kilometers.
- ☛ **Galileo's most important contributions were his descriptions of the behavior of moving objects.**
- ☛ **Although others had theorized the existence of a force that keeps the planets from going in a straight line, Newton was the first to formulate and test the law of universal gravitation.**
 - The law of universal gravitation states that every body in the universe attracts every other body with gravitational force. The greater the mass of the object, the greater the gravitational force.

22.2 The Earth-Moon-Sun System

- ☛ **The two main motions of Earth are rotation and revolution.**
 - **Rotation** is the turning, or spinning, of a body on its axis.

Chapter 22 Origin of Modern Astronomy

- **Revolution** is the motion of a body, such as a planet or moon, along its orbit around some point in space.
 - At **perihelion**, Earth is closest to the sun—about 147 million kilometers away.
 - At **aphelion**, Earth is farthest from the sun—about 152 million kilometers away.
 - **Precession** is the slow motion of Earth's axis as it traces a circle in the sky. The period of precession, or the amount of time the axis takes to complete one circle, is 26,000 years.
 - At a point known as **perigee**, the moon is closest to Earth.
 - At a point known as **apogee**, the moon is farthest from Earth.
- ☛ **Lunar phases are caused by the changes in how much of the sunlit side of the moon faces Earth.**
- The **phases of the moon** are the monthly changes in the amount of the moon that appears lit.
- ☛ **During a new-moon or full-moon phase, the moon's orbit must cross the plane of the ecliptic for an eclipse to take place.**
- A **solar eclipse** occurs when the moon moves directly between Earth and the sun, casting a dark shadow on Earth.
 - A **lunar eclipse** occurs when the moon moves within Earth's shadow.

22.3 Earth's Moon

- ☛ **Most craters on the moon were produced by the impact of rapidly moving debris or meteoroids.**
- **Craters** are round depressions in the surface of the moon.
 - Splash marks that radiate outward for hundreds of kilometers from a crater are called **rays**.
- ☛ **Maria, ancient beds of basaltic lava, originated when asteroids punctured the lunar surface, letting magma "bleed" out.**
- A dark, relatively smooth area on the moon's surface is called a **mare** (plural: maria).
 - Long channels called **rilles** are associated with maria. Rilles look somewhat similar to valleys or trenches.
 - The **lunar regolith** is a soil-like layer on the moon composed of igneous rocks, glass beads, and fine lunar dust.
- ☛ **A widely accepted model for the origin of the moon is that when the solar system was forming, a body the size of Mars hit Earth.**

Chapter 23 Touring Our Solar System

Summary

23.1 The Solar System

☛ Size is the most obvious difference between the terrestrial and the Jovian planets.

- The **terrestrial planets**—Mercury, Venus, Earth, and Mars—are relatively small and rocky.
- The **Jovian planets**—Jupiter, Saturn, Uranus, and Neptune—are huge gas giants.

☛ Density, chemical makeup, and rate of rotation are other ways in which the two groups of planets differ.

☛ According to the nebular theory, the sun and planets formed from a rotating disk of dust and gases.

- A cloud of dust and gas in space is called a **nebula**.
- As solid bits of matter began to clump together, they formed small, irregularly shaped bodies called **planetesimals**.

23.2 The Terrestrial Planets

☛ Mercury has the greatest temperature extremes of any planet.

- Mercury is only slightly larger than our moon, has cratered highlands and smooth terrains like maria. It's very dense, with a large iron core.

☛ Data have confirmed that basaltic volcanism and tectonic activity shape Venus's surface.

- Venus is similar to Earth in size, mass, and density. It is covered by thick clouds, and has a surface temperature of 475° C.

☛ Although the atmosphere of Mars is very thin, extensive dust storms occur and may cause the color changes observed from Earth.

- The surface features on Mars, including volcanoes and canyons, are 1–4.5 billion years old. Recent evidence points to the possibility that liquid water once existed on the surface.

23.3 The Outer Planets (and Pluto)

☛ Jupiter has a mass that is $2\frac{1}{2}$ times greater than the mass of all the other planets and moons combined.

- Although called a gas giant, Jupiter is believed to be an ocean of liquid hydrogen. Jupiter has a ring system, large storms, and 63 moons.

☛ The most prominent feature of Saturn is its system of rings.

Chapter 23 Touring Our Solar System

- Saturn's atmosphere is very active with winds of 1500 kilometers per hour. It has 56 moons, the largest of which, Titan, has its own atmosphere.
- ➡ **Instead of being generally perpendicular to the plane of its orbit like the other planets, Uranus's axis of rotation lies nearly parallel with the plane of its orbit.**
- ➡ **Winds exceeding 1000 kilometers per hour encircle Neptune, making it one of the windiest places in the solar system.**
- ➡ **Pluto is considered a dwarf planet because it has not cleared the neighborhood around its orbit.**
 - A **dwarf planet** is a round object that orbits the sun but has not cleared the neighborhood around its orbit.

23.4 Minor Members of the Solar System

- ➡ **Most asteroids lie in the asteroid belt between the orbits of Mars and Jupiter. They have orbital periods of three to six years.**
 - **Asteroids** are small rocky bodies that orbit the sun.
 - **Comets** are pieces of rocky and metallic materials held together by frozen water, ammonia, methane, carbon dioxide, and carbon monoxide.
 - The glowing head of a comet, called a **coma**, is caused by vaporized frozen gases.
- ➡ **A small glowing nucleus with a diameter of only a few kilometers can sometimes be detected within a coma. As comets approach the sun, some, but not all, develop a tail that extends for millions of kilometers.**
 - Comets originate in two regions of the outer solar system. Those with short orbital periods come from the Kuiper belt, and those with long orbital periods come from the Oort cloud.
- ➡ **Most meteoroids originate from any one of the following three sources: (1) interplanetary debris that was not gravitationally swept up by the planets during the formation of the solar system, (2) material from the asteroid belt, or (3) the solid remains of comets that once traveled near Earth's orbit.**
 - A **meteoroid** is a small solid particle that travels through space.
 - Meteoroids that enter Earth's atmosphere and burn up are called **meteors**.
 - A meteoroid that actually reaches Earth's surface is called a **meteorite**.
 - Scientists used evidence from meteorites, moon rocks, and Earth rocks to determine the age of the solar system.

Chapter 24 Studying the Sun

Summary

24.1 The Study of Light

☛ Electromagnetic radiation includes gamma rays, X-rays, ultraviolet light, visible light, infrared radiation, microwaves, and radio waves.

- The arrangement of electromagnetic radiation according to their wavelengths and frequencies is called the **electromagnetic spectrum**.
- In some instances, light behaves like waves.
- In some cases, light acts like a stream of particles called **photons**. Photons can push on matter, and they exert radiation pressure.
- **Spectroscopy** is the study of the properties of light that depend on wavelength.
- A **continuous spectrum** is an uninterrupted band of light produced by an incandescent solid, liquid, or gas under high pressure.
- An **absorption spectrum** is produced when visible light is passed through a cool gas under pressure. Because the gas absorbs some wavelengths, the spectrum appears continuous with dark lines running through it.
- An **emission spectrum** is a series of bright lines of particular wavelengths produced by a hot gas under low pressure.

☛ When the spectrum of a star is studied, the spectral lines act as “fingerprints.” These lines identify the elements present and thus the star’s chemical composition.

☛ In astronomy, the Doppler effect is used to determine whether a star or other body in space is moving away from or toward Earth.

- The **Doppler effect** refers to the apparent change in frequency of electromagnetic or sound waves that are emitted from a source that is moving away or toward an object.

24.2 Tools for Studying Space

☛ The most important lens in a refracting telescope, the objective lens, produces an image by bending light from a distant object so that the light converges at an area called the focus.

- A **refracting telescope** uses a lens to bend or refract light.
- The **chromatic aberration** is an effect caused by the fact that when a refracting telescope is in focus for red light, blue and violet light are out of focus and vice versa.

☛ Most large optical telescopes are reflectors. Light does not pass through a mirror so the glass for a reflecting telescope does not have to be of optical quality.

Chapter 24 Studying the Sun

- **Reflecting telescopes** use a concave mirror that focuses the light in front of a mirror, rather than behind it, like a lens.
 - Both refracting and reflecting telescopes have three properties: light-gathering power, which makes brighter images; resolving power, which makes sharper images; and magnifying power, which makes larger images.
- ➡ A radio telescope focuses incoming radio waves on an antenna, which absorbs and transmits those waves to an amplifier, just like a radio antenna.
- ➡ Space telescopes orbit above Earth's atmosphere and thus produce clearer images than Earth-based telescopes.

24.3 The Sun

- ➡ We can divide the sun into four parts: the solar interior; the visible surface, or photosphere; and two atmospheric layers, the chromosphere and corona.
- The **photosphere** (*photos* = light, *sphere* = ball) radiates most of the sunlight we see and can be thought of as the visible "surface" of the sun.
 - Just above the photosphere lies the **chromosphere**, a relatively thin layer of hot gases a few thousand kilometers thick.
 - The outermost portion of the solar atmosphere, the **corona** (*corona* = crown) is visible only when the brilliant photosphere is covered.
 - The streams of protons and electrons that flow from the corona constitute the **solar wind**.
- ➡ Sunspots appear dark because of their temperature, which is about 1500 K less than that of the surrounding solar surface.
- **Sunspots** are the dark regions on the surface of the sun.

Chapter 24 Studying the Sun

➡ **Prominences are ionized gases trapped by magnetic fields that extend from regions of intense solar activity.**

- **Prominences** are huge cloudlike structures consisting of chromospheric gases and appear as great arches that extend into the corona.

➡ **During their existence, solar flares release enormous amounts of energy, much of it in the form of ultraviolet, radio, and X-ray radiation.**

- **Solar flares** are brief outbursts that normally last about an hour and appear as a sudden brightening of the region above a sunspot cluster.
- An **aurora** is a bright display of ever-changing light in the poles caused by solar radiation interacting with the upper atmosphere.

➡ **During nuclear fusion, energy is released because some matter is actually converted to energy.**

- **Nuclear fusion** occurs when four hydrogen nuclei combine to make the nucleus of one helium atom. This releases a tremendous amount of energy and is how the sun produces its energy.

Chapter 25 Beyond Our Solar System

Summary

25.1 Properties of Stars

➡ Color is a clue to a star's temperature.

➡ Binary stars are used to determine the star property most difficult to calculate—its mass.

- The word **constellation** is used to designate an area of the sky that contains a specific pattern of stars.
- Two stars that orbit each other, pulled toward each other by gravity, are called **binary stars**.

➡ The nearest stars have the largest parallax angles, while those of distant stars are too small to measure.

- **Parallax** is the slight shifting in the apparent position of a nearby star due to the orbital motion of Earth. Parallax is the most basic way to measure star distance.
- The **light-year** is the distance light travels in one year—about 9.5 trillion kilometers.

➡ Three factors control the apparent brightness of a star as seen from Earth: how big it is, how hot it is, and how far away it is.

- A star's brightness as it appears from Earth is called its **apparent magnitude**.
- Astronomers are also interested in how bright a star actually is, or its **absolute magnitude**.

➡ A Hertzsprung-Russell diagram shows the relationship between the absolute magnitude and temperature of stars.

- A **main sequence star** is a star that falls into the main sequence category on the Hertzsprung-Russell diagram. This category contains 90 percent of stars.
- **Red giants** are very bright stars that lie above and to the right of the main sequence in the H-R diagram.
- **Supergiants** are very large, very bright red giants.
- **Cepheid variables** are stars that get brighter and fainter in a regular pattern.
- A **nova** is a sudden brightening of a star.
- **Nebulae** are clouds of dust and gases found in "the vacuum of space."

25.2 Stellar Evolution

- A medium-mass star like the sun goes through several stages of development. It starts as a nebula, which contracts into a **protostar**—a developing star not yet hot enough for nuclear fusion to occur.

Chapter 25 Beyond Our Solar System

➡ When the core of a protostar has reached about 10 million K, pressure within is so great that nuclear fusion of hydrogen begins, and a star is born.

- At some point after fusion begins, a star becomes a balanced, main-sequence star. For an average star, this stage lasts 90 percent of the star's life.
- Once all of the hydrogen in a star's core is consumed, the star expands and cools, becoming a red giant.

➡ All stars, regardless of their size, eventually run out of fuel and collapse due to gravity.

- The final stage of a star's life cycle depends on the star's mass. Low-mass stars go from being a main-sequence star to becoming a white dwarf. Medium-mass stars become planetary nebulae. Massive stars end in a supernova.
- A **supernova** is a brilliant explosion that causes a star to become millions of times brighter than its prenova stage.
- The process that produces chemical elements inside stars is called nucleosynthesis.

➡ The sun began as a nebula, will spend much of its life as a main-sequence star, and then will become a red giant, planetary nebula, white dwarf, and finally, a black dwarf.

- **White dwarfs** are the remains of low-mass and medium-mass stars.
- **Neutron stars**, which are smaller and more massive than white dwarfs, are thought to be the remnants of supernova events.
- A spinning neutron star that appears to give off pulses of radio waves is called a **pulsar**.
- Dense objects with gravity so strong that not even light can escape their surface are called **black holes**.

Chapter 25 Beyond Our Solar System

25.3 The Universe

➤ **The Milky Way is a large spiral galaxy whose disk is about 100,000 light-years wide and about 10,000 light-years thick at the nucleus.**

- **Galaxies** are large groups of stars, dust, and gases held together by gravity.
- There are three types of galaxies. Spiral galaxies are disk shaped with arms extending from the center. Most galaxies are elliptical galaxies, which range in shape from round to oval. A small percent of galaxies have irregular shapes, and are called irregular galaxies.

➤ **In addition to shape and size, one of the major differences among different types of galaxies is the age of their stars.**

- A **galaxy cluster** is a group of galaxies.

➤ **The red shifts of distant galaxies indicate that the universe is expanding.**

- **Hubble's law** states that galaxies are retreating from us at a speed that is proportional to their distance.

➤ **The big bang theory states that at one time, the entire universe was confined to a dense, hot, supermassive ball. Then, about 13.7 billion years ago, a violent explosion occurred, hurling this material in all directions.**

- According to the **big bang theory**, the universe began as a violent explosion from which the universe continues to expand, evolve, and cool.