PART I

# SUBJECT REVIEWS

# Chapter 1

# Earth's Systems and Resources

Earth is a spectacular and ever-changing place, with constant activity and incredible transformations. The changes include everything from earthquakes and volcanoes to the formation of life and extinction of it. This chapter covers Earth's geologic changes and time scale, along with its atmosphere, water, and soil.

## Earth

To prepare for the AP Environmental Science exam and to fully understand the concepts and workings of Earth's systems, you need to understand how the planet functions and its composition.

With a unique set of characteristics and features, Earth is the only planet in our solar system that is known to support life. It is the third planet from the sun, with the order of the planets being Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Although Pluto used to be considered a planet, it is now classified as a dwarf planet.

### Geologic Time Scale

At an age of approximately 4.6 billion years, Earth has seen many radical changes throughout its eons, eras, periods, and epochs. This span of time, and the changes that have taken place in it, are grouped into the **geologic time scale.** On the geologic time scale, eons are the largest spans of time; they include the Archean, Proterozoic, Hadean, and Phanerozoic. The eons Archean and Proterozoic are referred to as Precambrian time with seven eras. Eons are divided into eras, which are divided into periods.

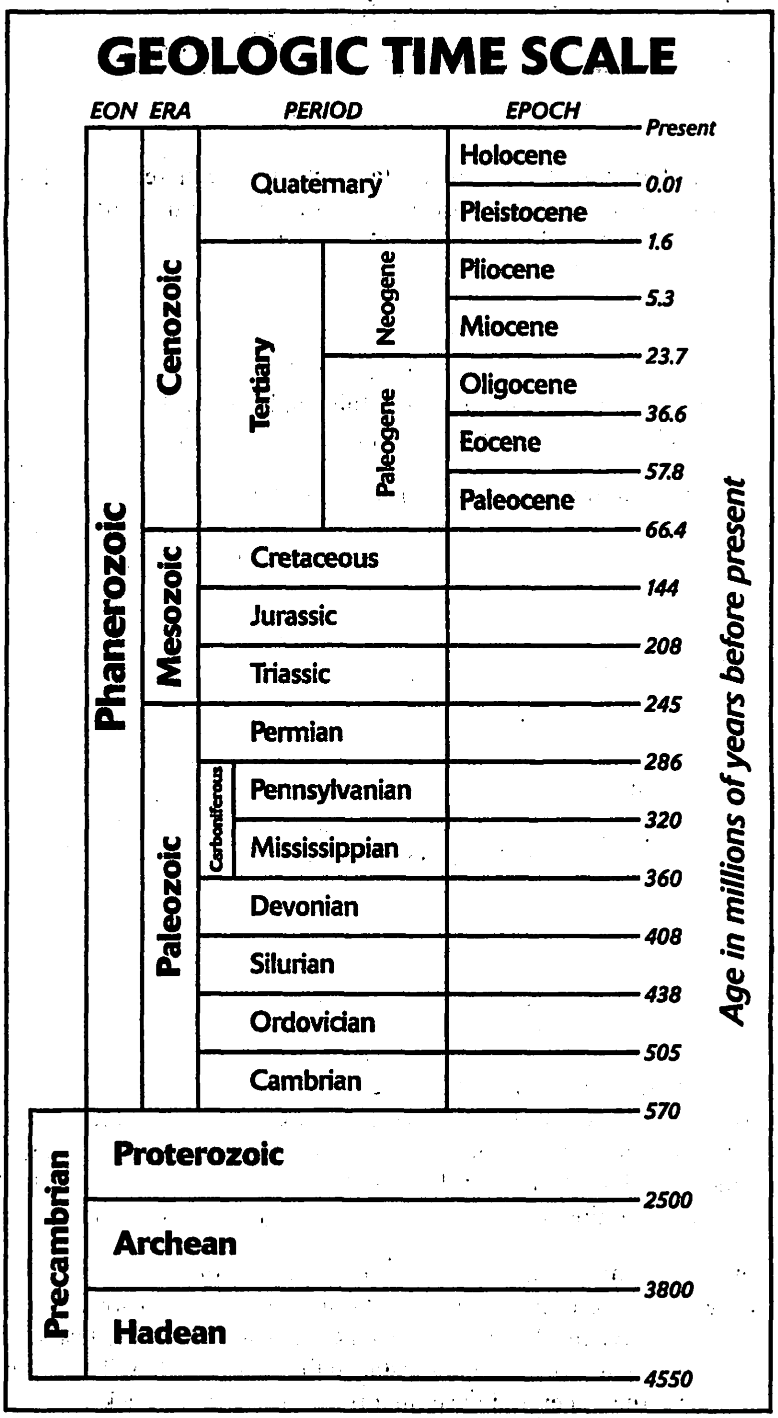
### Earth's Structure

With its varying composition and dense core, Earth is layered, and each layer has its own properties. From the interior outward, Earth is composed of a core, a mantle, and a crust.

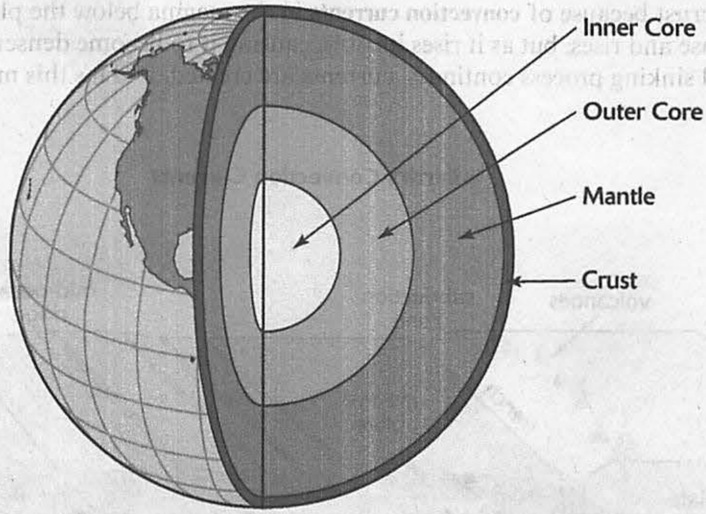
The **crust,** the outermost layer of the Earth and the surface on which we live, can be either continental crust or oceanic crust, depending on where it's found. **Oceanic crust** is denser than continental crust because it is, in large part, made up of basalt, which contains the heavier elements iron and magnesium. The **continental crust** has a high amount of granite, which is rich in the lighter element aluminum. Because of its brittle nature, the crust can fracture and lead to earthquakes. Continental crust is 22 to 44 miles thick, and oceanic crust is 3 to 6 miles thick.

Below the crust is the **mantle,** which makes up approximately 80 percent of Earth's volume. It contains the upper mantle and lower mantle. The crust and upper mantle are grouped together in a structure called the **lithosphere,** which is the rigid outer layer of the Earth. Below the lithosphere but still above the lower mantle is a layer called the **asthenosphere,** which is made up of a plastic-like substance that tends to flow. The lower mantle is semi-rigid and flows very slowly. Combined, the upper and lower mantle are 1,802 miles thick.

The dense **core** at the center of the Earth is similarly subdivided into an inner and outer core. The inner core is mainly made up of iron and nickel and is solid because of the extreme pressure from the other layers above it. The liquid outer core is composed mainly of iron and nickel; it is molten because of its extreme heat, which is at least 10,832°F. The outer core is about 1,429 miles thick, and the inner core is 746 miles thick.



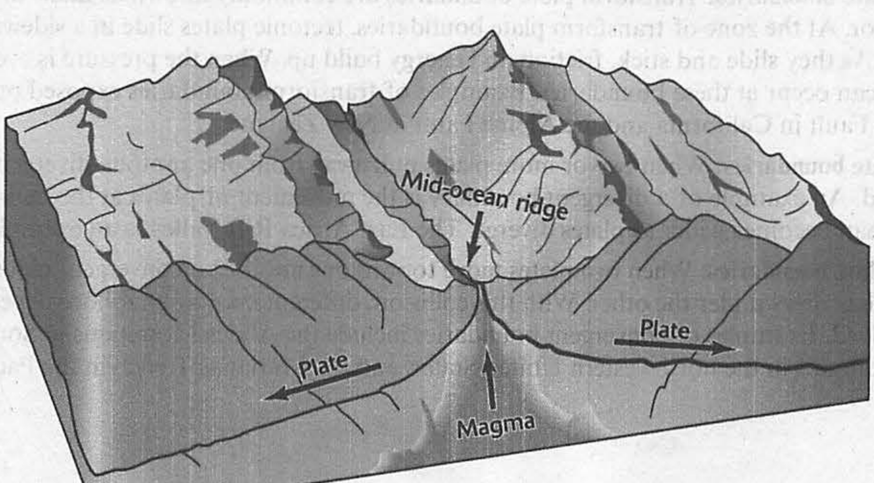

Source: U.S. Geological Survey




## Plate Tectonics

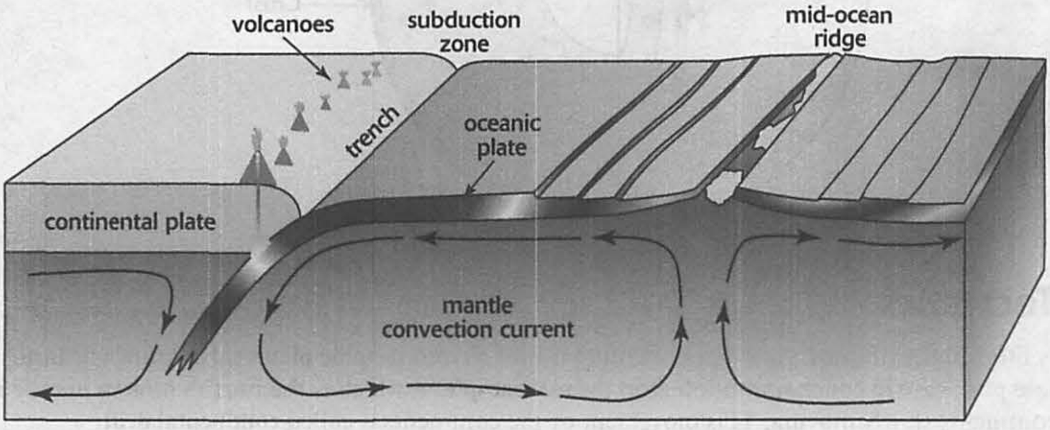
The Earth's lithosphere (the crust and upper mantle) is broken into **tectonic plates** (also known as lithospheric plates). These plates are in constant motion atop the **asthenosphere,** which is the Earth's molten mantle layer that keeps the continents slowly moving. This movement of the continents is called **continental drift.**

The reason that tectonic plates are in constant motion is a process called **seafloor spreading,** which is the movement of the seafloor at the **mid-ocean ridge.** A mid-ocean ridge is the location from which **magma** (molten rock within the Earth) rises to the surface from the asthenosphere. It looks like a scar across the ocean floor. As the magma pushes through the crust and hardens, new seafloor is created. As new magma surfaces, it pushes away the existing seafloor, causing it to spread and move apart.



Magma rises through the crust because of **convection currents** in the magma below the plates. When magma is heated, it becomes less dense and rises, but as it rises it cools, causing it to become denser and sink. As the heating and cooling, rising and sinking process continues, currents are created, and it's this movement that drives the plate motion.

**Earth's Convection Currents**

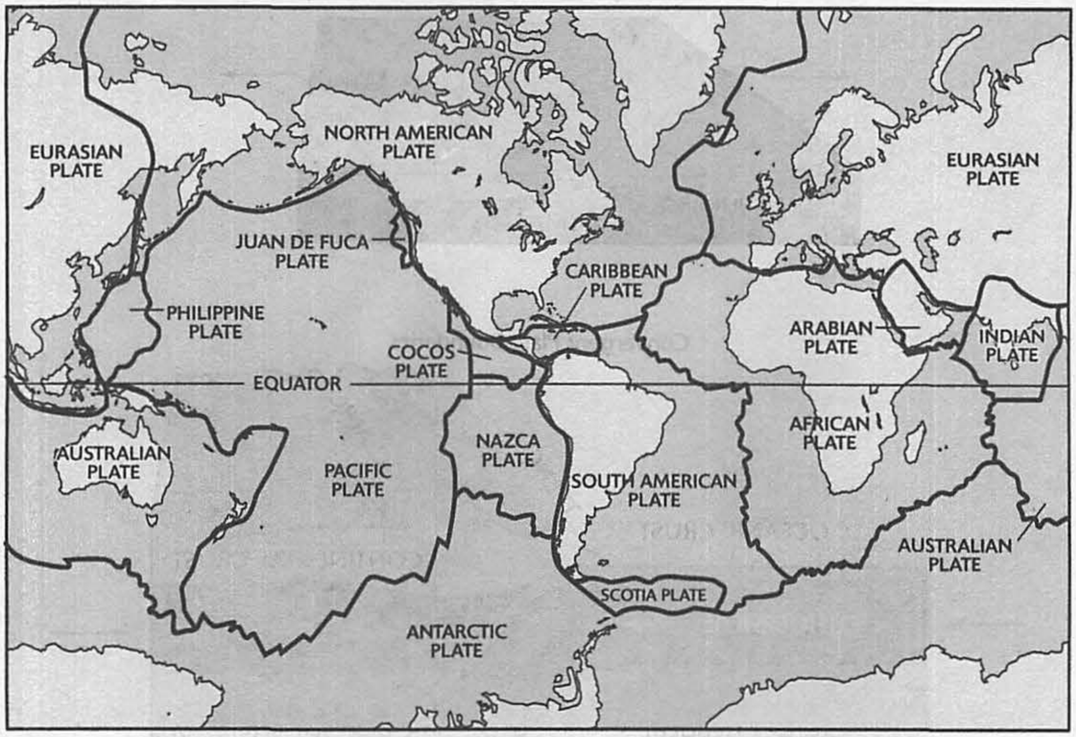



## Plate boundaries

At plate boundaries, major geologic activity occurs, including earthquakes, volcanoes, and the formation of mountain ranges. The type of activity depends on the type of plate movement. The three types of plate boundaries are

- **Transform plate boundaries:** Transform plate boundaries are commonly known as **faults** and are found on the ocean floor. At the zone of transform plate boundaries, tectonic plates slide in a sideways motion past one another. As they slide and stick, friction and energy build up. When the pressure is eventually relieved, earthquakes can occur at these boundaries. Examples of transform boundaries exposed on land include the San Andreas Fault in California and the Alpine Fault in New Zealand.
- **Divergent plate boundaries:** When two or more plates pull away from one another, divergent plate boundaries are created. An example of a divergent boundary is the movement of plates at the mid-ocean ridge, where the ocean becomes wider as plates diverge. The East Africa Rift Valley is an example.
- **Convergent plate boundaries:** When two plates move toward one another, a convergent plate boundary is created as one plate dives under the other. With this collision, different events can follow, depending on the type of crust involved. Examples of convergent boundaries include the Andes Mountains in South America, the Cascade Mountains in the northwestern United States, and the Marianas Trench in the Pacific Ocean.

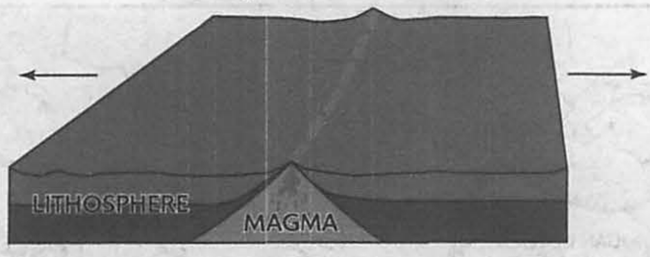
Earth's Plates and Plate Boundaries



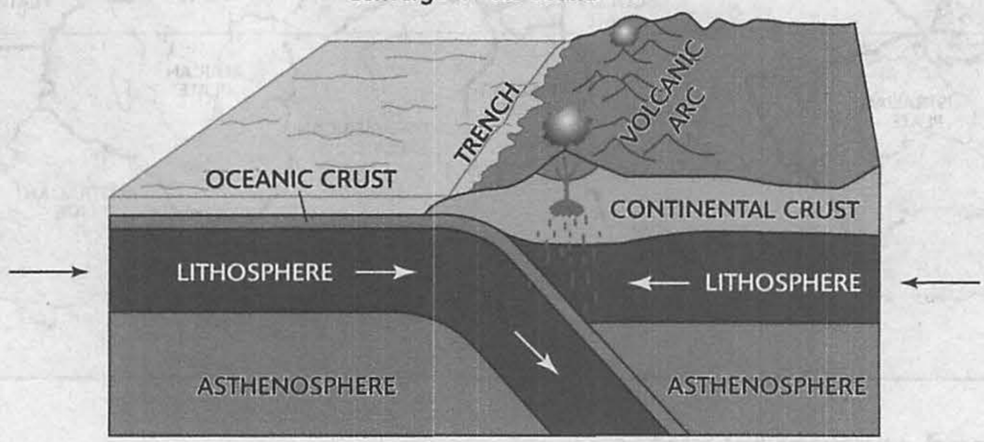

## Oceanic and continental plates

Oceanic and continental plates in collision lead to **subduction.** Subduction of oceanic plates at plate boundaries is the cause of continental crust being older than oceanic crust. The denser oceanic plate is pushed below the lighter continental plate. When the crust is compacted and pushed up during the collision of two continental plates, mountain ranges are formed. This motion created the Himalaya Mountains, which are still growing today. When two oceanic plates collide, one plate may be pushed below the other, forming a trench or producing a volcano and allowing magma to rise. Formations created from convergent boundaries include the Andes Mountains in South America, the Cascade Mountains in the northwestern United States, and the Marianas Trench in the Pacific Ocean. Earthquakes also can occur as a result of movement at plate boundaries.

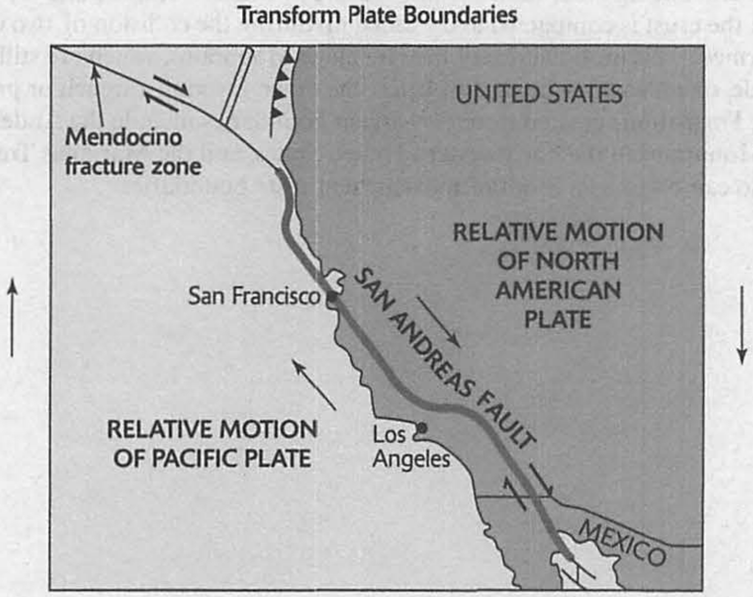
Divergent Plate Boundaries




Convergent Plate Boundaries




Transform Plate Boundaries




Source: U.S. Geological Survey

## Earthquakes

At times, pressure builds up at plate boundaries because of friction from plate movement, and stress is created. When this stress is ultimately discharged, energy is released throughout the Earth's crust, causing vibrations, or

**earthquakes.** Often, earthquakes are caused by movement of the lithospheric plates and occur at plate boundaries. The focus of an earthquake is the location at which the earthquake originates within the Earth. Above the focus is the **epicenter,** which is the first place on the Earth's surface affected by the earthquake.

The types of faults from which earthquakes can occur include strike-slip, normal, and reverse. **Strike-slip faults** occur where the plates slide past one another horizontally. **Normal faults** are caused by tension from a pulling-apart motion. **Reverse faults** are caused from compression.

Earthquakes themselves do not generally kill people, but their effects on human-built structures do. Because an earthquake is a vibration of the Earth caused by a sudden release of energy, this movement transfers into buildings, roadways, and other infrastructures. The consequences of structural failure in constructed facilities ultimately cause harm. **Tsunamis** are seismic sea waves generated from undersea earthquakes or volcanic eruptions and are an exception to this statement, though. They are not dangerous while traveling through the ocean, but they can cause massive destruction once they reach a coastline, which can be thousands of miles from the location of the earthquake or volcano.

# Volcanoes

Volcanoes are openings in the Earth's surface that allow magma, gases, ash, cinder, and other volcanic material to escape from the mantle. A volcano's structure includes a magma chamber, which contains a pool of magma deep within the earth; a pipe (conduit) that brings lava, gases, and other materials from the magma chamber to the surface; and a vent, which is the opening through which lava and other material escapes. Some volcanoes also have a crater, or depression, at the mouth,

Because of the ever-changing interior of the Earth, volcanoes have various stages and remain active for a period of time. An **active volcano** is either presently erupting or will eventually erupt because of a large amount of seismic and thermal activity occurring within it. A **dormant volcano** is inactive but could potentially erupt again. An **extinct volcano** is not erupting and most likely will never erupt again.

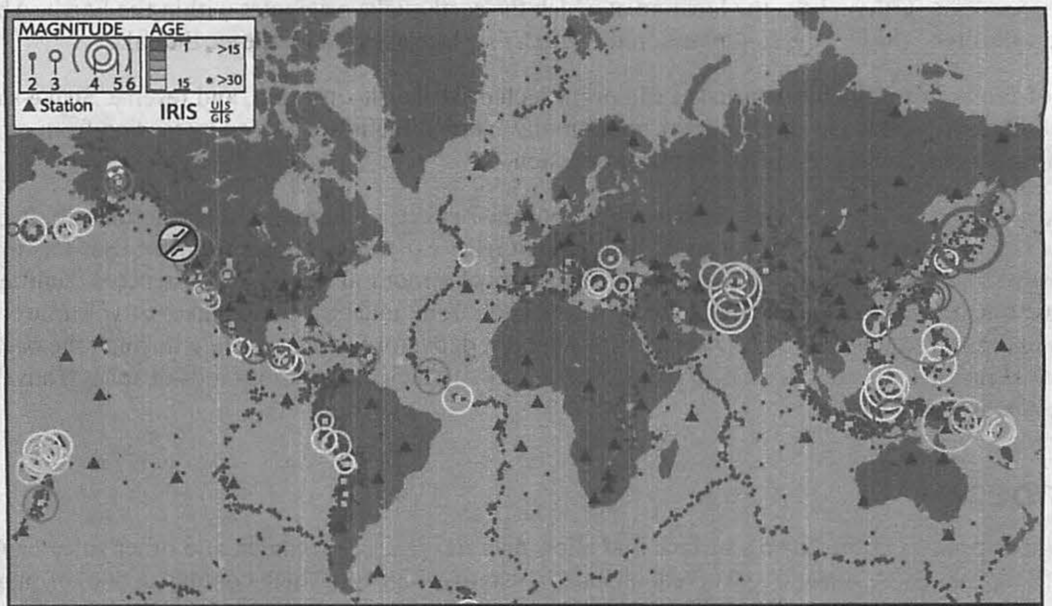
## Types of volcanoes

Three main types of volcanoes have been identified:

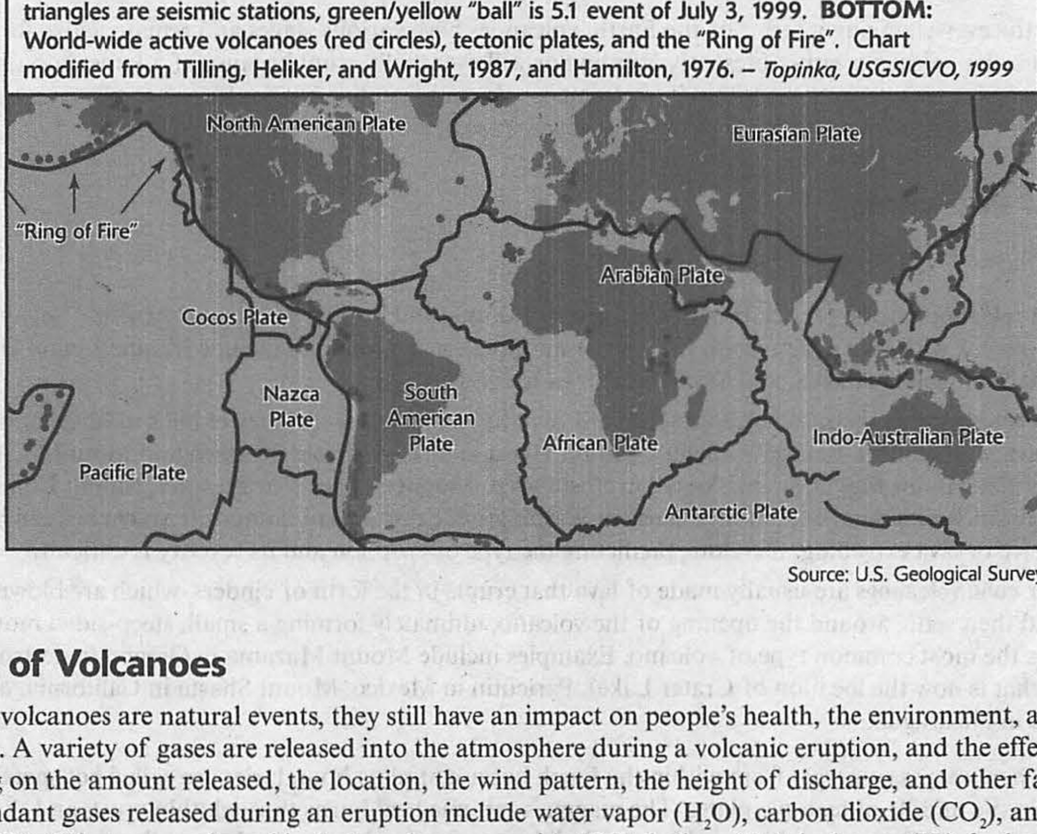
- **Shield volcanoes** are large with broad sides, gradual slopes, and usually a crater at the top. They typically erupt slowly, with lava oozing from the vent or multiple vents. Examples include Mauna Loa in Hawaii, Mount Wrangell in Alaska, and Skjaldbreiður in Iceland.
- **Composite volcanoes** (strato volcanoes) are tall, symmetrical, and steep. They're built of alternating layers of ash, lava, and cinders. Examples include Mount Hood in Oregon, Mount Lassen and Mount Shasta in California, Mount Fuji in Japan, Arenal in Costa Rica, Mount Cotopaxi in Ecuador, Mount Etna in Italy, and Mount Rainier and Mount St. Helens in Washington. Eruptions of composite volcanoes can be either explosive or lava extruding; therefore, predicting the type of eruption and its severity is difficult.
- **Cinder cone volcanoes** are usually made of lava that erupts in the form of cinders, which are blown into the air and then settle around the opening of the volcano, ultimately forming a small, steep-sided mountain. This is the most common type of volcano. Examples include Mount Mazama in Oregon (a destroyed volcano that is now the location of Crater Lake), Paricutin in Mexico, Mount Shasta in California, and Cerro Negro in Nicaragua.

Locations where magma emerges from within the Earth but not at plate boundaries are called **hot spots.** Hot spots form in the middle of tectonic plates. The magma's extreme heat burns through thin crust, and then cools and forms new crust. Over time, this new land can build up to form volcanoes in the middle of plates or islands in the ocean. Examples of places where hot spots have occurred include the Hawaiian Islands, the Galapagos Islands, Iceland, and Yellowstone National Park.

Earthquakes, Active Volcanoes, and Plate Tectonics




**TOP:** World-wide earthquakes on July 7, 1999, and past 5 years, demonstrating how earthquakes define boundaries of tectonic plates. Data from NEIC. Chart from IRIS Consortium, USGS, U. Colorado, Reel Illusions, Inc., and U. Washington. Chart modified for web use. Purple triangles are seismic stations, green/yellow "ball" is 5.1 event of July 3, 1999. **BOTTOM:** World-wide active volcanoes (red circles), tectonic plates, and the "Ring of Fire". Chart modified from Tilling, Heliker, and Wright, 1987, and Hamilton, 1976. – *Topinka, USGSICVO, 1999*




Source: U.S. Geological Survey

## Effects of Volcanoes

Although volcanoes are natural events, they still have an impact on people's health, the environment, and other organisms. A variety of gases are released into the atmosphere during a volcanic eruption, and the effects vary, depending on the amount released, the location, the wind pattern, the height of discharge, and other factors. The most abundant gases released during an eruption include water vapor ($H_2O$), carbon dioxide ($CO_2$), and sulfur dioxide ($SO_2$). Other gases released include carbon monoxide (CO), helium (He), hydrogen ($H_2$), hydrogen chloride (HCl), hydrogen sulfide ($H_2S$), and hydrogen fluoride (HF).

Posing the potentially most harmful effects on organisms and the environment are

- **Hydrogen fluoride (HF),** also called sewer gas, which can cause respiratory tract irritation, bone degeneration, and pulmonary edema in high concentrations. At lower concentrations, exposure can cause eye irritation, diarrhea, dizziness, excitement, and staggering. When HF coats grass and animals then ingest it, poisoning can occur, as can bone degeneration and even death. HF also contributes to acid rain.
- **Carbon dioxide ($CO_2$)** has a density greater than that of air, so it sinks and can kill animals, people, and plants. The $CO_2$ replaces the air, so asphyxiation can occur in areas with abundant $CO_2$. This gas can also collect in soils, which can affect the microbial population in the soil and nutrient intake by plants.
- **Sulfur dioxide ($SO_2$)** can lead to acid rain, air pollution, and smog at a local level. On a global level, it can lower surface temperatures and exacerbate depletion of the ozone layer. $SO_2$ also can harm human health mainly by affecting the respiratory system and also irritating skin, eyes, nose, and throat.
- **Hydrogen chloride (HCl)** causes irritation of the eyes, throat, and respiratory system. It can lead to acid rain because of its solubility in water, as well as to loss of ozone.

## Atmospheric Effects of Volcanoes

Because these volcanic gases are released into the atmosphere, the effects can be dramatic:

- Ozone can be broken down when reactions occur with HCl or $SO_2$. Fortunately, the ozone depletion diminishes once the gases are reduced in the atmosphere.
- Volcanic gases can contribute to global warming because $CO_2$ and water vapor trap and absorb solar energy, raising the temperature of the planet over time.
- The gases can contribute to the haze effect (smog), in which particulate matter in the atmosphere blocks out solar radiation and ultimately can lower the mean global temperature.

These effects usually are not long-term when they occur because of volcanic activity, but they're exacerbated by human activities that also release these gases into the atmosphere.

# Solar Radiation, Intensity, and Seasons

Solar energy affects the entire dynamic of the planet, including climate, weather, biodiversity, and life's productivity. The amount of solar energy the Earth receives depends on the tilt of Earth's axis, its rotation around that axis, and its revolution around the Sun. One rotation equals one day, and a revolution equals a year.

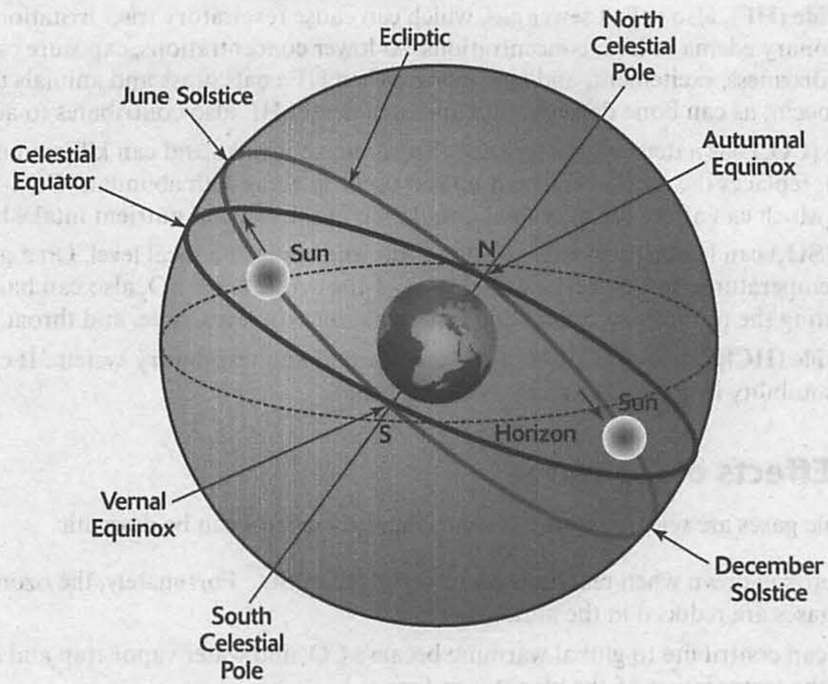
Throughout the year, Earth has two **equinoxes,** times when day and night are equal. Toward the end of March, the **vernal equinox** occurs, signifying the start of spring in the Northern Hemisphere and fall in the Southern Hemisphere. The **autumnal equinox,** marking the beginning of fall in the Northern Hemisphere and spring in the Southern Hemisphere, occurs at the end of September.

**Solstices** occur when the sun is most north or south of the celestial equator. In the Northern Hemisphere, the summer solstice, when the sun is northernmost, occurs on June 21 over the Tropic of Cancer. The winter solstice occurs on December 21 over the Tropic of Capricorn and is when the sun is southernmost. In the Northern Hemisphere, the summer solstice is the longest day of the year, and the winter solstice is the shortest.

## Seasons

Earth's seasons are created by the tilt of Earth's axis to its orbital plane and its rotation around the sun, which is 23.5 degrees. At different times throughout the year, different parts of the Earth are facing the sun. **Summer** occurs when the sun's rays hit Earth's surface at the most direct angles, also giving summer the longest daylight hours. During **winter** the angle of the sun's rays are more oblique, giving that portion of the Earth shorter days and less solar energy. The seasons are not related to Earth's distance from the sun. The Earth is actually closest to the sun in January **(perihelion)** and farthest away in July **(aphelion)**.

Celestial Coordinate System




# The Atmosphere

As a protector of Earth, the atmosphere deflects many harmful UV rays from the sun and helps to maintain a stable temperature by helping to retain heat with a natural greenhouse effect. Without the atmosphere, life as we know it would not be able to exist on this planet. It is also a dynamic aspect of Earth, changing over the 4.6 billion years of the planet's existence.

## Composition

Earth's atmosphere is composed of 16 dry gases and water, usually in the form of water vapor.

| Atmospheric Gases | |
|---|---|
| Nitrogen ($N_2$) | Nitrogen makes up approximately 78 percent of the total composition of the atmosphere. It is in equilibrium with Earth's abiotic and biotic systems. Nitrogen enters the biotic system either through nitrogen fixation or lightning, which turns nitrogen gas into usable forms of nitrogen for plants. In order to be converted back to atmospheric nitrogen, nitrogen in the lithosphere undergoes denitrification. The combustion of biomass can also release nitrogen into the atmosphere. |
| Oxygen ($O_2$) | Oxygen represents approximately 21 percent of the total composition of the atmosphere. Oxygen is released to the atmosphere during photosynthesis and is used by plants and animals during cellular respiration. |

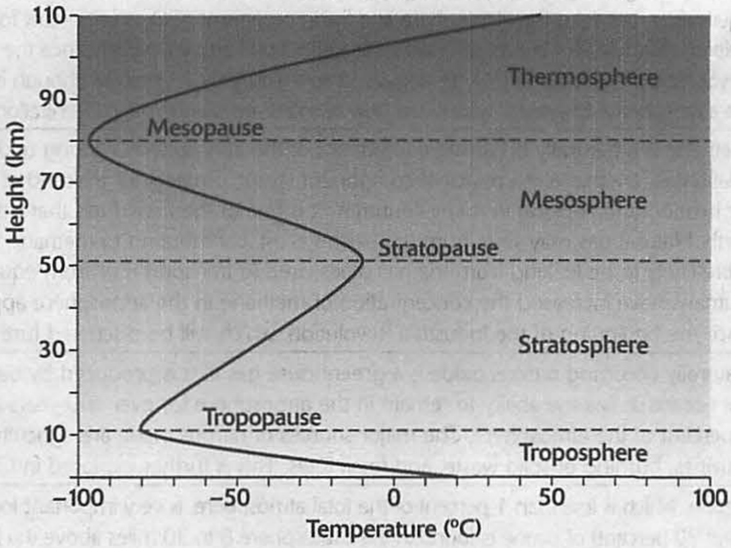
| Natural Greenhouse Gases | |
|---|---|
| Water vapor ($H_2O$) | The concentration of water vapor in the atmosphere varies greatly depending on location, but it is about trace to 4 percent of the total composition of the atmosphere. Above the world's oceans, near the equator, and in the tropical regions, the water vapor percentage is higher than it is in the atmosphere over the poles and the world's deserts, where it can be very low. |

| | |
|---|---|
| Carbon dioxide ($CO_2$) | Since the beginning of the last ice age and prior to the Industrial Revolution, carbon dioxide has been in equilibrium between the atmosphere and living organisms. $CO_2$ is important for photosynthesis and for helping to maintain the natural greenhouse effect on Earth. However, since the beginning of the Industrial Revolution, the volume of $CO_2$ has increased approximately 25 percent (though it is still less than 1 percent of the atmosphere). Chapter 7 will discuss how humans are altering the concentration of $CO_2$ in the atmosphere. |
| Methane ($CH_4$) | Methane is a naturally occurring component of the atmosphere, making up less than 1 percent of the total gases. Methane is a principal component (approximately 87 percent) of natural gas and is used for heating and cooking in many countries. It is one of the fossil fuels that is tapped by drilling into the Earth. Natural gas may seep from the Earth's crust, contributing to methane in the atmosphere, but it's more likely to be leaking from the gas pipes used to transport it or from equipment that burns it. Humans have increased the concentration of methane in the atmosphere approximately 150 percent since the beginning of the Industrial Revolution, which will be discussed further in Chapter 7. |
| Nitrous oxide ($N_2O$) | Naturally occurring nitrous oxide is a greenhouse gas that is produced by bacteria in solids and from the oceans. It has the ability to remain in the atmosphere for over 100 years and makes up less than 1 percent of the atmosphere. The major sources of nitrous oxide are agricultural practices, industrial activities, burning of solid waste, and fossil fuels. This is further explored in Chapter 7. |
| Ozone ($O_3$) | Ozone, which is less than 1 percent of the total atmosphere, is very important for life on Earth. The majority (over 90 percent) of ozone is found in the stratosphere 8 to 30 miles above the Earth. The ozone layer absorbs UV radiation from the sun, thereby protecting life on Earth from harmful rays. Ozone ($O_3$) is formed by a naturally occurring reaction in the atmosphere. The chemical reaction for the formation of ozone is:<br>$O_2 + UV \rightarrow O + O$<br>$O + O_2 \rightarrow O_3$<br>Troposphere ozone is considered a pollutant. Ozone in the stratosphere was once in equilibrium. These issues are further discussed in Chapter 7. |

## The Structure of the Atmosphere

Temperature is the criterion for determining the different layers in Earth's atmosphere. In the troposphere and mesosphere, the temperature decreases with increased altitude. In the stratosphere and thermosphere, the temperature increases with increased altitude. Between these four major layers are small layers where the temperature stays roughly the same. These are the pauses between the layers: the tropopause, stratopause, and mesopause.

| Layer Name | Height (miles) | Temperature | Comments |
|---|---|---|---|
| Troposphere | 0–9 | Decreases with increasing altitude; coldest reaching –70°F | Life exists in this layer and weather occurs here. Holds most of atmospheric water vapor. Significantly thinner at the poles than at the equator. Contains 75 percent of the atmosphere's mass due to higher air density near Earth's surface. |
| Stratosphere | 9–31 | –60°F to 5°F | Contains ozone layer. Temperature increases with distance from Earth. Heat is produced as part of the process of ozone being created. Aircraft usually fly within this layer. Warmer air is located above cooler air, so little vertical mixing occurs. |
| Mesosphere | 31–50 | Can drop to –130°F | Contains coldest temperatures in atmosphere, with temperatures decreasing as distance from Earth increases. Low air pressure due to thinning of gas particles. Least explored part of atmosphere. |
| Thermosphere | 50+ (no well-defined upper limit) | Up to 2,192°F | Known as the upper atmosphere and contains very thin air. Little mixing of air particles, which are moving fast but are very far apart. High temperatures due to absorption of high energy wavelengths from solar radiation. |




# Weather and Climate

**Weather** is the name given to the short-term events of temperature, wind, and precipitation. The constant patterns developed from averaging the daily weather for an extended period of time is **climate.** Climate is typically the weather averages for at least 30 years. Many areas have recorded data for more than 100 years now, though the more recent data is more accurate as instruments have become more standardized and computerized.

The transfer of heat energy causes weather, and the source of heat energy is solar energy heating the Earth. This solar energy heats the Earth unevenly because of the distribution of water and land on the Earth and the specific heat of each. This heating of the Earth is reflected in the temperature, movement of air masses, and availability of sunshine. The rotation of the Earth also plays a role in the weather patterns.

**Latitude and altitude** have an effect on the climate of a region. The farther from the equator, the less solar radiation and the cooler the climate. There is also a greater seasonal variation throughout the year when farther from the equator. Altitude, the distance above the Earth's surface (sea level), is also a determining factor on the climate of a region. Each 1,000-foot gain in altitude reflects a 4°F decline in air temperature. For example, at 10,000 feet, an alpine tundra climate zone air temperature might average 35°F. Changes in latitude and altitude influence plant and animal distribution.

# Atmospheric Circulations

The circulation of air in the atmosphere is the result of solar heating, the rotation of the Earth, and the properties of air, land, and water. Earth is heated unevenly for three reasons:

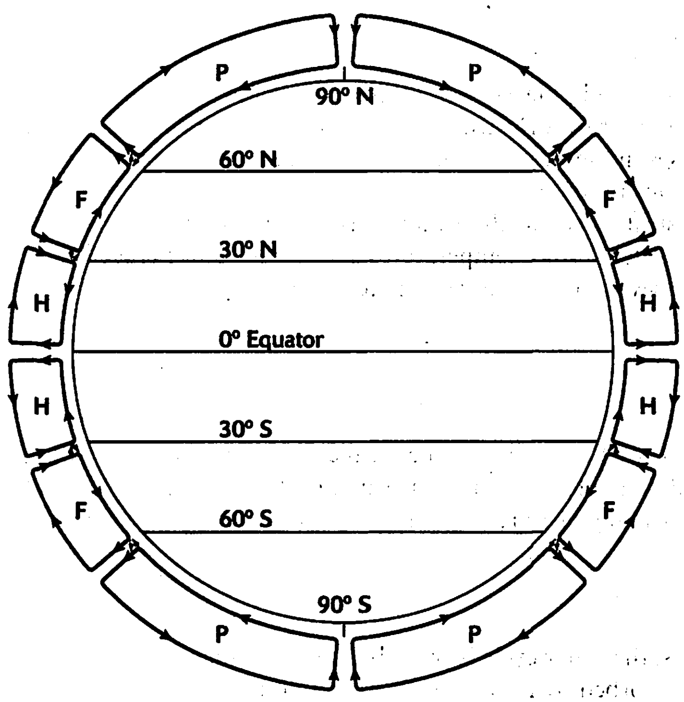
- **More solar energy hits the Earth at the equator than the poles, and the per unit of energy by per surface square area varies.**
- **The tilt of the Earth on its axis points some regions toward the sun and others away from the sun.** Areas angled toward the sun receive more direct energy than areas angled away from the sun. The various seasons on Earth are caused by the tilt of the planet's axis and the rotation of Earth around the sun over the course of a year.
- **Earth's surface is moving faster at the equator than the poles.** This is the reason for the phenomenon known as the Coriolis effect (the apparent deflection of a moving object in a rotating reference frame).

As solar energy heats the Earth's surface, some heat is transferred to the atmosphere by radiational heating. This energy warms the gases, the gases expand, they become less dense and then rise, whereupon they cool and fall back to the Earth's surface to be reheated again, thus creating a continuous cycle. This constant heating and cooling creates vertical currents called convection currents. On a global scale, these convection currents are called the Hadley, Ferrel, and Polar cells:

- **Hadley air circulation cells** occur close to the equator. The surface air in this region is warmed from the strong solar radiation, causing the air to rise and expand. This process releases moisture and provides high amounts of rain, a major contributing factor for the tropical rainforests in the equatorial region. The air, now holding less water, heads north and south, ultimately cooling and sinking back towards the surface. Now containing very little water, the arid air helps to produce deserts. The Hadley cell is the strongest of the three air circulation cells.
- **The Ferrel air circulation cells** generally occur at mid-latitudes between the Polar and Hadley cells. Because of the sinking air coming from the Hadley cells and the rising air brought in by the Polar cells, westerly surface winds are produced in these regions.
- **The Polar air circulation cells** are the northernmost of the three types of cells and contain dense, cold air moving towards the poles. As the air reaches the poles, it sinks and then moves south back towards the mid-latitudes. In this process, air starts to warm and rise again, creating low pressure areas.

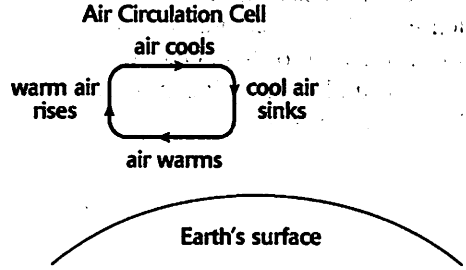
Another component of atmospheric circulation is the **Coriolis effect.** This occurrence creates the deflection of objects from otherwise moving in a straight line. This is due to the rotation of Earth. For example, if you spin a disk and try to draw a line from the center to the edge, the result will be a curved line. This is caused by the Coriolis effect. This effect causes winds in the Northern Hemisphere to deflect to the right and in the Southern Hemisphere to deflect to the left. The Coriolis effect contributes to the creation of the three air circulation cells and has effects on weather patterns and ocean circulation.

Air Circulation Cells




H Hadley
F Ferrel
P Polar

Air Circulation Cell



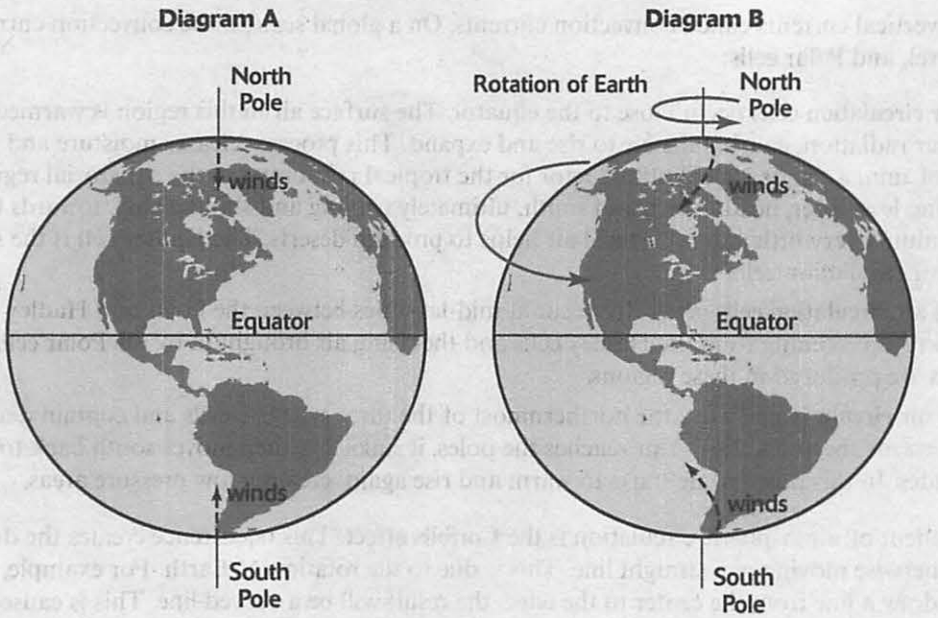



**Diagram A:**
**Path of polar winds if Earth did not rotate**

**Diagram B:**
**Path of the polar winds with the Earth's rotation. This effect is called the Coriolis Effect.**

## El Niño and La Niña

El Niño is a period of ocean warming in the eastern tropical Pacific Ocean. During the El Niño, the surface waters warm due to strong undercurrents of warm water inhibiting the upwelling of colder, nutrient-rich waters. The air surface pressure increases in the western Pacific, resulting in milder climates in the northern United States and Canada and wetter conditions in the eastern United States and regions of Peru and Ecuador, while the Philippines, Indonesia, and Australia become drier than normal. The frequency of Atlantic hurricanes is reduced as well. During La Niña years, water surface temperatures are colder than average in the eastern Pacific Ocean. Both events occur in a three- to seven-year cycle, relating to large-scale atmospheric circulation.

# Water Dynamics

The water cycle is considered one of Earth's biogeochemical cycles, but it is also very important to weather patterns, ocean circulation, and most life on Earth. The water cycle is the most important cycle because it's responsible for the movement of many of Earth's nutrients and impacts other biogeochemical cycles.

## Water Cycle

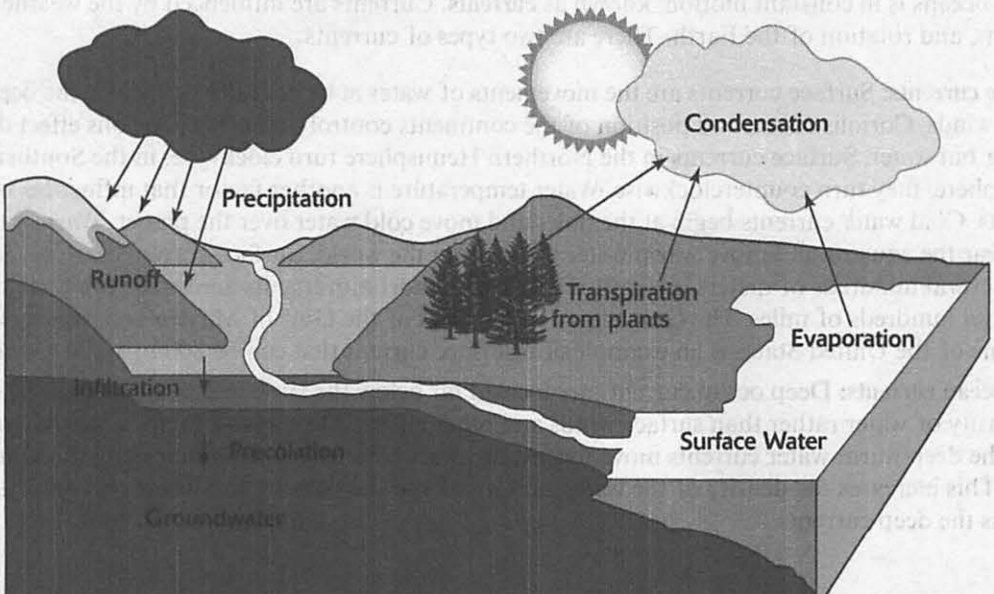
Of all the biogeochemical cycles, the water cycle is probably most familiar. Energy provided by solar radiation fuels the cycle. Solar energy is absorbed by Earth's surfaces and bodies of water, increasing the heat content and driving evaporation. Water evaporates from these bodies of water and transpires from vegetation. Once in the atmosphere, water condenses and forms clouds. When the clouds contain enough water, the water falls as precipitation in the form of rain, snow, sleet, or hail. Once on the ground, water can run off as surface water, infiltrate Earth's surface and become groundwater, or it can be evaporated again. Water near soil's surface can be absorbed by plants and used in photosynthesis.

The following is a list of terms related to the water cycle:

- **Condensation:** The transformation of water vapor from gaseous to liquid phase, with water droplets condensing onto atmospheric particles and producing clouds and fog.
- **Evaporation:** The transformation of water from liquid to gas phase due to heating of the water, usually from solar radiation.
- **Groundwater:** Water that is located beneath the Earth's surface in the pore spaces of soil, the fractures in rock formations, or held in aquifers.
- **Infiltration:** The process by which surface water seeps into the soil.
- **Percolation:** The movement of water down through the soil.
- **Precipitation:** Condensed water vapor in the atmosphere that falls to Earth's surface in the form of rain, snow, hail, and sleet.
- **Runoff:** Water that flows along the Earth's surface but does not infiltrate the surface, ultimately percolating into the ground, evaportating into the atmosphere, or running into other bodies of water such as rivers, lakes, streams, or oceans.
- **Transpiration:** The loss of water vapor from plants, mainly from leaves.

Water can be stored in three main areas: the atmosphere, on Earth's surface, or within the ground. There are a variety of sinks (where water is stored), including polar ice and glaciers, bodies of water such as oceans and rivers, below the surface of the Earth in aquifers, and as water vapor in the atmosphere. In some of these sinks, water may be trapped for millions of years.

The oceans hold 97 percent of Earth's water. Approximately 78 percent of the global precipitation falls over the surface of the oceans. Evaporation from ocean waters accounts for 86 percent of all evaporation. This constant precipitation and evaporation helps keep the Earth from overheating.




Source: National Oceanic and Atmospheric Administration

## Freshwater

Only 2.5 percent of Earth's water is freshwater, most of which is locked in polar ice caps and glaciers. Therefore, only about 21 percent of the 2.5 percent is available in the form of groundwater, lakes and rivers, and water vapor in the atmosphere. Freshwater is critical for life on Earth because most life forms need water on a daily basis in order to survive, and freshwater ecosystems support an abundance of life.

# Oceans/Saltwater

Most saltwater is found in Earth's oceans, with a small amount in terminal lakes such as the Great Salt Lake in Utah. On average the salt content in the oceans is 3.5 percent. Ocean water is a mixture of salts, with sodium chloride (NaCl), magnesium chloride (MgCl), and calcium chloride (CaCl) being the three primary salts. The salts are transported mainly in runoff and wind as sediment from continental land. There are many unique and diverse ecosystems that depend on the saltwater environment.

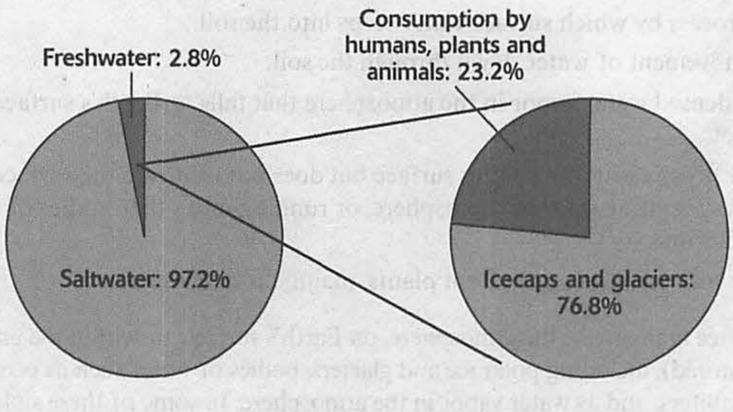



Diagram A: Earth's distribution of salt and freshwater

Diagram B: Distribution of Earth's freshwater

# Ocean Currents

Water in the oceans is in constant motion, known as **currents.** Currents are influenced by the weather, location of the continents, and rotation of the Earth. There are two types of currents:

- **Surface currents:** Surface currents are the movements of water at or near the surface of the ocean. The global winds, Coriolis effect, and position of the continents control them. The Coriolis effect deflects not only air but water. Surface currents in the Northern Hemisphere turn clockwise; in the Southern Hemisphere, they turn counterclockwise. Water temperature is another factor that influences ocean surface currents. Cold water currents begin at the poles and move cold water over the planet. Warm water currents start near the equator and move warm water throughout the world. Surface currents can be shallow or reach several hundreds of meters in depth. They can be short movements across the top of the surface or can travel hundreds of miles. The Gulf Steam coming out of the Gulf of Mexico and moving up the eastern coastline of the United States is an example of a surface current that can be 800 to 1,200 meters deep.
- **Deep ocean currents:** Deep ocean currents are located far below the surface and are created by differences in the density of water rather than surface winds and other effects. Density is a factor of salinity and temperature. The deep warm water currents move toward the poles where ice forms, increasing the salinity of the water. This increases the density of the water, and it sinks to the ocean floor, where this cold, dense water flows as the deep currents.

# Soil Dynamics

Soil is more than simply dirt. It is a complex system that includes eroded rock material, organic matter, nutrients, air, water, and living organisms. The air and water are held within pore spaces throughout the soil. Because soil is largely composed of weathered rock, soil types depend on which type of rock is the parent material in a given location. Ultimately, this basic rock material is one of the factors that affects the type of vegetation that grows in specific locations.

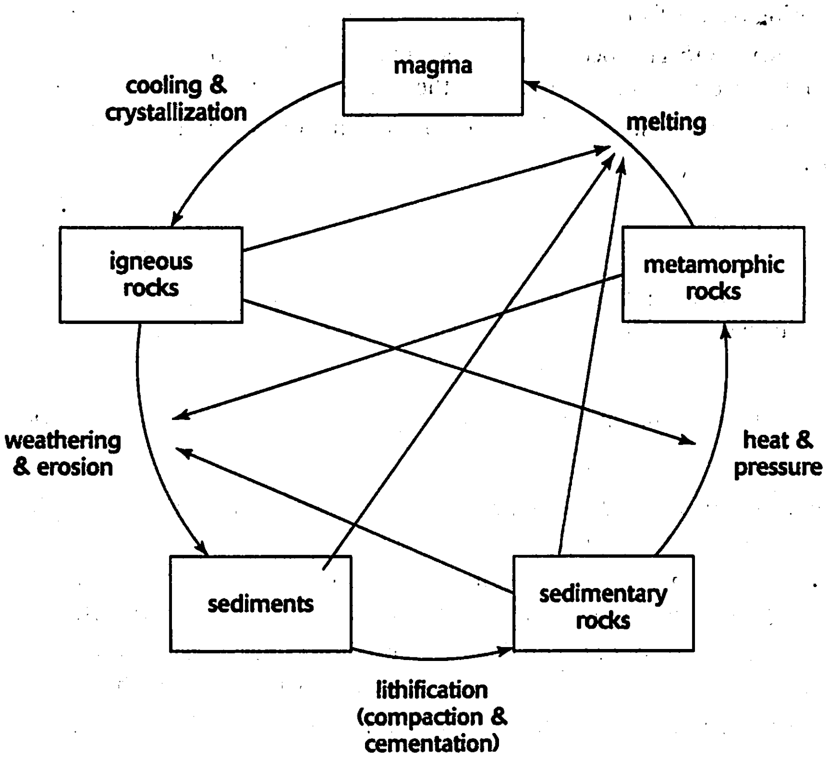
# Rock Cycle

Before studying soil formation, it is important to understand how rocks are created and broken down on Earth. The rock cycle is a continual process that breaks down, alters, and re-forms rock into one of three types. The three types of rock are:

- **Igneous rock:** Igneous rock is formed from cooling magma. When magma cools slowly below Earth's surface, it forms intrusive igneous rock, and when it cools quickly, as when ejected from a volcano, it forms extrusive igneous rock. Examples of igneous rock include granite (intrusive) and basalt (extrusive).
- **Sedimentary rock:** Sedimentary rock is the result of sediments derived from erosion and weathering being compressed and cemented together. Clastic sedimentary rock is formed after rock is physically eroded, and chemical sedimentary rock is formed when dissolved minerals precipitate from water. Examples of sedimentary rock include sandstone (clastic) and limestone (chemical).
- **Metamorphic rock:** Metamorphic rock is formed under extreme heat and pressure, usually deep underground. When heat and pressure force minerals to align and create a layered formation, this is called foliated rock. Unfoliated rock is not layered. Examples of metamorphic rock include marble (unfoliated) and slate (foliated).

One type of rock can be converted into another type through Earth's continual geologic processes.

**The Rock Cycle**




# Soil Formation

Rocks are continually being altered by the rock cycle, and this parent material is the basis of soil formation, but other factors also have an effect on the formation of soil.

Soil formation is based on five factors, each of which plays a role in how and what type of soil is formed in an area. The five factors include parent material, living organisms, topography, climate, and time.

- **Parent material:** The core component of soil is the parent material, which is eroded and weathered from the existing geologic material in a given area.
- **Living organisms:** Living organisms play a role in turning and aerating soil while also aiding in the decomposition and addition of organic matter. Worms, insects, snails, spiders, fungi, bacteria, gophers, squirrels, and many other organisms contribute to this process.
- **Topography:** Earth's shapes and features, called topography, aid in soil formation by the angles of hills, valleys, mountains, and other structures. Factors relating to topography include slope, wind exposure, sun exposure, and water.
- **Climate:** Another factor in soil formation is climate because precipitation and temperature affect climate, and both have an impact on the erosion and weathering of parent material.
- **Time:** It takes time for weathering and erosion to occur, so the amount of time an area has been exposed to various elements affects the makeup of the soil and size of the soil particles.

## Weathering

Parent material is broken down by water, wind, temperature fluctuations, and living organisms through a process called **weathering.** Three types of weathering have been identified, and each breaks down rock in a different way:

- **Biological weathering** occurs from the daily activities of organisms moving through and over soil.
- **Physical (mechanical) weathering** occurs when rock material is broken down without any chemical change taking place, usually through wind, water, and other forces.
- **Chemical weathering** occurs when chemical reactions occur from water and atmospheric gases reacting with parent material.

# Soil Profile

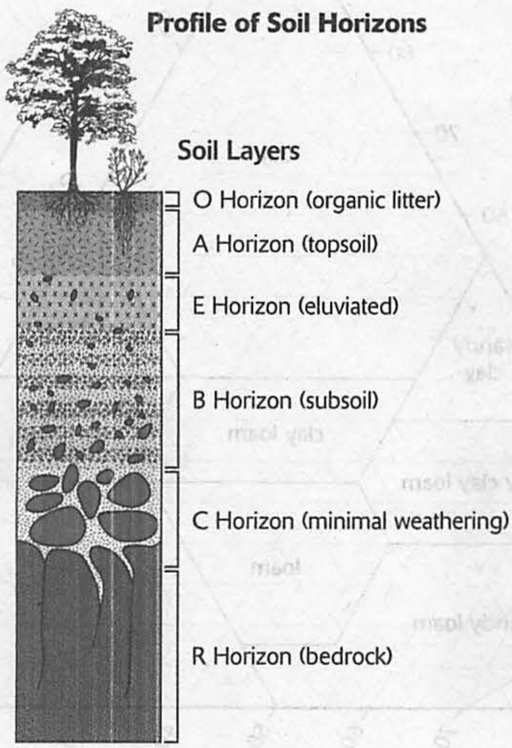
Soil types vary from place to place in both composition and characteristics. Layers of soil develop over time, and the cross-section of these layers is called the **soil profile.** Each layer has specific characteristics based on its location in the soil profile.

Starting with the outermost layer and ending with the deepest, the following list of items describes a cross-section of a soil profile:

- **O Horizon (organic litter):** The O horizon is composed of organic matter, including living organisms, as well as decaying organic matter and waste.
- **A Horizon (topsoil):** The A horizon is a mix of organic matter with inorganic materials. This includes weathered parent material. Topsoil is an important factor in plant growth and productivity.
- **E Horizon (eluviated):** The E horizon is mainly composed of mineral material. E horizon soil is leached from this layer and transported with water as it percolates downward through the soil.
- **B Horizon (subsoil):** The B horizon contains many components leached from the soil layers above it, including nutrients, organic matter, and minerals.
- **C Horizon (minimally weathered):** The C horizon is weathered from parent material, but the weathering and erosion it has experienced is minimal, so it contains mainly larger fragments.
- **R Horizon (bedrock):** The R horizon is the parent material and is called bedrock.

The O and A horizons are where most soil organisms live, while the A horizon contains the most nutrients for plant growth. The concentrations of organic matter and the extensiveness of weathering decrease with depth. *Minerals* are transported through each horizon by **leaching.**

**Profile of Soil Horizons**




## Soil Properties

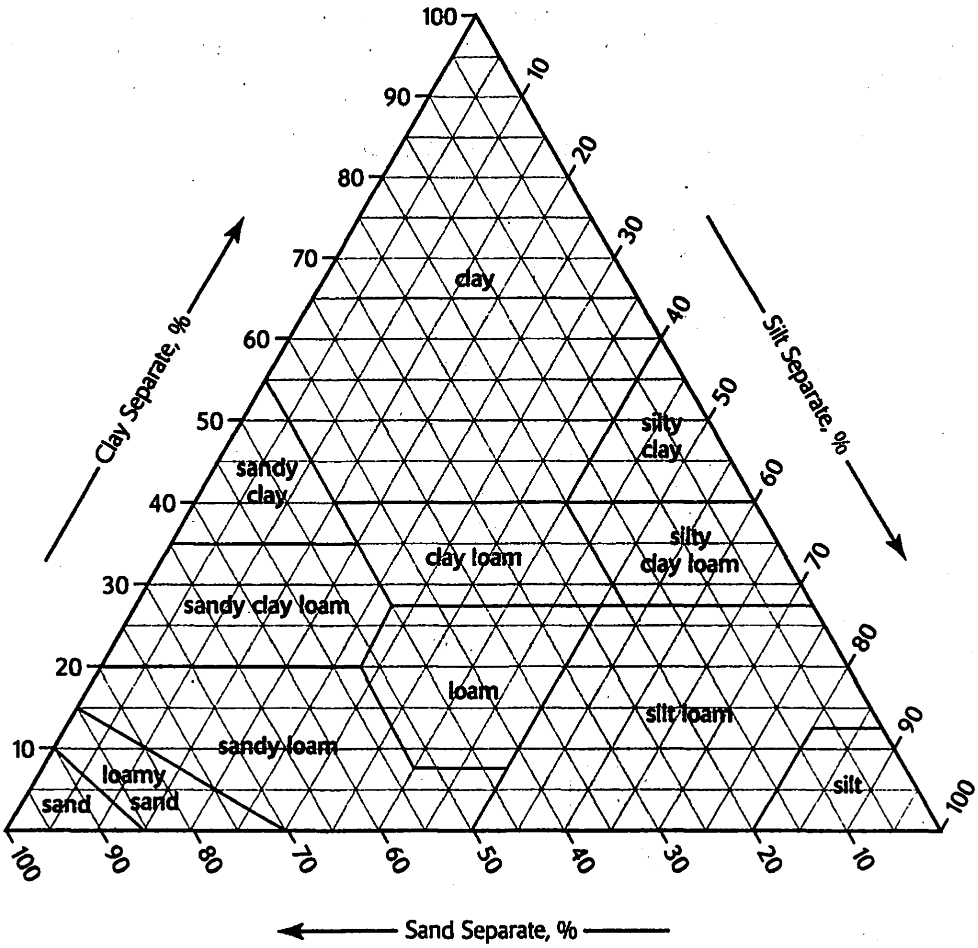
Soil is classified based on the properties of pH, texture, color, and structure. Soil texture affects the other properties, including porosity and permeability. **Soil porosity** is the amount of open space between each soil particle, the ratio of void space to total volume. Water, air, or other gases fill these pore spaces. More pore space means a high water-holding capacity and, therefore, a higher porosity. Conversely, lower porosity means a lower water-holding capacity. **Soil permeability** is the ability of a liquid to flow through the soil. Larger particles have large pore spaces, allowing water to pass through more easily. Clay is considered to have low permeability because it's hard for water to flow through easily. Sand has a higher permeability.

## Soil Texture

Soil texture is used to describe grain sizes in soils. It is divided into three main groups:

- **Clay** is classified as having very fine particles and low permeability (water does not pass through easily). Particle diameter is less than 0.002 mm.
- **Silt** has fine particles, but they are larger than those of clay. Particle diameter is 0.002 to 0.05 mm.
- **Sand** particles are larger than those of silt, so water passes through relatively easily. Particle diameter is 0.05 to 2 mm. Sand is not conducive to plant growth or crop growth unless the plants' requirements for water are low.

**Loam** is an even mixture of sand, silt, and clay particles. Generally, loamy soils with a pH close to neutral are ideal for agricultural plant growth because of their ability to retain water and nutrients.




Source: U.S. Department of Agriculture

## pH

The pH scale measures hydrogen ion concentrations on a scale of 1 to 14. Acidic substances range from 1 to 6.9, and alkaline (or basic) substances range from 7.1 to 14; a pH of 7 is neutral. Soils that are acidic lack nutrients, and alkaline soils can contain an excess of sodium. In general, agricultural soils are best in the range of 3 to 7.

Soil characteristics and properties vary from place to place depending on temperature and precipitation. Human activities are having a profound impact on soils globally because of deforestation, nutrient depletion, overgrazing, overuse, and ultimately erosion. Human effects on soil are reviewed in Chapter 4.

# Practice

1. Tectonic plate boundaries are an important component of geologic activity because:

   **A.** Plate movement affects wave motion and tides.
   **B.** Minerals form at the boundaries.
   **C.** Earthquakes, volcanoes, and formation of mountain ranges occur here.
   **D.** Gases are released here.
   **E.** Weather is affected by the activity at the plate boundaries.

*Questions 2–4 refer to the following answer choices.*

**A.** Sulfur dioxide
**B.** Carbon dioxide
**C.** Hydrogen fluoride
**D.** Carbon monoxide
**E.** Hydrogen chloride

2. An atmospheric gas that can cause acid rain and increase the rate of ozone depletion.

3. An atmospheric gas that may cause bone deterioration, poisoning of animals, and acid rain.

4. An atmospheric gas that replaces breathable air and can lead to asphyxiation.

5. On Earth, summer occurs when:

   **A.** The Earth is closest to the sun.
   **B.** The sun's rays are at the steepest angle on the Earth.
   **C.** The sun's rays are at their most direct angle to Earth.
   **D.** The Earth is farthest from the sun.
   **E.** The vernal equinox occurs.

6. Which is NOT a component of the water cycle?

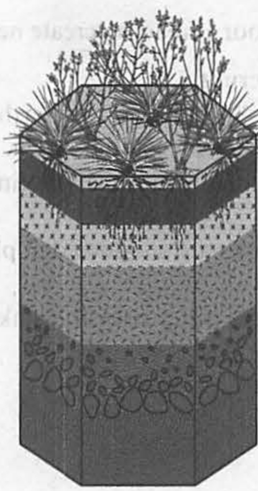
   **A.** Water is stored in sinks, including ice caps, oceans, rivers, and lakes.
   **B.** The sun is a key component and acts as a power source for the water cycle.
   **C.** The movement of nutrients is largely dependent upon the water cycle.
   **D.** Water vapor is considered an atmospheric gas.
   **E.** Most water is held in freshwater sources, such as rivers and lakes.

7. Which of the following has an effect on surface currents?

   I. Water temperature
   II. Coriolis effect
   III. Winds
   IV. Dissolved oxygen
   V. Location of continents

   **A.** I and II only
   **B.** I, II, and III only
   **C.** I, II, III, and IV only
   **D.** IV and V only
   **E.** None of the above

*Questions 8–10 refer to the following figure and answer choices.*




**A.** O horizon layer
**B.** A horizon layer
**C.** E horizon layer
**D.** B horizon layer
**E.** R horizon layer

8. Which soil profile horizon contains most nutrients for plant growth?

9. Which soil profile horizon is considered subsoil?

10. Which soil profile horizon is the parent material?

11. Which of the following is NOT an effect of El Niño?

A. A loss of nutrients in the affected ocean waters
B. A warming of the waters off the western coast of South America
C. Dryer conditions in the eastern United States, Peru, and Ecuador
D. A cooling cycle known as La Niña
E. Dryer conditions in the Philippines, Indonesia, and Australia

12. Which layer of the atmosphere has most of the mass and is the layer where weather occurs?

A. Troposphere
B. Stratosphere
C. Mesosphere
D. Thermosphere
E. Exosphere

13. How does sea floor spreading create new land?

A. Volcanoes erupt.
B. Magma pushes through the Earth's crust at the mid-ocean ridge and hardens.
C. Plates continually move, disrupting the magma.
D. Oceanic plates are subducted at plate boundaries.
E. Heated ocean water rises and sinks at the mid-ocean ridge.

14. In which way do volcanic gases NOT temporarily affect the atmosphere?

A. Ozone is broken down when reactions occur with HCl or $SO_2$.
B. Gases ultimately lower the mean global temperature.
C. Acid rain is reduced.
D. The temperature of the planet increases over time.
E. Smog is created regionally.

15. Three convection currents impact atmospheric circulation: the Ferrel, Hadley, and polar air circulation cells. Which of the following is NOT true of these convection cells?

A. The polar air circulation cells are characterized by two major biomes, tundra and taiga.
B. Both the Hadley and polar circulation cells influence the Ferrel air circulation cells.
C. Two distinct regions—the equatorial region of high humidity and heavy rain and the subtropical region of low humidity, few clouds, and high water evaporation—characterize the Hadley air circulation cells.
D. The three types of convection cells occur only in the northern hemisphere.
E. Ferrel circulation cells are defined by the four traditional seasons—spring, summer, fall, and winter.

# Answers

1. **C** Earthquakes, volcanoes, and the formation of mountain ranges take place at plate boundaries and occur due to the continual movement of the tectonic plates. Plates can converge, diverge, or slide past one another, leading to geologic activity and the creation of geologic structures.
2. **A** Sulfur dioxide chemically reacts with hydrogen and oxygen to form $H_2SO_4$, which forms acid and increases the rate of ozone depletion.
3. **C** Hydrogen fluoride can cause bone deterioration, poisoning of animals, and acid rain. Excess fluorine in animals can poison animals and can lead to fluorosis, which deteriorates bones and may lead to death.
4. **B** Carbon dioxide is denser than air, so excess amounts can create pockets of $CO_2$ close to the ground in low-lying areas. Ultimately, this could lead to asphyxiation and death.
5. **C** Summer occurs when the sun's rays hit the Earth's surface at the most direct angles. Summer is also marked by the longest daylight hours.
6. **E** Of the Earth's water, 97.5 percent is held in oceans, while 2.5 percent is freshwater.
7. **B** Ocean currents are impacted by the movement of wind, the heating of the ocean's surface by the sun, the Coriolis effect, and density differences in the water.
8. **B** The A horizon is considered the topsoil and is an organic and inorganic mix of materials.
9. **D** The B horizon contains many components leached from overlying layers, including nutrients, organic matter, and minerals.
10. **E** The R horizon is bedrock, the parent material that erodes through time, and is the main component from which soil is made.
11. **C** The other four answers are effects of El Niño. El Niño causes wetter conditions in the eastern United States, Peru, and Ecuador.
12. **A** The layers of the atmosphere are listed in order from the innermost layer to the outermost layer. As you move away from the Earth's surface, the mass decreases; thus, the inner layer, the troposphere, has the greatest mass. In addition, weather is caused by the transfer of heat from solar energy hitting the Earth's surface, where the lower layer of Earth's atmosphere, the troposphere, is located.
13. **B** At the mid-ocean ridge, magma pushes through the crust and hardens, creating new seafloor. As new magma surfaces, it pushes away the existing seafloor, causing it to spread and move apart. Magma rises through the crust because of convection currents in the magma in the asthenosphere below the plates.
14. **C** Acid rain increases with larger amounts of certain gases in the air, such as HCl and $SO_2$.
15. **D** The three types of convection currents occur in both the Northern and Southern hemispheres.