

12.2 Features of Plate Tectonics

Earth has distinct layers. The asthenosphere is the partly molten layer of Earth located beneath the lithosphere. Convection currents from the asthenosphere push magma to Earth's surface, causing tectonic plates to move and sometimes converge. When tectonic plates converge, one plate may slide beneath the other or the edges of the plates may crumple, forming mountains. Tectonic plates can also diverge, or spread apart, forming rifts on land and ridges in the ocean. Tectonic plates may begin to slide past one another at a transform boundary, resulting in the build-up of pressure, which may be released as an earthquake. Volcanoes occur at tectonic plate boundaries or over geologic hot spots, where magma is coming up through Earth's crust.

Words to Know

asthenosphere
epicentre
lithosphere
mantle convection
plate boundary
ridge push and slab pull
rift valley
subduction zone
volcanic belt

Did You Know?

A region of Nazko, British Columbia, is showing signs of active volcanism for the first time in over 7000 years. In 2006, a worker was monitoring the temperature of a roadway and discovered a 1 km stretch of road that was 9°C warmer than the surrounding area. It turned out that a new source of magma was getting closer to Earth's surface.

Picture yourself on a jagged mountain peak, 6500 m high. Try to imagine the details of what lies beneath your feet: the types of rock, structures, and any valuable minerals. The difficulty of the task is obvious. And yet, less than 100 years ago, the only way to determine what was inside Earth was to make inferences based on what geologists could see on the surface.

The existence of mountains, volcanoes, and earthquakes suggests that Earth's interior is not simply a solid ball of rock. However, it was not until the study of earthquakes had advanced that geologists truly began to understand the nature of Earth's interior.

Scientists believe that Earth began as a molten ball over 4.5 billion years ago. Like any other molten body, as Earth cooled, the lighter materials floated to the surface and the heavier materials sank toward the interior. You may have observed the same process after letting gravy sit for a while. As the gravy cools, fat, which is light, floats to the top, forming a skin. When early Earth cooled, the lighter elements, such as silicon and oxygen, separated from the molten material, floated to the top, and formed the layer we know today as the **crust**. Three quarters of Earth's crust is made from the elements silicon and oxygen, which combine to form a group of rocks called silicates.

Just as an apple is made of up different layers—a skin, an inner layer, and a core—Earth is made of four layers with distinct characteristics (Figure 12.13 on the next page).

Tectonic Plates

Imagine a hard-boiled egg with its shell broken in several places. If the pieces of shell could move, they might slide past one another, bump, or move apart. Similarly, Earth's outer layer is composed of several large, rigid but mobile chunks of rock known as tectonic plates or simply plates. Made up of the crust and the uppermost mantle, tectonic plates form the **lithosphere**, which ranges in thickness from 65 to 100 km (Figure 12.14 on page 520). There are about 12 major tectonic plates and many smaller ones. There are two types of tectonic plates. Oceanic plates contain the dense rock basalt. Continental plates and the continents themselves contain large amounts of granite.

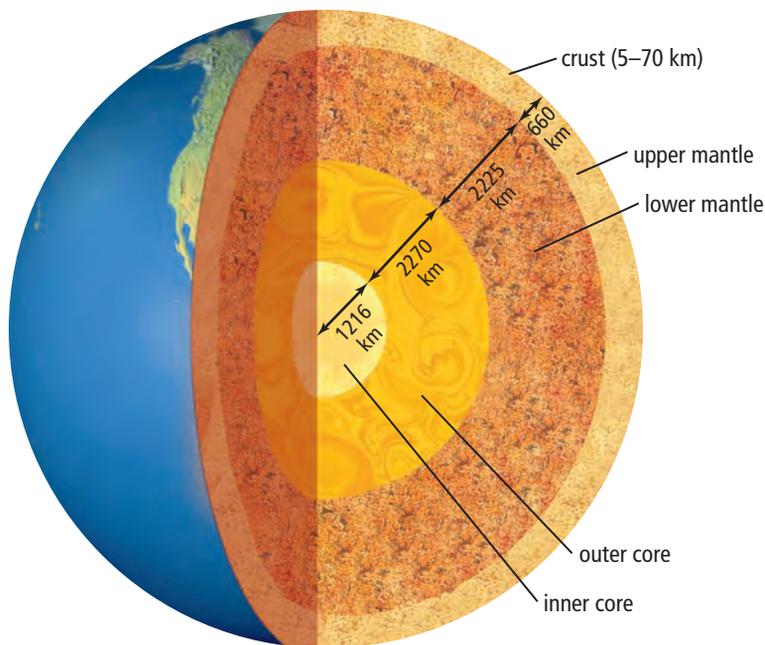
A Cross-Section of Earth

The Crust

The crust is Earth's outermost layer. It is made from solid, brittle rock. The thickness and type of rock varies in different parts of the crust. Continental crust is made from a lighter type of rock called granite and can be as thick as 70 km. Oceanic crust is made from a dense, dark rock called basalt and can be as thick as 10 km.

The Mantle

The **mantle** is Earth's thickest layer. About 2900 km thick, it makes up 70 percent of Earth's volume. It is mostly solid and can be divided into two sections: the upper mantle and the lower mantle. The upper mantle is composed of partly molten rock containing iron and magnesium. The upper mantle magma flows like thick toothpaste. A transition zone separates it from the lower mantle, which begins at a depth of about 660 km. The lower mantle is made of solid, dense material that contains the elements magnesium and iron.



The Outer Core

The layer below the mantle is the **outer core**. Unlike the other layers of Earth, the outer core is liquid. It is about 2300 km thick and is composed mainly of a mixture of iron and nickel.

The Inner Core

The **inner core** lies at Earth's centre. A sphere with a radius of about 1200 km, the inner core is composed mainly of iron and some nickel. Although temperatures at the core range from 5000°C to 6000°C—four times the melting point of iron—the incredible pressures at the core keep it solid. Scientists believe that the inner and outer cores rotate at different speeds and may be responsible for Earth's magnetic field.

Figure 12.13 A cross-section of Earth

12-2A Modelling Earth's Crust

Find Out ACTIVITY

Earth's surface is made up of the thin, metal-rich oceanic crust and the comparatively thick continental crust. In this activity, your teacher will use a piece of steel to model the oceanic crust and a block of Styrofoam® to model the continental crust. Water will represent magma under the crust.

Materials

- deep glass baking dish
- water
- 5 cm × 5 cm sheet of steel
- 5 cm × 5 cm block of Styrofoam®

Science Skills

Go to Science Skill 8 for more help with using models in science.

What to Do

1. Your teacher will place the steel sheet and the Styrofoam® block side by side in a baking dish full of water. Predict which material will float.
2. Observe what happens to the different materials.

What Did You Find Out?

1. Compare the materials used in this activity to oceanic crust and continental crust in terms of:
(a) thickness (b) density
2. Ocean basins are deep, wide depressions in Earth's surface that contain the oceans. Why have the ocean basins formed over oceanic crust and not over continental crust?

Connection

Chapter 7 has more information on radioactive elements.

Did You Know?

On average, Earth's plates move about 2 cm per year—the same rate at which your fingernails grow. This rate may not seem significant enough to change the face of our planet, but multiply 2 cm over 500 million years and it is clear how tectonic plates can move halfway around the world!

Plate Motion

Below the lithosphere is the **asthenosphere**, a partly molten layer in the upper mantle. The temperature of the asthenosphere varies throughout. Geologists believe that this is because large quantities of radioactive elements such as uranium occur in some areas. Radioactive decay heats up the mantle in these spots. As explained by the kinetic molecular theory (see Chapter 10), heated particles have more kinetic energy and so move around more, causing them to spread farther apart. A convection current results as the hotter, and therefore less dense, material in the mantle rises, cools, and then sinks again, only to be reheated (Figure 12.15).

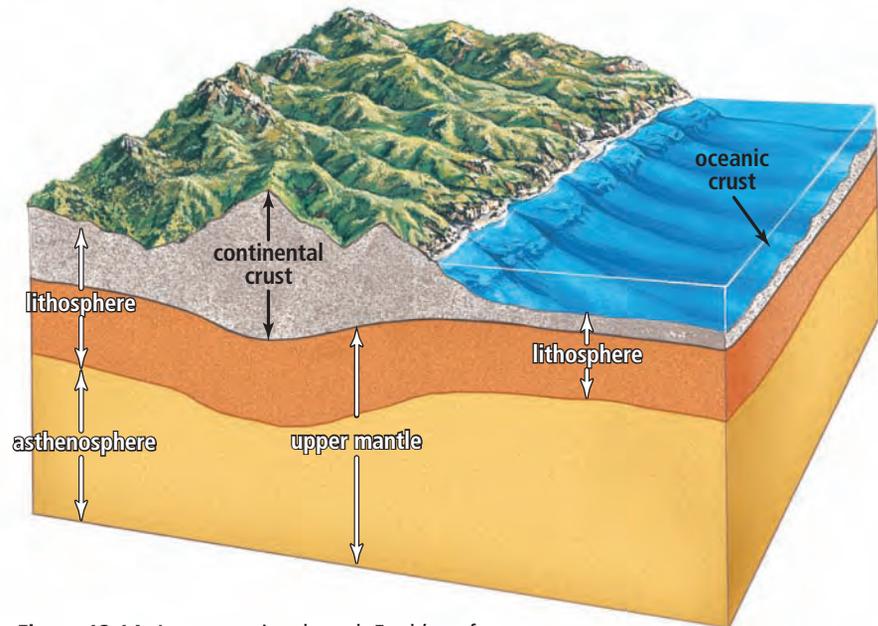


Figure 12.14 A cross-section through Earth's surface

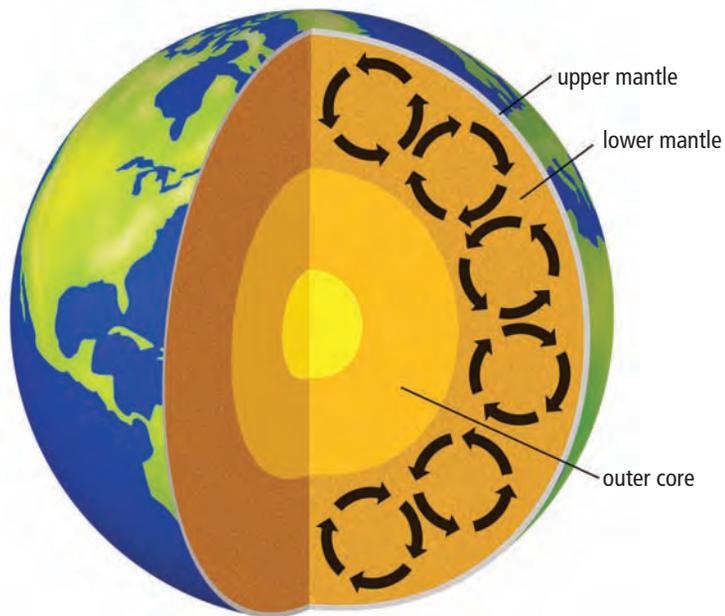


Figure 12.15 Convection currents in Earth's mantle circulate heat and magma.

Scientists hypothesize that this **mantle convection** is one of the driving forces behind plate movement. A similar process occurs when you put a cookie with large chocolate chunks into a pot of hot milk on the stove. As the milk circulates, it carries the cookie with it, and the chocolate chunks move with the cookie. Like the chocolate chunks carried by the cookie, continents are attached to tectonic plates. Currents in the asthenosphere move the tectonic plates above, and the continents move with them.

12-2B Cardboard Tectonics

Find Out ACTIVITY

Earth's surface is broken into large, solid but mobile pieces of rock known as tectonic plates. In this activity, you will simulate the motion of tectonic plates in order to investigate the mechanism that causes them to shift positions.

Safety



- Be careful when handling the scissors.
- Do not touch the surface of the hot plate.

Materials

- thin 21.5 cm × 28 cm piece of cardboard
- scissors
- pencil or permanent marker
- baking pan
- hot plate
- water



What to Do

1. Draw a random shape that covers $\frac{2}{3}$ of the piece of cardboard. Cut out the shape, and put the remaining cardboard aside.
2. Cut the shape into four pieces. Label the pieces A to D. Using the remainder of the cardboard, cut out four other smaller pieces. Label the smaller pieces E to H.
3. Carefully centre the baking pan on the hot plate. Fill the pan $\frac{1}{2}$ full with water.
4. Carefully place the pieces of cardboard on the surface of the water, as close to the centre of the pan as possible. Pieces A to D should be placed together in their original shape. Place the remaining pieces, E to H, at various positions around the baking pan. Sketch the starting positions of each piece of cardboard.
5. Turn the hot plate on low. Heat until the water is warm but not boiling. Observe the pieces of cardboard. Make another sketch, using arrows to show the movement of the cardboard pieces relative to one another.
6. Clean up and put away the equipment you have used.

What Did You Find Out?

1. (a) What happened to the pieces of cardboard once the water was heated?
(b) How can you account for your observation?
2. How does this activity simulate the process of moving tectonic plates? Use the terms "convection" and "continental drift" in your explanation. Be sure to explain what the cardboard pieces, water, and hot plate represent.
3. In what ways is this simulation an inaccurate model of plate movement?
4. (a) How could you increase the rate at which the pieces of cardboard separated?
(b) Suggest what might control the rate of separation of continents.

internet connect

In the 1960s, in an attempt to drill into the crust-mantle boundary, scientists drilled 12 km into the ocean floor off the coast of Mexico. Unfortunately, "Project Mohole," as it was known, came up many kilometres short. Even so, the project allowed scientists to collect samples from deeper underground than ever before. To learn about a new deep ocean drilling project off the coast of Japan, visit www.bcsience10.ca and follow the links.

Push and pull

Rising currents of magma eventually reach Earth's surface at spreading centres. If a spreading centre occurs in the ocean, it is called a spreading ridge, or oceanic ridge; if it occurs on land, which is less common, it is called a **rift valley**. Magma cools as it reaches the surface and becomes "new" rock. As new material at a ridge or rift pushes older material aside, the tectonic plates move away from the ridge. This process is called **ridge push** (Figure 12.16).

As you can imagine, when tectonic plates are pushed apart, eventually one or both will bump into another plate. If a dense oceanic plate collides with a continental plate, the heavy oceanic plate will dive deep under the lighter continental plate, an event known as subduction. **Subduction** is the action of one plate pushing below another.

Areas of subduction, called **subduction zones**, typically experience large earthquakes and volcanic eruptions. Subduction zones themselves are thought to contribute to plate motion. Picture yourself standing at the edge of a swimming pool. A friend passes and you are accidentally knocked over. As you fall, you instinctively grab onto your friend, but gravity pulls both of you into the pool. Similarly, as the edge of a tectonic plate subducts deep into the mantle, it pulls the rest of the plate with it. This process is called **slab pull**. Along with convection currents and ridge push, slab pull helps keep tectonic plates in motion.

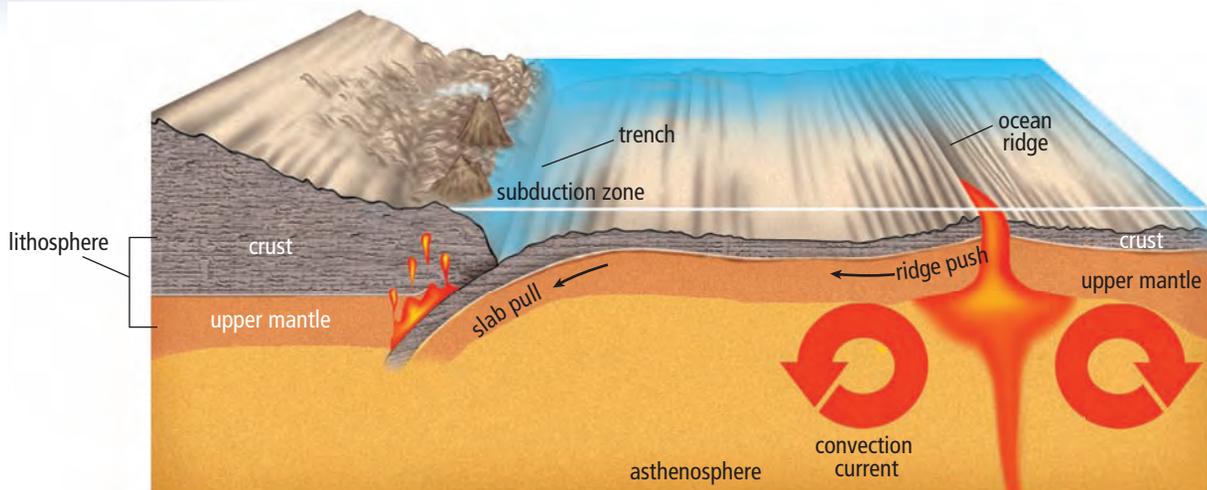


Figure 12.16 Thermal energy from inside Earth, gravity, and tectonic plate interactions affect the movement of tectonic plates.

Reading Check

1. Name the four layers of Earth, in order from the inside out.
2. What is a tectonic plate made of?
3. List three processes that contribute to the motion of tectonic plates.
4. What is subduction?

Plate Interactions

A region where two tectonic plates are in contact is known as a **plate boundary** (Figure 12.17). The interaction of tectonic plates has played an important role in both the geological and the biological history of Earth. There are three main types of plate interaction: divergence (spreading apart), convergence (moving together), and transform (sliding by). The way in which tectonic plates interact depends on two main factors:

- the type of plate
- the direction the plates are moving relative to one another

Divergent plate boundaries

Divergent plate boundaries mark the areas where tectonic plates are spreading apart (Figures 12.18). Plates that are spreading apart are known as **diverging plates**. The Mid-Atlantic Ridge, for example, is a system of spreading ridges that is separating the Americas from Africa, Europe, and Asia. About 16 000 km long, the Mid-Atlantic Ridge is the largest mountain range on Earth, with the greatest amount of volcanic activity.

In the ocean, sea floor spreading causes plates to separate. A similar process can occur on the continents. For example, diverging plates at the East African Rift are slowly breaking Africa into pieces.

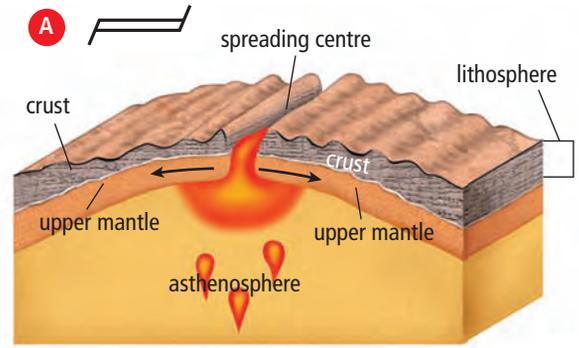


Figure 12.18 A spreading centre at a divergent plate boundary (A). The East African Rift (B)

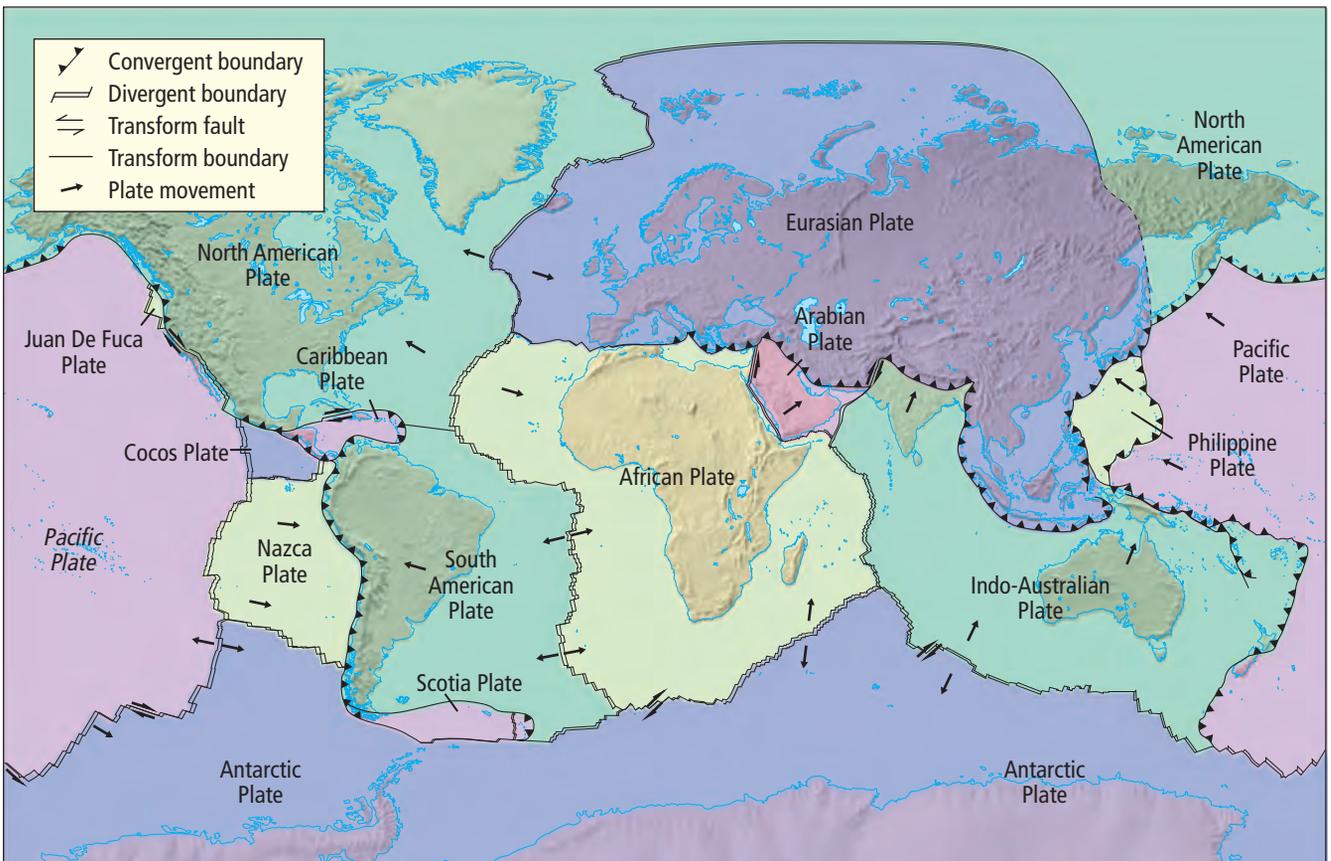


Figure 12.17 Tectonic plate boundaries

Convergent plate boundaries

A **convergent plate boundary** occurs where tectonic plates collide. Plates that collide are known as **converging plates**. The collision can have various results, depending on the nature of the converging plates.

Oceanic-continental plate convergence

When a dense oceanic plate collides with a continental plate, the oceanic plate is forced to slide beneath the continental plate. A deep underwater valley, called a **trench**, forms where the tectonic plates make contact (Figure 12.19A). As the subducting plate moves deeper, large pieces melt off. Much of this melted material cools and crystallizes into large rock masses below the surface of the continental plate. If conditions are right, magma can work its way to the surface, forming cone-shaped volcanoes. The distinctive cone-shaped volcanoes of the west coast of North America are the result of oceanic-continental convergence between the Juan de Fuca Plate (an oceanic plate) and the North American Plate (a continental plate). This convergent boundary is known as the Cascadia subduction zone. A long chain of volcanoes, called a **volcanic belt**, has formed along North America's west coast as a result of these plate interactions. Geologists suggest 8 to 10 of these volcanoes could become active.

The force of the collision between oceanic and continental plates creates mountain ranges as the continental rock crumples and folds. Such collisions produced British Columbia's Coast Mountains and Cascade Mountain Range. Although the tectonic plates move slowly, great forces are involved. Frequently, colliding plates resist the force of convection currents, ridge push, and slab pull. Pressure builds as long as the plates remain stuck in place. When the stress is too great to resist, the energy is released, resulting in an earthquake.

Oceanic-oceanic plate convergence

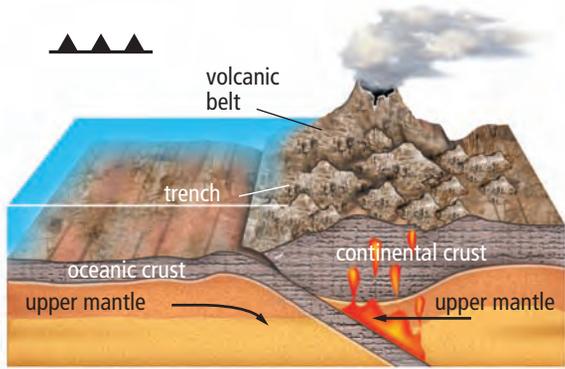
Subduction also occurs where two oceanic plates converge (collide). Cooling will cause one plate to be denser than the other, and the denser plate will slide deep into the mantle. In this case, convergence may produce a long chain of volcanic islands known as a **volcanic island arc** (Figure 12.19B). The islands of Japan and Indonesia and the Aleutian Islands of Alaska are examples of volcanic island arcs. Such regions can experience earthquakes of various magnitudes.

Continental-continental plate convergence

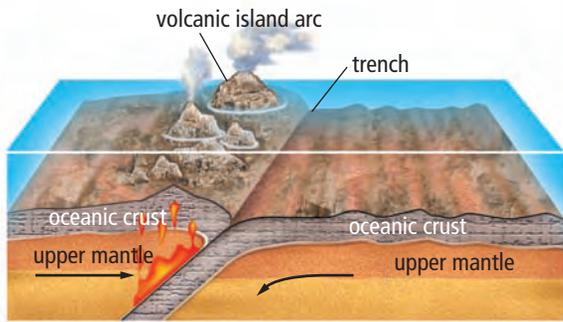
When continental plates collide, subduction does not occur since the plates' similar densities prevent either one from being forced into the mantle (Figure 12.19C). As the massive rocky plates slowly collide, their edges fold and crumple, forming great mountain ranges. The youngest and highest mountain range in the world is the Himalayas, which formed as a result of the Indian continent colliding with the Asian continent, 40 million to 50 million years ago. The mountains of the Himalayas continue to increase in elevation by several centimetres per year due to the steady northward movement of the Indian tectonic plate.

Did You Know?

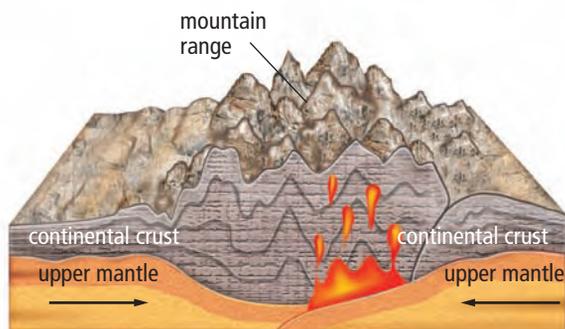
On December 26, 2004, an extremely large earthquake occurred in the Sumatra area of Indonesia. The high-energy earthquake generated a large sea wave, or tsunami, that killed over 200 000 people.



A. The convergence of an oceanic and a continental plate produced the Coast Mountains of British Columbia.



B. The convergence of two oceanic plates can produce a volcanic island arc, such as the Aleutian Islands of Alaska, in the United States.



C. The convergence of two continental plates is gradually forcing the Himalayas higher.



Figure 12.19 Convergent plate boundaries

Transform plate boundaries

Convection currents in the mantle often cause tectonic plates to slide past each other. Such regions, which mostly occur near ocean ridges, are known as transform plate boundaries (Figure 12.20). At these boundaries, since rock slides past rock, no mountains or volcanoes form. However, earthquakes and **faults** (breaks in rock layers due to movement on either side) may result. A fault that occurs at a transform plate boundary is known as a **transform fault**. A famous transform fault on land is the San Andreas Fault of California in the United States. The fault is due to the oceanic Pacific Plate sliding past the continental North American Plate.

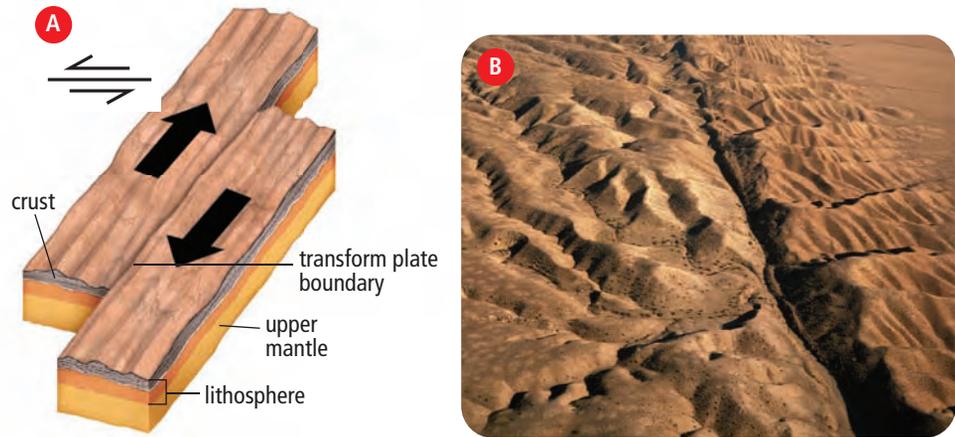


Figure 12.20 Transform faults can occur when tectonic plates move alongside one another (A). The San Andreas Fault is in the United States (B).

Reading Check

1. Name and draw the three main types of tectonic plate boundaries.
2. Why does subduction occur at some kinds of tectonic plate boundaries?
3. Describe the process that results in a volcanic island arc.
4. Name a mountain range produced by continental-continental plate convergence.

Earthquakes

It takes a tremendous amount of energy to move tectonic plates along the surface of the asthenosphere. Friction between moving tectonic plates often works against convection currents, producing stress (the build-up of pressure). When the plates can no longer resist the stress, there is an earthquake—a massive release of energy that shakes the crust. Although earthquakes can occur anywhere on Earth, 95 percent occur at tectonic plate boundaries. About 80 percent of earthquakes occur in a ring bordering the Pacific Ocean.

In and around British Columbia, all three types of plate boundaries are found (Figure 12.21). In the north, the Pacific Plate grinds past the North American Plate at the Queen Charlotte Fault. This transform boundary is a source of earthquakes. To the west of Vancouver Island is the Juan de Fuca Ridge, a divergent plate boundary. Sea floor spreading at this boundary adds material to the Juan de Fuca Plate and pushes it towards the North American Plate. At the convergent plate boundary, the plates are wedged against one another. Sometimes the plates break loose and there is an earthquake that releases energy that has built up for centuries.

Geologists study the deposits left by these great earthquakes to find out how often they have occurred. In British Columbia, there have been great earthquakes every 200 to 800 years. As recounted in First Nations oral history, one of the largest earthquakes in the world occurred on January 26, 1700. The earthquake caused the collapse of the houses of the Cowichan people living on Vancouver Island and produced a tsunami that destroyed a village at Pachena Bay on the island's west coast. The tsunami travelled across the Pacific Ocean and caused damage in Japan.

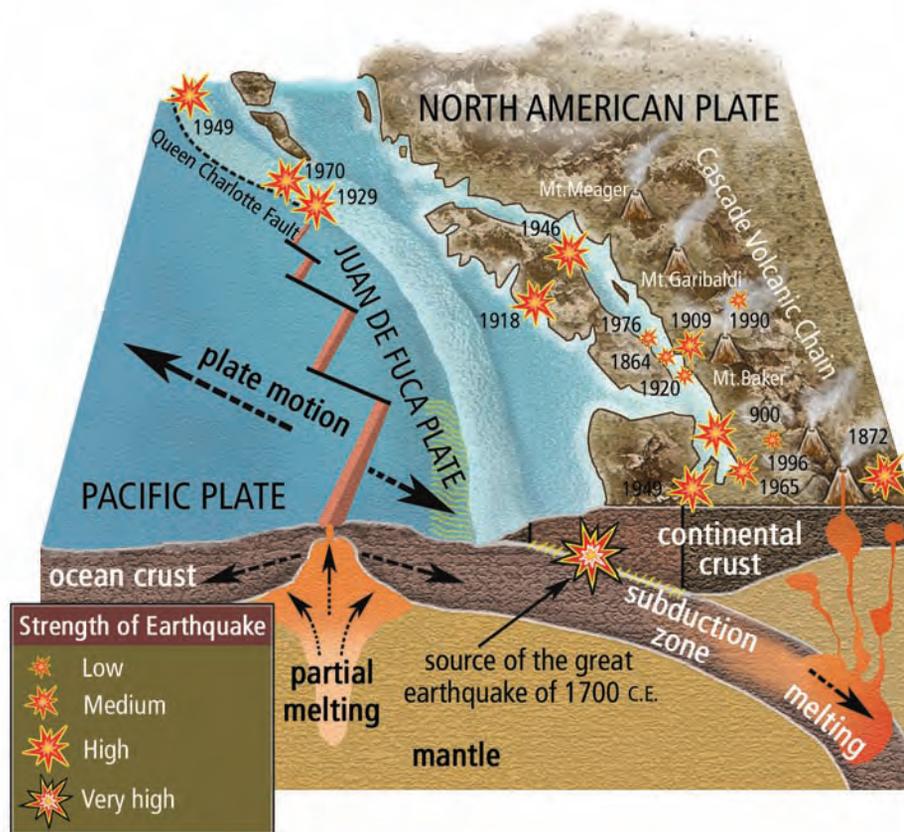


Figure 12.21 British Columbia sits near the boundary of the North American and Juan de Fuca Plates, an area where large earthquakes can occur.

Describing earthquakes

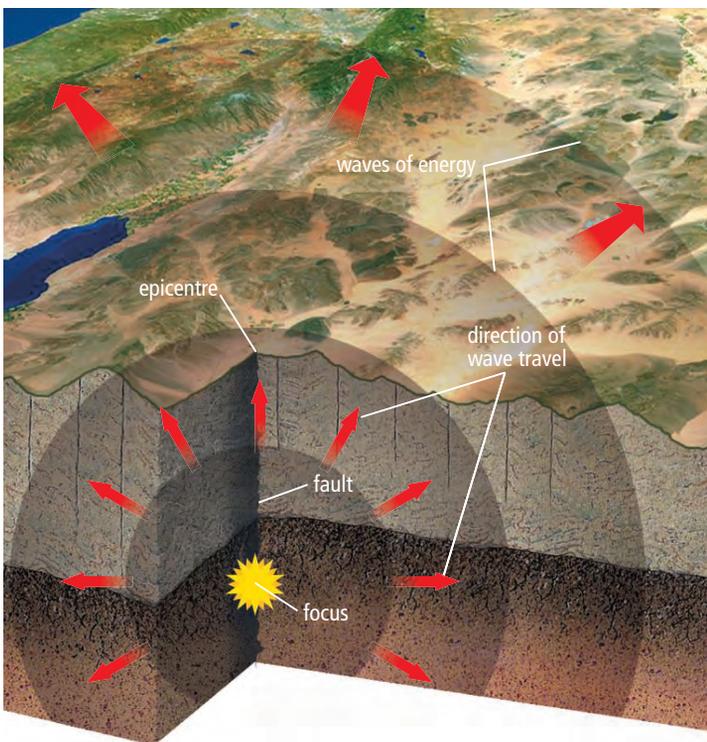
Because every earthquake involves a unique set of forces and geological structures, it is very difficult to accurately predict the timing, size, and location of a particular earthquake. Furthermore, the events leading to earthquakes occur over time periods that dwarf a human lifespan. However, the plate tectonic theory has greatly helped scientists to understand where and how often earthquakes occur. This understanding has led to improved designs for earthquake-resistant buildings and has helped make it safer to live in British Columbia and other places where earthquakes occur.

The **focus** (plural **foci**) is the location inside Earth where an earthquake starts. Energy release begins at the focus. The **epicentre** is the point on Earth's surface directly above the focus (Figure 12.22). For example, an earthquake with an epicentre 200 km southwest of Vancouver, British Columbia, might have a focus 40 km underground.

Earthquakes occur at various depths, depending on the type of tectonic plate interaction involved. An earthquake at a subduction zone, for instance, could be deeper than an earthquake at a transform plate boundary. Scientists classify earthquakes according to the depth of the foci (Table 12.2).

Table 12.2 Depth of Origin of Earthquakes

| Classification | Depth of Focus |
|--------------------|---------------------|
| Shallow focus | 0 to 70 km |
| Intermediate focus | 70 to 300 km |
| Deep focus | Greater than 300 km |



The amount of surface damage an earthquake can cause depends on its depth. Energy travelling up from a deep focus must travel a long distance and therefore may not cause much damage at the surface. On the other hand, a shallow-focus earthquake begins close to the surface and may cause great destruction. Over 90 percent of earthquakes have foci that are less than 100 km deep. About 3 percent of measurable earthquakes have deep foci.

Figure 12.22 Waves of energy travel outwards from the focus of an earthquake. The epicentre of an earthquake is the point on Earth's surface directly above the focus.

Seismic waves

Geologists cannot explore Earth's interior directly. The deepest mine in the world reaches down less than 4 km, whereas Earth's radius is over 6000 km. Nevertheless, people have found creative ways to interpret clues provided by nature above ground. Energy released by an earthquake produces vibrations known as **seismic waves**. **Seismology** is the study of earthquakes and seismic waves. By studying how seismic waves travel through Earth's interior, scientists can determine much about the composition and thickness of Earth's layers. Records of seismic waves also help scientists to describe earthquakes.

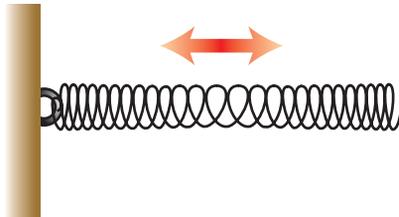
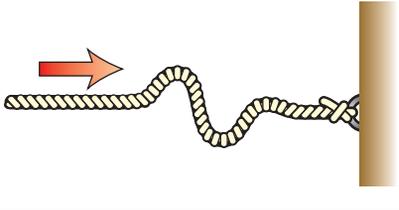
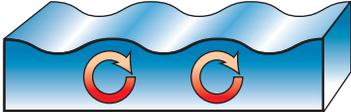
Seismic waves can be either body waves, which travel underground, or **surface waves (L-waves)**, which roll along Earth's surface much like ripples in a pond. Body waves travel faster than surface waves and are usually the first energy waves felt after an earthquake.

There are two types of body waves. **Primary waves (P-waves)** travel at about 6 km/s through Earth's crust. Like sound waves, P-waves can travel through solids, liquids, and gases. P-waves cause the ground to compress and stretch like a spring in the direction in which the wave is travelling. **Secondary waves (S-waves)** are also known as shear waves. S-waves travel at about 3.5 km/s and cause the ground to compress and stretch at right angles to the direction of the wave's motion. S-waves usually cause more structural damage than P-waves because S-waves are larger. The features of different seismic waves are summarized in Table 12.3.

internet connect

The Yasaka Pagoda is a five-storey temple in Kyoto, Japan. Although earthquakes are common in Japan, the temple has survived for over 500 years. Modern engineers have learned how to improve designs for earthquake-proof buildings by studying the structure of the ancient temple. To find out more about earthquake-resistant building designs, visit www.bcscience10.ca and follow the links.

Table 12.3 Types of Seismic Waves

| Seismic Wave | Abbreviation | Description | Ground Motion |
|----------------|--------------|--|---|
| Primary wave | P | <ul style="list-style-type: none"> Type of body wave First to arrive (fastest) Ground squeezes and stretches in direction of wave travel. Travels through solids, liquids, and gases |  |
| Secondary wave | S | <ul style="list-style-type: none"> Type of body wave Second to arrive (slower) Ground motion is perpendicular to direction of wave travel. Travels through solids but not liquids |  |
| Surface wave | L | <ul style="list-style-type: none"> Travels along Earth's surface Last to arrive (slowest) Ground motion is a rolling action, like ripples on a pond. |  |

The movement of body waves through Earth's interior is affected by the composition and depth of the different layers. The waves bounce off of some layers, speed up or slow down in others, or are refracted (bent). Figure 12.23 shows the paths of different types of waves. The paths of the body waves are curved because of increasing density with depth in the mantle. S-waves disappear at the bottom of the mantle because they cannot travel through the liquid outer core.

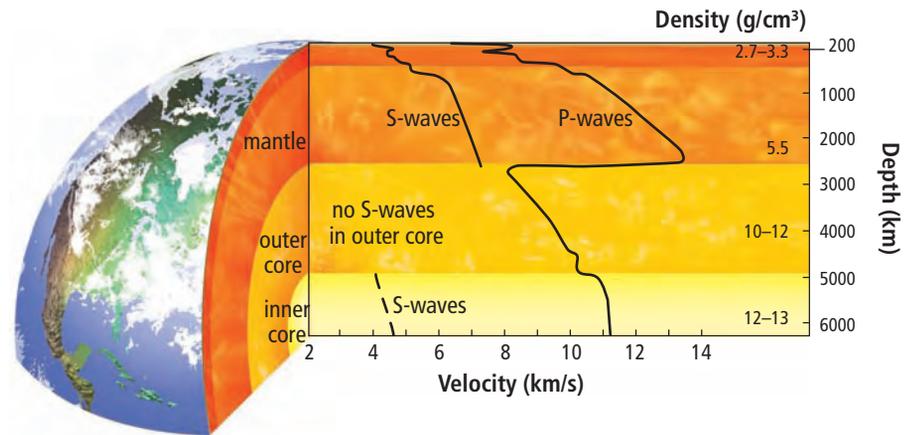
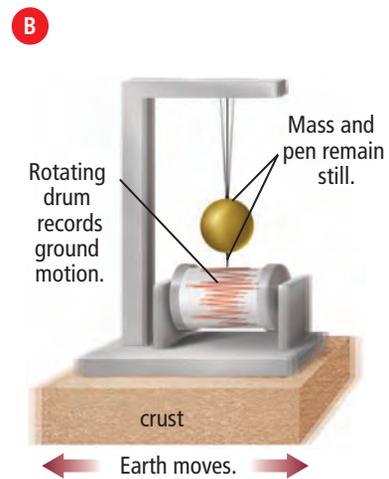


Figure 12.23 The path of seismic waves. P-waves and S-waves travel underground and are affected by the density of the material they travel through. Because L-waves travel along Earth's surface, they move more slowly than P-waves and S-waves.

Measuring earthquakes

In China, records of seismic wave energy date back over 3000 years. Early records were obtained using simple **seismometers** (also called seismographs), devices that measure the amount of ground motion caused by an earthquake. Different seismometers measure different types of ground motion. The seismometer in Figure 12.24B specifically measures horizontal (side to side) ground motion. Other seismometers measure vertical (up and down) ground motion.

Figure 12.24 Each sculpted dragon on this ancient Chinese seismometer holds a metal ball in its mouth. When the ground shakes, some of the balls will fall into the mouths of the frog statues below (A). A simple non-digital seismometer includes a base with a roll of paper on a rotating drum and a pen attached to a heavy weight. As the ground shakes, the pen remains motionless while the drum and paper move. The process is much like writing your signature by holding a pen steady while moving the paper underneath it (B).



A seismometer produces a record of ground motion called a **seismogram** (page 534). Seismograms provide geologists with information such as the time of the earthquake, how long it lasted, and the amount of ground shaking. You may have heard the term magnitude used on the news to describe the strength of an earthquake. **Magnitude** is a number that rates the strength (energy) of an earthquake. Higher magnitude numbers indicate larger—and usually more devastating—earthquakes.

With each 1-step increase on the magnitude scale, the size of the seismic waves is 10 times larger. Thus, the seismogram for a high-magnitude earthquake looks like a series of waves with high peaks and deep valleys. Earthquakes can be felt if they are over magnitude 2.0. Over magnitude 6.0, they can damage buildings that are not designed to withstand earthquakes.

Seismograms can also be used to determine how fast seismic waves are travelling. Seismic waves can travel quickly. (Deep underground, P-waves can travel at over 14 km/s.) A time-distance graph shows the average time it takes a seismic wave to travel a particular distance. As shown in Figure 12.25, a P-wave took 5.5 min to travel 3000 km, while an S-wave took about 10 min to travel the same distance. Time-distance graphs can also help determine the distance from a particular earthquake monitoring station to the epicentre of the earthquake.

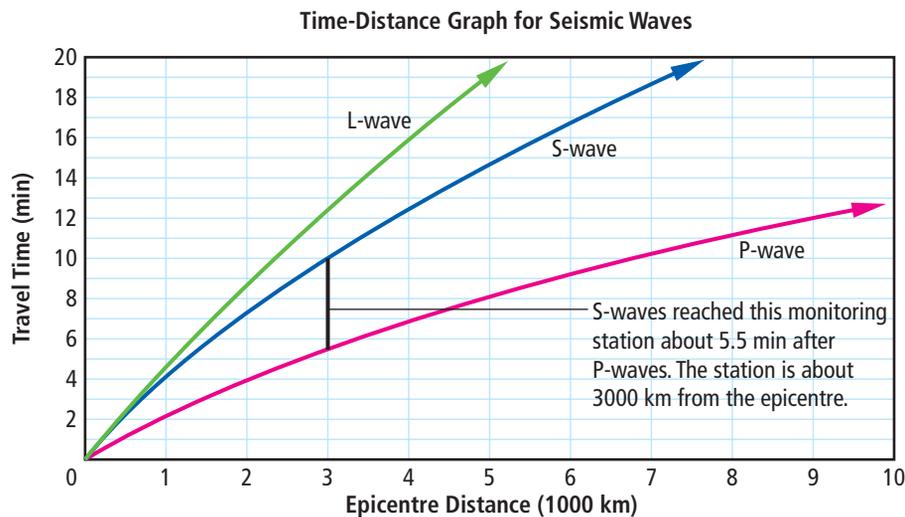


Figure 12.25 A time-distance graph shows how long it takes for different seismic waves to travel a certain distance.

Suggested Activity
Think About It 12-2C on page 534

Word Connect

Charles Richter was the first to suggest that scientists classify earthquakes by measuring seismic waves on seismograms. He came up with this system in the 1930s while studying shallow earthquakes in California in the United States. Since then, scientists have improved techniques for measuring magnitude, but the magnitude scale is still popularly known as the Richter scale.

Reading Check

1. Where is the focus of an earthquake in relation to the epicentre?
2. Name three types of seismic waves.
3. How do scientists measure the magnitude of an earthquake?

Volcanoes

The movement of tectonic plates produces three distinct types of volcanoes: composite volcanoes, shield volcanoes, and rift eruptions. The type of volcano formed depends on the tectonic plate boundary involved. Figure 12.26 shows the locations and types of volcanoes in and near British Columbia.

Suggested Activity

Conduct an Investigation 12-2D on page 535

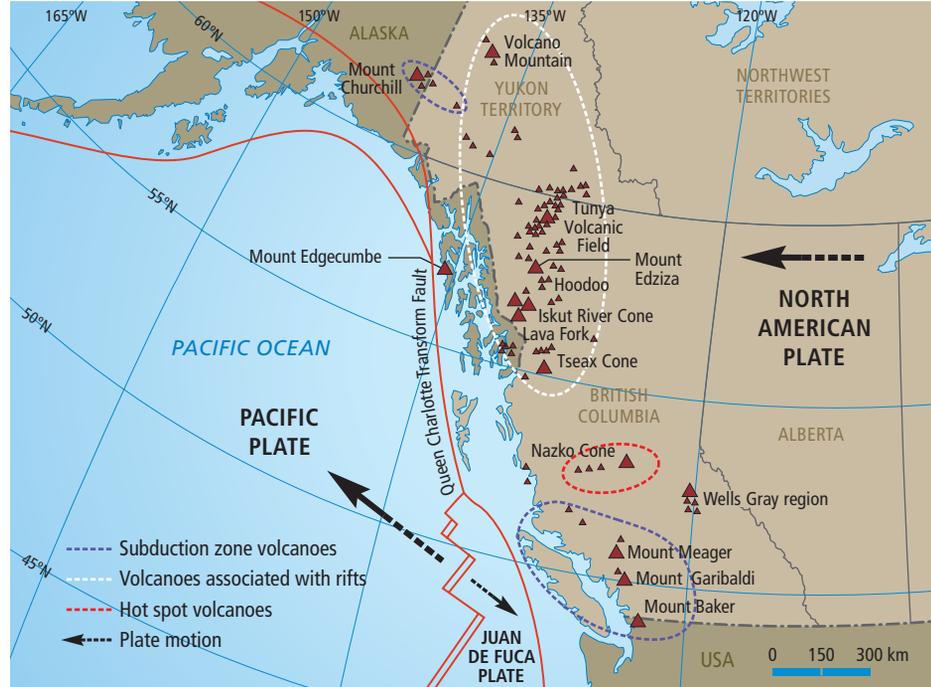
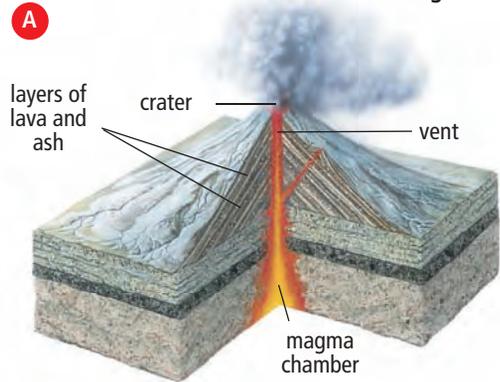


Figure 12.26 Volcanoes in and near British Columbia



Composite volcanoes

You might think of volcanoes as large, cone-shaped mountains, belching ash, rocks, and lava. This picture does in fact describe a type of volcano known as a **composite volcano** (Figure 12.27). The cone shape results from repeated eruptions of ash and lava, which build up layers, or strata, much like layers in a cake. The magma that forms these volcanoes is usually very thick. As the magma approaches the surface, gas gets trapped below, and pressure builds up. Once the pressure is too great to be contained, there is an explosive volcanic eruption. Composite volcanoes are usually found near subduction zones, where they form volcanic belts. Mount Garibaldi in British Columbia is a composite cone volcano that is part of a volcanic belt that stretches down the west coast of North America. Most other composite volcanoes in Canada have been eroded by glacial ice and do not have the distinctive cone shape.



Figure 12.27 A composite volcano (A). Mount St. Helens, Washington (B).

Shield volcanoes

The largest volcanoes on Earth are **shield volcanoes** (Figure 12.28). Shield volcanoes do not occur at plate boundaries but instead form over hot spots. A hot spot occurs where a weak part of the lithosphere allows magma to break through. The magma that produces shield volcanoes is much thinner than the magma that forms composite cone volcanoes, and it traps less gas. The thinner magma flows more easily when it reaches the surface. As a result, shield volcano eruptions are often less explosive than composite volcano eruptions. A shield volcano takes shape after many eruptions of lava build up the slopes of the volcano. (The name “shield” refers to the shape of the volcano, which looks like an ancient soldier’s shield lying on the ground.)

Shield volcanoes typically occur in ocean basins, where the lithosphere is thinner than it is on continents. The Hawaiian Islands are an example of a chain of shield volcanoes. Kilauea on the Big Island of Hawaii is one of the most active large volcanoes on Earth. It has been erupting continuously since 1983.

A few hot spots are found on continents. The Anahim Belt is a chain of shield volcanoes located over a hot spot in the middle of British Columbia. Yellowstone National Park in the United States marks the location of a series of shield volcanoes found over a hot spot. Over the past several million years, there have been several forceful volcanic eruptions in Yellowstone National Park, which have shaped the landscape in the region. The Columbia Plateau is the result of an eruption that began 30 million years ago and lasted for 10 million to 15 million years. The eruption, which was due to the same hot spot that sits under Yellowstone National Park, covered a 160 000 km² area that stretches from the southern border of Canada to northern California in the United States. In some places, the hardened lava flows are 2 km thick.

Did You Know?

The largest volcano in the solar system is a shield volcano on Mars. The Martian volcano Olympus Mons is almost six times the height of Hawaii’s Mauna Loa, Earth’s highest volcano.

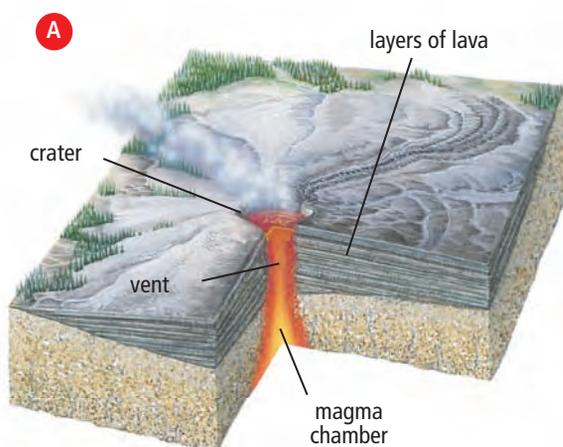


Figure 12.28 A shield volcano (A). Yellowstone National Park lies over a hot spot. The most recent volcanic eruption in the area occurred about 70 000 years ago (B).

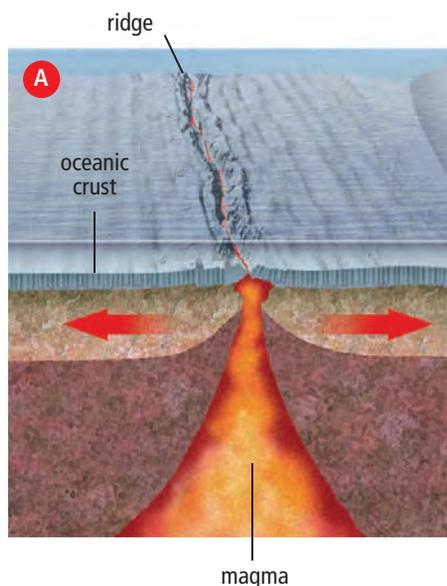
Explore More

"Supervolcano" is a term used to describe past volcanoes with massive eruptions that not only destroyed nearby areas but also affected life around the planet. Find examples of supervolcanoes and learn about their effects on ecosystems and the human population. Begin your search at www.bcsience10.ca.

Figure 12.29 Ridges are due to rift eruptions under the ocean (A). The Krafla volcano, northern Iceland (B). Iceland is an island that is part of the Mid-Atlantic Ridge.

Rift eruptions

Rift eruptions occur when magma erupts through long cracks in the lithosphere. Curtain-like fountains of lava erupt at spreading ocean ridges or at rifts in continental crust (Figure 12.29). Rift eruptions are usually not very explosive or violent, but they can release enormous amounts of lava. Along the Mid-Atlantic Ridge, at the boundary between the North American Plate and Eurasian Plate, rift eruptions are common.



12-2C Interpreting Seismograms

Think About It

Seismograms are graphs that show the arrival times and sizes of seismic waves. The height of the peaks and the depth of the valleys in the graph correspond with the energy of the seismic waves. In this activity, you will interpret a seismogram in order to track the timing and strength of an earthquake.

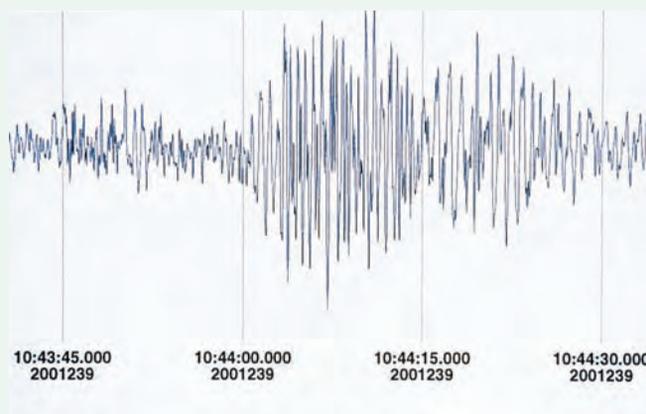
What to Do

1. Study the seismogram on the right and answer the following questions.

What Did You Find Out?

1. When were the strongest seismic waves recorded? How do you know?
2. At about what time did P-waves reach the monitoring station?
 - (a) 10:44:30
 - (b) 10:44:02
 - (c) 10:43:00
3. Explain your response to question 2.

4. Suppose the monitoring station is 300 km from the epicentre of the earthquake. About how fast are the P-waves travelling? Show your calculations.
5. How long did the S-wave ground motion continue?
6. Many buildings were damaged in this earthquake. When did most of the damage occur?



Seismogram of vertical ground movements

Teacher Demonstration

Skill Check

- Predicting
- Observing
- Modelling
- Explaining systems

Safety



- Wear safety goggles when you are near the model volcano.

Materials

- 1000 mL beaker
- candle wax
- red crayon
- sand
- water
- Bunsen burner
- flame striker or matches

Science Skills

Go to Science Skill 8 for help with using models in science.

Volcanic eruptions produce various geological features. They also drive tectonic plate movement. In this activity, you will observe a model volcano in order to investigate the effects of volcanism.

Question

How do volcanic eruptions occur?

Procedure

Part 1 Making a Prediction

1. Sketch the model volcano prepared by your teacher, and label your sketch. The red wax represents magma inside Earth.
2. Before the demonstration begins, predict what you think will happen to the model volcano once the Bunsen burner is ignited. Write your prediction in your notebook.



Part 2 Observing the Simulation

3. Your teacher will turn on the Bunsen burner. Carefully observe what happens (once the process begins, it will happen very quickly).
4. In your notebook, sketch the results of the model volcanic eruption.

Analyze

1. What happened to the wax at the bottom of the beaker?
2. Using your textbook as a guide, label as many geologic features as you can on the sketch you made in step 4 of Part 2.

Conclude and Apply

1. (a) In what ways did the demonstration accurately simulate the effects of rising magma?
(b) Describe the inaccuracies of the model.
2. (a) What happened to the heated wax when it reached the surface of the water and the model crust?
(b) What does the melted wax represent in the model?
3. The demonstration is a model of volcanic activity in the ocean. Could a similar process occur on land? Explain.

Volcanologist

Catherine Hickson's interest in geology was sparked by summer trips to Mount Rainier and Yellowstone National Park in the United States. On May 18, 1980, at 8:32 A.M., she was just 12 km away from Mount St. Helens and looking at the awakening volcano when it erupted. After running for her life, she decided to become a volcanologist—a scientist who studies volcanoes. Today, Dr. Hickson travels the world as a research scientist with Natural Resources Canada. She has written a book about Mount St. Helens, *Surviving the Stone Wind*. Recently, she has been remapping British Columbia's Garibaldi volcano belt, which was very active about 10 000 years ago.



Dr. Catherine Hickson near Mount Meager, British Columbia

- Q.** What do you do as a research scientist?
- A.** I try to understand the processes that created a particular volcano and associated hazards, such as lava flows, hot chunks of rock, and gas that come spewing out of the volcano. We also work with communities all around the world so they understand the hazards volcanoes pose to their communities. A lot of this entails mapping.
- Q.** What training do you need to become a research scientist?
- A.** To work for the federal government, you need to go to university and get a doctorate (PhD) in a science specialty, such as volcanoes. I did a four-year undergraduate degree and then another four years for my graduate degree. For my PhD, I mapped and studied the volcanoes of Wells Gray Provincial Park in east-central British Columbia.

- Q.** What is a typical day like for you?
- A.** In the winter, I check volcanic observation websites to see what is happening, since eruptions in Alaska and to the south of us can cause ash plumes that enter Canadian airspace. I follow up on various research projects and travel, especially to South America. In the summer, fieldwork takes most of my time, mapping the rocks that make up the volcanoes, collecting samples for age dating, and hanging off cliffs with backpacks and hammers.
- Q.** What is age dating, and why is it important?
- A.** To complete a hazard analysis, it is really important to know how often a volcano erupts or landslides happen. With volcanic rocks, we can measure the amount of radioactive elements in the sample. Testing can tell us the age of the rock and help us figure out how often a volcano erupts.
- Q.** What is the Tseax Volcano?
- A.** The Tseax volcano, approximately 60 km north of Terrace, British Columbia, erupted in 1775. It is one of the most recent eruptions in Canada. My colleagues and I have surveyed the area in detail. We are working on lava flow modelling to try to understand why the lava from this eruption went more than 45 km. It destroyed an entire village of the Nisga'a, and 2000 people lost their lives. This is the largest geological disaster that we know of in Canadian history.
- Q.** How does a volcanic eruption affect climate?
- A.** With large eruptions, there is an enormous amount of ash, which is ground-up rock, floating in the high atmosphere. This can reflect the sunlight and create a cooling trend, as happened for a short time following the 1991 eruption of Mount Pinatubo in the Philippines. Sometimes a volcano will release large amounts of carbon dioxide and sulfur dioxide, which has the opposite effect, since these are greenhouse gases and can cause warming.

Questions

- List four things Catherine Hickson does as a research scientist.
- Why is age dating important to a community planning for natural disasters?
- What are two ways in which a large volcanic eruption can affect climate?

Check Your Understanding

Checking Concepts

1. List three kinds of plate boundaries.
2. What is ridge push?
3. How is the worldwide pattern of earthquakes and volcanoes related to tectonic plates?
4. (a) What are convection currents?
(b) Name the region of Earth's interior where convection currents occur.
(c) How do convection currents affect tectonic plates?
5. (a) Name the type of island chain that forms over geologic hot spots.
(b) How does an island chain form over a geologic hot spot?
6. What geologic feature is associated with rift eruptions?
7. Which type of seismic waves can travel through Earth's outer core?
8. What do seismometers detect and record?
9. What does a time-distance graph of seismic waves show?
10. After an earthquake, what type of seismic wave is the first to reach earthquake monitoring stations?

Understanding Key Ideas

11. Describe the movement of tectonic plates in the following locations.
 - (a) a mid-ocean ridge
 - (b) a convergent boundary
 - (c) a transform boundary
12. Why do volcanoes usually form at subduction zones but not at transform boundaries?
13. How does the ground motion produced by a P-wave compare to the ground motion produced by a surface-wave?
14. Refer to the time-distance graph (Figure 12.25) on page 531 of the text. How far does each seismic wave (P, S, and L) travel in 8 min?

15. What are the correct names for the types of volcanoes shown below?

(a)



(b)



(c)



Pause and Reflect

The rock that continents are made of can be as old as 4 billion (4 000 000 000) years. The oldest rock on the ocean floor is less than 200 million (200 000 000) years. Use the plate tectonic theory to explain this observation.

Prepare Your Own Summary

In this chapter, you learned how heat transfer in Earth moves large pieces of rock at the surface. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 11 for help with using graphic organizers.) Use the following headings to organize your notes:

- Continental Drift Theory
- Plate Tectonics
- Plate Boundaries
- Volcanoes
- Earthquakes

Checking Concepts

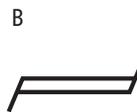
- Why did Wegener call his hypothetical supercontinent Pangaea?
- Create a series of Venn diagrams to compare and contrast the following terms.
 - asthenosphere and lithosphere
 - shield volcanoes and rift eruptions
 - P-waves and S-waves
 - seismometers and seismograms
 - focus of an earthquake and epicentre
- Explain how the following pieces of evidence supported the continental drift theory.
 - matching continental margins
 - similar animal fossils in South America and Africa
 - similar rock types and structures in North America and northern Europe
 - magnetic striping in rocks
- Why do earthquakes and volcanoes occur at tectonic plate boundaries?
- Describe the age of rocks relative to their distance from an ocean ridge at a divergent plate boundary.
- What plate boundaries experience the deepest earthquakes? Explain your answer.
- Explain how sea floor spreading occurs.
- Where do shield volcanoes occur?
- Why do composite volcanoes usually produce violent eruptions?
- Describe two similarities and two differences between P-waves and S-waves.
- What causes earthquakes?

Understanding Key Ideas

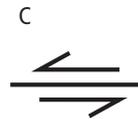
- In the early 1600s, the English philosopher and statesman Sir Francis Bacon suggested that South America and Africa looked like broken parts of the same piece of continent. What later theory explained his observation?
- Match the mapping symbols given below with the correct tectonic plate boundaries.



Transform plate boundary



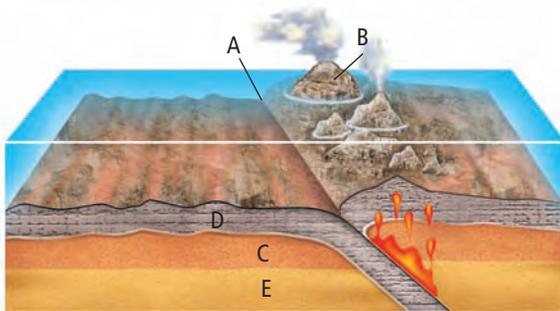
Convergent plate boundary



Divergent plate boundary

- Volcanoes do not usually form at continental-continental plate boundaries or transform plate boundaries. Why not?
- How does the pattern of mountain ranges on different continents provide evidence for continental drift?
- Describe what might happen if mantle convection suddenly stopped.
- How does studying volcanoes give geologists clues about Earth's interior?

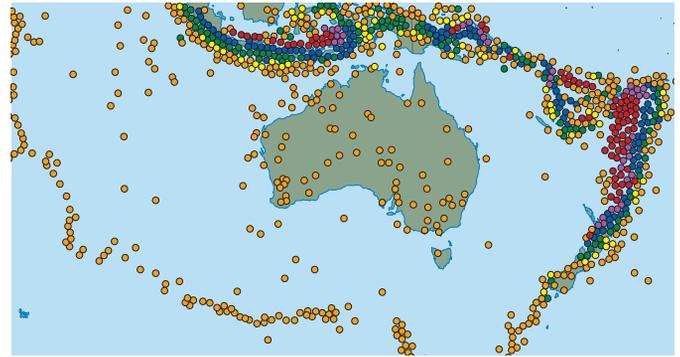
18. Explain why most volcanic activity on Earth occurs at or near tectonic plate boundaries.
19. Although rift eruptions are not violently explosive, what effects would be caused by such an eruption in southwestern British Columbia?
20. Earthquakes occur frequently, all over the world. Why is it difficult to study earthquakes as they occur?
21. Label the features on the tectonic plate boundary shown below.



22. A geologist studying ancient lava flows in central British Columbia discovers three different layers of flows, one on top of the other. She analyzes samples of each flow and determines that the middle flow has a magnetic orientation exactly opposite to that of the flows above and below it. What can she conclude from her observation?

Applying Your Understanding

23. Australia is part of the Indo-Australian Plate. As the tectonic plate is pushed north, it collides with the Eurasian Plate, the Philippine Plate, and the Pacific Plate. The plate interactions cause a great deal of stress to build up in the interior of the Indo-Australian Plate. The diagram below is a map of the Indo-Australian Plate. The shapes on the map indicate different depths of earthquake foci on the plate and at the plate boundary. Use the information above and the diagram below to answer the questions that follow.



Depth in metres

- | | | |
|--------------|----------------|----------------|
| • 0 to -35 | • -70 to -150 | • -300 to -500 |
| • -35 to -70 | • -150 to -300 | • -500 to -800 |

- (a) What types of plate boundaries are shown in the diagram?
- (b) Which way are the plates moving relative to each other?
- (c) Which circle colour indicate the location of what were likely the most destructive earthquakes mapped in the diagram?
- (d) Why do earthquakes occur in Australia?

Pause and Reflect

Ancient Hawaiians noticed that the northwest islands of Hawaii had different types of soil and plants than the southeast islands. These differences supported their belief that the northwest islands were much older than the southeast islands. How does the knowledge of the ancient Hawaiians relate to the plate tectonic theory and the concept of geologic hot spots?

10 The kinetic molecular theory explains the transfer of thermal energy.

- Matter has thermal energy due to the kinetic energy of its particles, which are in constant motion. (10.1)
- Temperature is a measure of kinetic energy, and heat is the amount of thermal energy transferred. (10.1)
- Heat can be transferred by conduction, convection, and radiation. (10.1)
- Earth's atmosphere is a complex system with four layers. (10.2)
- Solar radiation transfers heat to Earth, and conduction and convection transfer heat throughout the atmosphere. (10.2)
- Weather is the condition of the atmosphere at a specific time and place. (10.2)
- The Coriolis effect deflects winds due to Earth's rotation.
- Differences in atmospheric pressure cause prevailing winds, local winds, and extreme weather. (10.2)

11 Climate change occurs by natural and human processes.

- Climate describes long-term weather patterns for a region. (11.1)
- Earth has undergone a number of ice ages and periods of warming. (11.1)
- Earth's atmosphere produces a natural greenhouse effect. (11.1)
- Many natural processes affect climate. (11.1)
- Evidence shows that climates worldwide are changing. (11.2)
- Earth's average global temperature is increasing. (11.2)
- Many human activities contribute to the enhanced greenhouse effect. (11.2)
- Many individuals and nations are making an effort to address climate change. (11.2)

12 Thermal energy transfer drives plate tectonics.

- Geologic evidence suggests that at one time the continents were joined as a supercontinent. (12.1)
- The process of sea floor spreading provides a mechanism for continental drift. (12.1)
- Earth's surface is made up of solid but mobile pieces of rock called tectonic plates. (12.1)
- Mantle convection causes tectonic plates to converge, diverge, or slide past one another. (12.2)
- Subduction zones occur where one plate slides beneath another; mountains form where two plates bump together. (12.2)
- Earthquakes and volcanic eruptions can result at the boundaries between tectonic plates. (12.2)



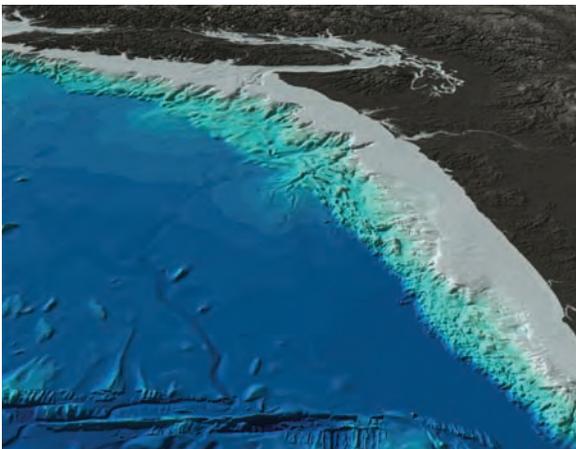
Key Terms

- atmosphere
- conduction
- convection
- Coriolis effect
- heat
- kilopascals
- kinetic molecular theory
- prevailing winds
- thermal energy
- tornado



Key Terms

- El Niño
- greenhouse gases
- La Niña
- ozone layer
- permafrost



Key Terms

- asthenosphere
- continental drift theory
- converging plates
- diverging plates
- earthquakes
- epicentre
- fault
- hot spot
- inner core
- lithosphere
- mantle
- mantle convection
- outer core
- paleoglaciation
- plate boundary
- plate tectonic theory
- primary waves
- ridge push and slab pull
- rift valley
- secondary waves
- spreading ridge
- subduction zone
- surface waves
- tectonic plates
- transform fault
- trench
- volcanic belt
- volcanic island arc
- volcanoes

Minimizing Your School's Carbon Footprint

“Think globally, act locally” has been a rallying cry of environmentalists since the late 1960s. The slogan suggests that, collectively, the small changes made by many individuals can have worldwide effects. Your carbon footprint is the amount of carbon dioxide produced by your activities. Each year, the average Canadian produces about 5.5 tonnes of carbon dioxide through daily activities—giving us one of the largest carbon footprints in the world. In this project, you will work in groups to plan a strategy for reducing your school's carbon footprint.

Problem

How can your school act locally to reduce its global carbon footprint?

Materials

- poster paper
- notebooks
- felt pens or pencil crayons

Criteria

- The ideas that your group presents must involve steps that your school can take in real life.
- The steps should require little or no money and should be tasks that all students can do.
- Focus on ideas that reduce fuel, electricity, water, and other resources.

Procedure

1. Have each member of your group work individually to come up with five or more ideas for minimizing your school's carbon footprint.
2. As a group, review each person's ideas. Work together to create a master list of ideas for your group.
3. As a group, decide if there are any smaller steps that must be considered for each of your ideas to be carried out.
4. Create a poster that lists the steps in your group's carbon-reduction plan for your school.

Report Out

1. After you have completed your poster, each group will present their ideas to the class.
2. One classmate will act as a recording secretary. This person will list the different groups' ideas on the board or on flipchart paper.
3. As a class, assess each idea. Vote on the top three ideas that you would like to implement.
4. Present the top three class ideas to a school administrator.



Climate Change: Where Do We Go from Here?

In this investigation, you will research the most up-to-date information on climate change from one of three perspectives: environmental, technological, or societal.

Background

Environmental scientists note that Earth's atmosphere—and climate—is changing. But how should people respond? Our action plan will depend on the answers to many questions: What is happening to Earth's systems? How severe can we expect the effects of global warming to be? Are there technological solutions that can help? How will climate change affect our daily lives?

Find Out More

Choose one topic from the following list. Some related questions have been provided to guide your research. Use the Internet to find information (start at www.bcscience10.ca). In addition to newspapers, magazines, and books, you may wish to contact local experts, environmental groups, or companies that specialize in your research topic. Carefully record the information you discover. Be sure to note and credit the sources of information.

Topic 1 Is weather becoming more extreme?

- Are major storms (such as hurricanes) becoming more frequent and more intense?
- Are there more episodes of droughts and flooding around the world than there were in the past?
- Are temperature extremes greater than they have been historically?

Topic 2 How are humans using technology to deal with climate change concerns?

- What are some ways in which technology is being used to avert global warming?
- Describe some high-tech solutions that have been suggested to deal with the effects of climate change.
- What are some simple technologies or low-tech solutions that could minimize the effect of human activities on the environment?

Topic 3 What changes can society make in order to deal with the problems associated with climate change?

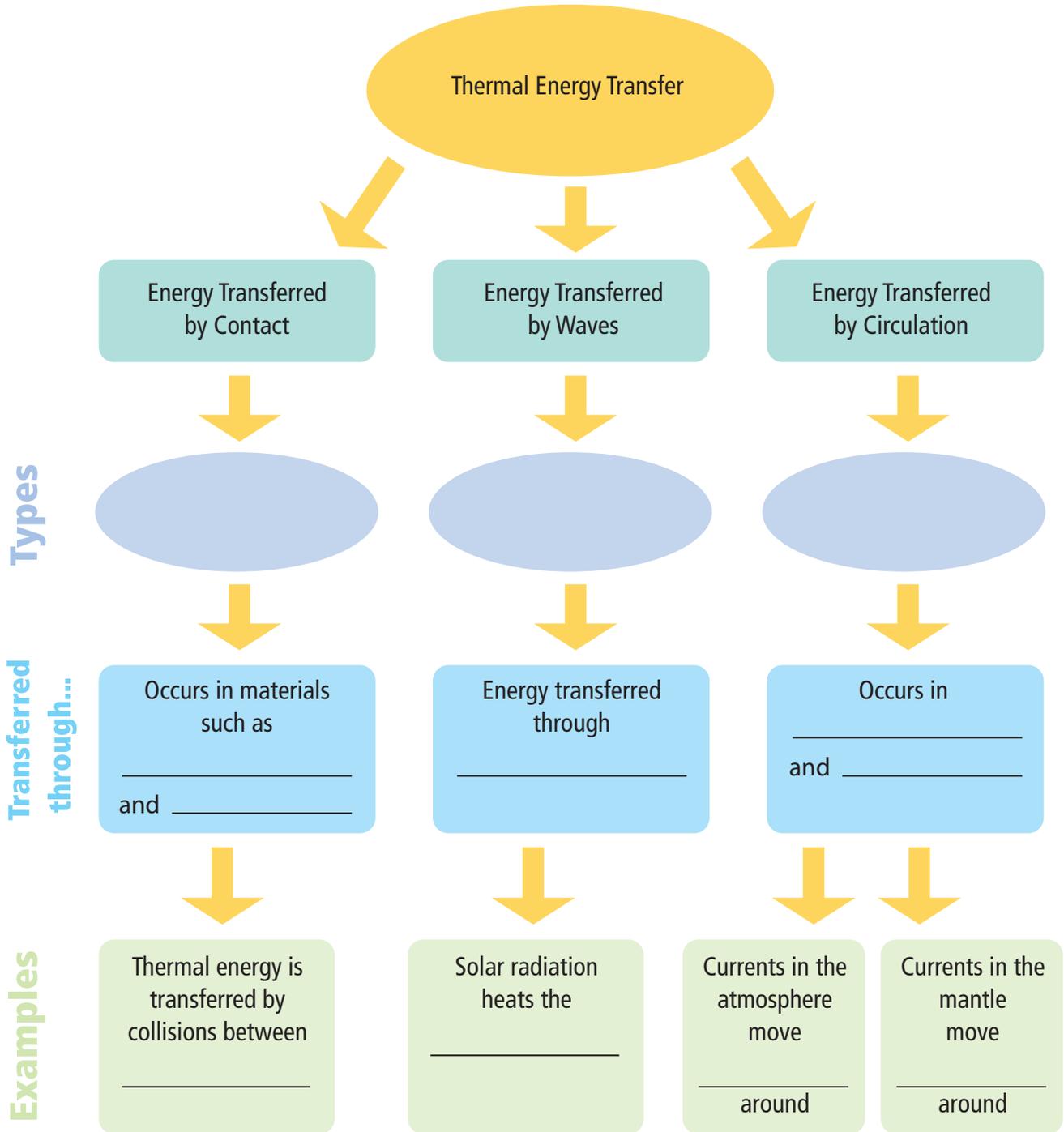
- What lifestyle changes can individuals make to minimize damage to the environment?
- How do societal values affect the lifestyle changes that people might be willing to make?
- What strategies can cities and communities take to address climate change?
- What is the role of government in supporting efforts to address climate change?

Report Out

1. Summarize your findings in a short written report, poster, or multimedia presentation.
2. Whichever form of presentation you use, be sure to include the following at the end of your report.
 - (a) your opinion on the issue
 - (b) a list of references for all data, graphs, or quotations that you used

Visualizing Key Ideas

- Copy the concept map below into your notebook. Fill in as many terms as you can without looking in your textbook. After you have completed as much of the concept map as you can, go back through the unit to check your work. Fill in any missing terms with a different colour of pen.



Using Key Terms

2. In your notebook, state whether each of the following statements is true or false. If a statement is false, rewrite it to make it true.
 - (a) Temperature is the average kinetic energy of all the particles in a sample of matter.
 - (b) Conduction is the transfer of heat through direct contact.
 - (c) All forms of electromagnetic radiation are invisible to the naked eye.
 - (d) Humans live in a layer of Earth's atmosphere called the thermosphere.
 - (e) The unit kilopascal (kPa) is used in weather forecasting to indicate the temperature of an area.
 - (f) The Coriolis effect causes winds to blow.
 - (g) Sea breezes result from the different rates at which land and water transfer thermal energy.
 - (h) The natural greenhouse effect makes Earth too warm for human life.
 - (i) El Niño is the name of strong winds that come from South America.
 - (j) A carbon sink produces carbon in the atmosphere.
 - (k) Tectonic plates move together at a mid-ocean ridge.
 - (l) Paleomagnetism is a record of magnetic reversals recorded in rock.
 - (m) Tectonic plates move over a partly melted layer of rock called the lithosphere.
 - (n) Trenches form at divergent plate boundaries.
 - (o) Earthquakes occur because of a sudden build-up of energy between tectonic plates.

Checking Concepts

10

3. List three different number scales that are used for measuring temperature.
4. What is the difference between heat and thermal energy?
5. What is electromagnetic radiation?
6. Humans cannot see infrared radiation. What are some visible effects of infrared radiation?

7. What layer of the atmosphere do we live in?
8. How do scientists determine where one layer of the atmosphere ends and the next begins?
9. What is insolation?
10. What type of weather is usually associated with high pressure areas?
11. What is atmospheric pressure?
12. Why does air pressure decrease the higher you go into the atmosphere?
13. State what the Coriolis effect does to winds in:
 - (a) the southern hemisphere
 - (b) the northern hemisphere
14. Copy the following table into your notebook. Match each of the weather front symbols with its name.

| | | |
|---|-------|------------------|
| (a)  | _____ | cold front |
| (b)  | _____ | warm front |
| (c)  | _____ | stationary front |
| (d)  | _____ | occluded front |

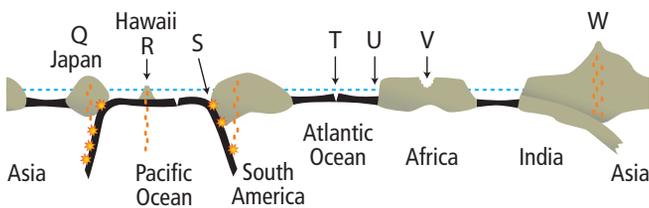
11

15. What is the term for the average conditions of the atmosphere in a large region over 30 years or more?
16. (a) What is the term for scientists who study past climates?
(b) List four types of evidence that scientists examine in order to study past climates.
17. List three factors other than human activities that affect Earth's average global temperature.
18. Name the three characteristics of Earth's movement in space that affect climate.

19. (a) What is an El Niño event?
(b) Where does it occur?
20. The ocean is considered one of the most important carbon sinks on our planet. What is a carbon sink?
21. (a) List three greenhouse gases.
(b) How do greenhouse gases affect the atmosphere?
22. What are general circulation models used for?

12

23. In which layer inside Earth do convection currents occur?
24. Name the two types of tectonic plates.
25. What is the term for molten rock that reaches Earth's surface?
26. The diagram below is a cross-section showing different types of tectonic plates and geological features. In your notebook, match the terms in the following list with the letters on the cross-section. No letter is used more than once.
 - (a) continental-continental plate convergence _____
 - (b) trench _____
 - (c) hot spot _____
 - (d) volcanic island arc _____
 - (e) mid-ocean ridge _____
 - (f) rift valley _____



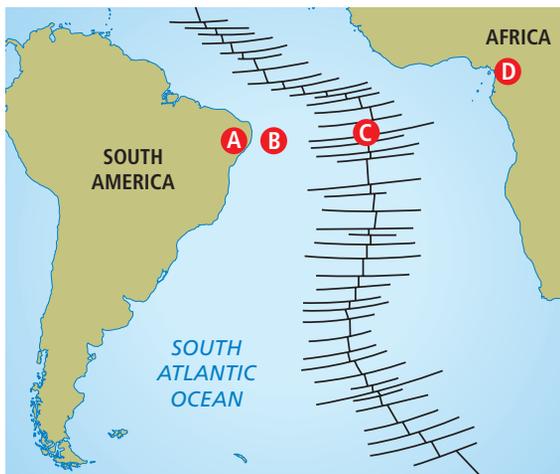
The drawing is not to scale

27. What is the continental drift theory?
28. How is a hot spot different from a subduction zone?
29. What instrument is used to measure the ground motion of an earthquake?

Understanding Key Ideas

30. A thermometer in a beaker of boiling water reads 100°. What is the temperature scale of the thermometer? (Assume that the beaker of water is located at Earth's surface.)
31. Describe how heat is transferred by conduction according to the kinetic molecular theory.
32. Why does conduction occur more easily in a solid than in a gas?
33. Why is the atmospheric pressure greater at sea level than it is at the top of a high mountain?
34. How would conditions on Earth be different without the natural greenhouse effect?
35. Describe the key features of a biogeoclimatic zone in British Columbia.
36. Earth wobbles as it spins on its axis. What effect can this wobble have on climate in the northern hemisphere?
37. How does the plate tectonic theory help explain the location of earthquakes and volcanoes?
38. Describe a direct effect of the thinning of Earth's ozone layer.
39. How does the presence of coal deposits in Antarctica support the idea that the continents were once in different locations than they are today?
40. Explain why each of the following affects the temperature at Earth's surface.
 - (a) the decay of radioactive materials under Earth's surface
 - (b) the Sun
 - (c) energy left over from Earth's formation
41. In which of the following would heat transfer occur by convection? Explain your answer(s).
 - (i) the oceans
 - (ii) Earth's atmosphere
 - (iii) Earth's mantle
 - (iv) the space between the Sun and Earth
42. Compare slab pull and ridge push.
43. Compare the formation of a composite volcano to that of a rift eruption.

44. Describe two pieces of evidence that indicate that Earth's climates are currently changing.
45. Use the diagram of the Mid-Atlantic Ridge, below, to answer the questions that follow.



- (a) How does the thickness of the crust at location A compare to the thickness of the crust location B?
 - (b) Where is the youngest rock located?
 - (c) How does the age of rock at A compare to the age of rock at D?
 - (d) Where is magma most likely to be rising to the surface?
46. Use a Venn diagram to compare and contrast the terms “weather” and “climate.”
 47. How is the natural greenhouse effect different from global warming?
 48. Describe how a catastrophic event such as a massive volcanic eruption can affect climate worldwide.
 49. Describe how the tilt of Earth's axis results in seasons.
 50. What causes the Coriolis effect?

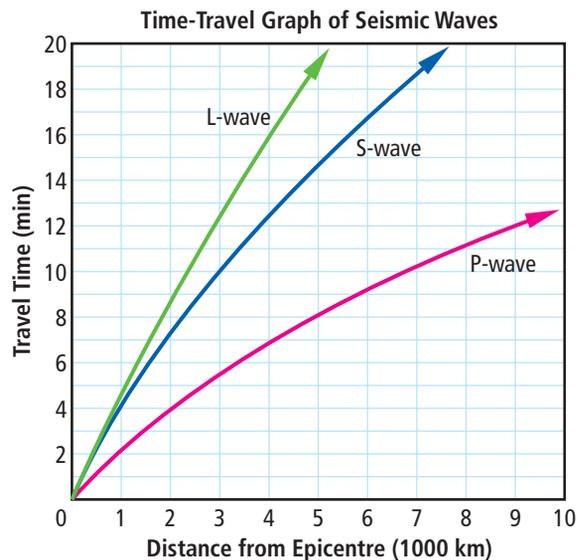
Thinking Critically

51. Why is copper a better thermal conductor than water?
52. Suppose that it is late July and a mass of cold air is approaching your town from the north. In what direction do you think the wind would be blowing? Explain.

53. Explain what the following statement means, using specific examples: The effects of climate change will be economic, social, and environmental.
54. Although both planets are about the same size, Earth's average albedo (0.367) is about half that of Venus (0.65). What factors might contribute to Venus's greater albedo?
55. Describe what you think would happen to Earth if all mantle convection were to suddenly increase in speed.
56. (a) Write a list of five major effects that climate change could have on British Columbia.
(b) Rank your list in order from the most important effect to the least important effect.
(c) Explain why you ordered the list in the way that you did.

Developing Skills

57. Use the graph below to answer the questions that follow.



- (a) How long does it take a P-wave to travel 4000 km?
- (b) How long does it take an S-wave to travel 4000 km?
- (c) How far does an L-wave travel in 16 min?

58. To demonstrate your understanding of the nature of winds, sketch the following.
- a high pressure area and a low pressure area, and the direction that the wind would blow
 - the direction of the wind at a shoreline during the night
 - the direction of a north to south wind in the northern hemisphere that has been deflected due Earth's rotation
59. Create a graphic organizer that demonstrates your understanding of tectonic plate movement. Show how convection currents in the mantle cause tectonic plate movement at five types of plate boundaries.
60. The data table below gives the ages of the Hawaiian Island chain of hot spot volcanoes. Distances are measured from the Kilauea volcano on the Big Island of Hawaii.

| Volcano Name | Distance Northwest from Kilauea (km) | Estimated Age (millions of years) |
|--------------|--------------------------------------|-----------------------------------|
| Kilauea | 0 | 0 (active) |
| Mauna Kea | 54 | 0.4 |
| West Maui | 221 | 1.3 |
| West Molokai | 280 | 1.9 |
| Koolau | 339 | 2.6 |
| Waianae | 374 | 3.7 |
| Kauai | 519 | 5.1 |
| Necker | 1058 | 10.3 |

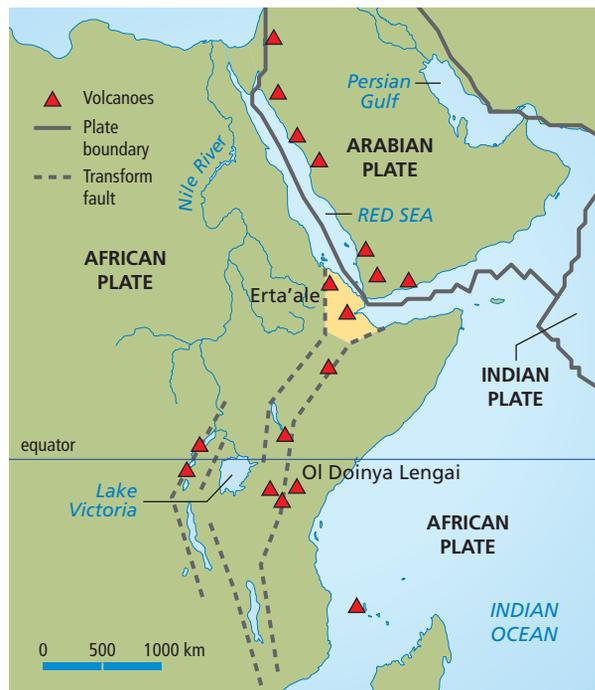
Source: Hawaii Center for Volcanology

- Plot the distance (x -axis) versus the age (y -axis) for each volcano. Connect the points with a line of best fit.
- What do you notice about the trend shown in your graph?
- About what age would you expect a volcano to be if it were located 800 km northwest of Kilauea?

- The Hawaiian Islands were formed when the Pacific plate passed over a hot spot. Magma broke through a weak part of the lithosphere, forming the chain of islands. Calculate the average rate of plate movement by determining the slope of the line ($\frac{x}{y}$). (**Hint:** To find the rate of plate movement in cm/year, multiply the distance in km by 100 000.)

Applying Your Understanding

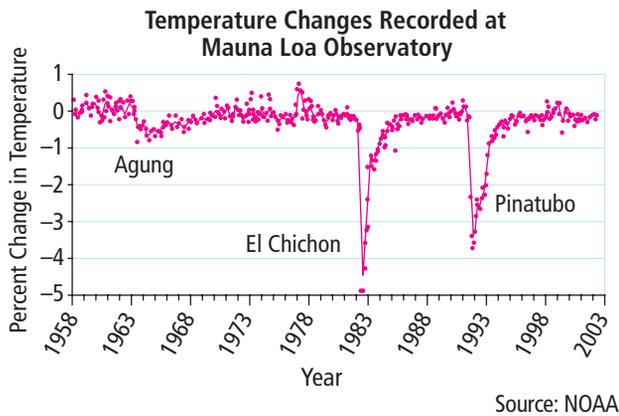
Use the following information to answer questions 61 and 62.



In September 2006, a 500 m strip of land in the African country of Ethiopia suddenly dropped over 3 m. It occurred so quickly that the resulting 8 m rip in the ground swallowed goats and camels and sent people running in panic. In the following three weeks, there were 160 earthquakes. As shown in the above map, two tectonic plates, the African Plate and Arabian Plate, are separating. It is estimated that, in the next million years or so, a large portion of the east coast of Africa will be cut off from the rest of the continent, forming a large island. As the plates drift apart, the crust between is weakening.

A few kilometres below ground, there is a magma chamber where the magma pools and expands. When the magma in the chamber reaches a critical pressure, the molten rock bursts free.

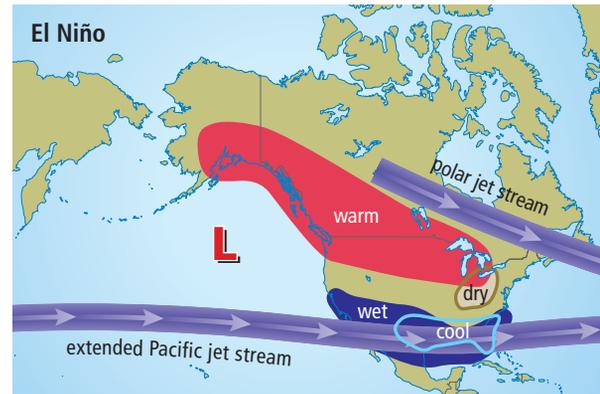
61. What type of plate boundary separates the African Plate and the Arabian Plate?
 - A. a subduction boundary
 - B. a convergent boundary
 - C. a divergent boundary
 - D. a transform boundary
62. What is the source of the magma that rises at the boundary between the African Plate and the Arabian Plate?
 - A. the outer core
 - B. the lithosphere
 - C. the asthenosphere
 - D. the crust
63. The Mauna Loa Observatory in Hawaii is a research facility run by the U.S. National Oceanic and Atmospheric Administration (NOAA). The graph below shows the average change in temperature measured at the Mauna Loa Observatory from 1958 to 2002. The graph also shows the timing of three volcanic eruptions: Mount Agung (1963), El Chichon (1982), and Mount Pinatubo (1991).



Why did the temperature drop so much in 1982?

- A. Volcanic eruptions released large amounts of greenhouse gases.
- B. Dust and debris from the El Chichon eruption blocked sunlight.
- C. Dust and debris from the Mount Pinatubo eruption blocked sunlight.
- D. Dust and debris from the Mount Agung eruption trapped sunlight.

Use the following information to answer questions 64 and 65.



During an El Niño event, surface water temperatures near the equator are warmer than usual. El Niño events can have devastating local effects. When the warm waters stay close to the surface, the organisms that fish eat tend to move to deeper, cooler waters. The fish follow their food, which causes problems for the fishing industry in many countries in South America.

64. What is the expected weather for January to March in southwestern British Columbia due to the El Niño event?
 - A. wet
 - B. warm
 - C. dry
 - D. cold
65. Which of the following is true about the effect of the El Niño event on the coastal waters of South America?
 - A. The cold waters of the El Niño event drive the fish away.
 - B. The ocean currents are reversed, carrying fish to new locations.
 - C. The food the fish eat moves deeper in the ocean.
 - D. Fish are not able to reproduce in the warm El Niño waters.

Pause and Reflect

Climate describes long-term weather patterns, while weather describes the conditions of the atmosphere in the short term. Scientists think that the enhanced greenhouse effect is resulting in climate change. How are climate change and weather connected? Draw a concept map to give your answer.