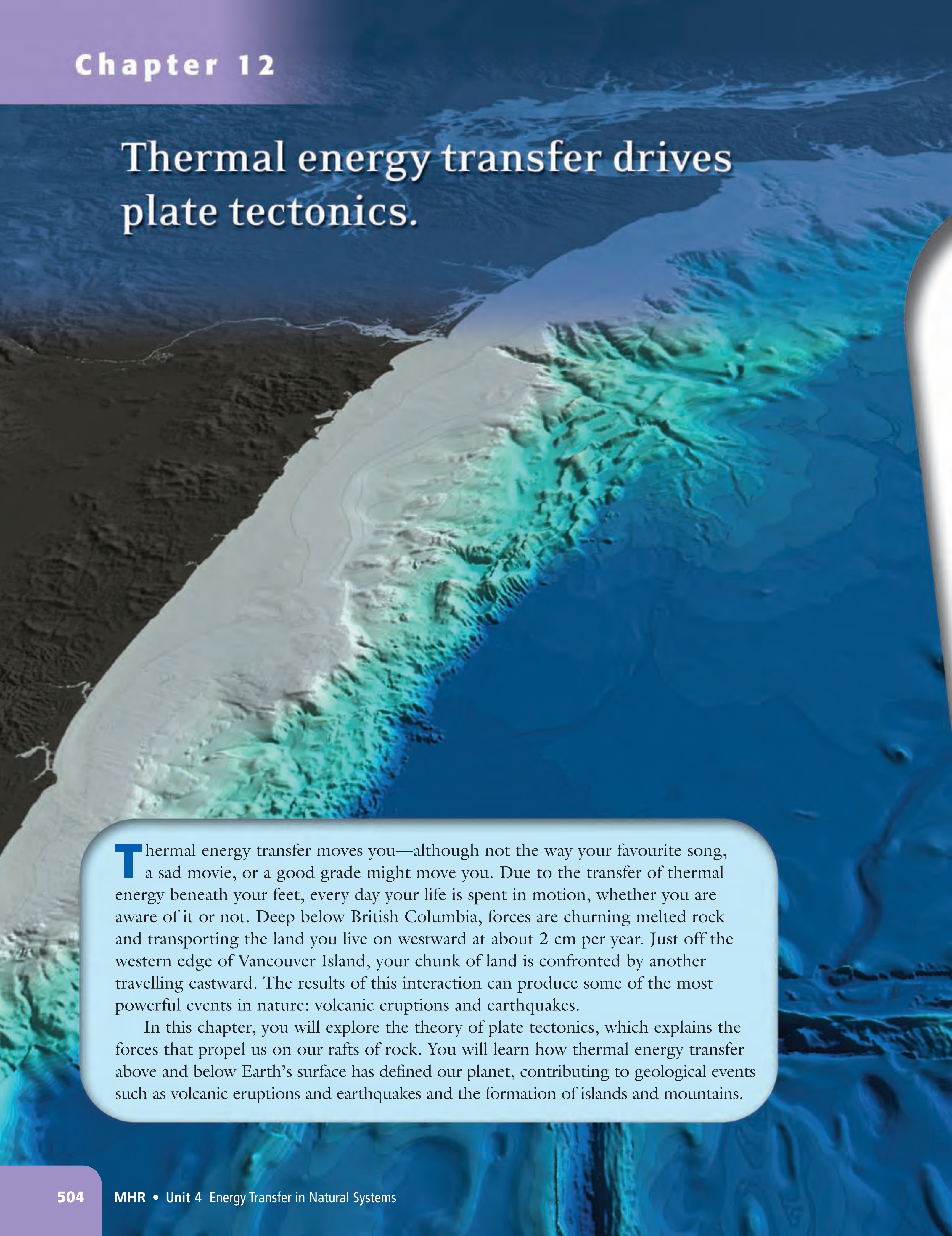
Chapter 12

Thermal energy transfer drives plate tectonics.



Thermal energy transfer moves you—although not the way your favourite song, a sad movie, or a good grade might move you. Due to the transfer of thermal energy beneath your feet, every day your life is spent in motion, whether you are aware of it or not. Deep below British Columbia, forces are churning melted rock and transporting the land you live on westward at about 2 cm per year. Just off the western edge of Vancouver Island, your chunk of land is confronted by another travelling eastward. The results of this interaction can produce some of the most powerful events in nature: volcanic eruptions and earthquakes.

In this chapter, you will explore the theory of plate tectonics, which explains the forces that propel us on our rafts of rock. You will learn how thermal energy transfer above and below Earth's surface has defined our planet, contributing to geological events such as volcanic eruptions and earthquakes and the formation of islands and mountains.

What You Will Learn

In this chapter, you will
- **define, describe,** and **analyze** the processes and features associated with plate tectonics
- **explain** tectonic plate movement and its effects
- **explain** the factors that contribute to the motion of tectonic plates
- **relate** plate tectonics to the layers of Earth
- **identify** sources of heat within Earth

Why It Is Important

The plate tectonic theory provides an explanation for geological events that affect our lives, such as earthquakes and volcanic eruptions. The theory helps explain the formation of mountains and the location of continents. As scientists put together clues about Earth's past, they can make better predictions about our planet's future.

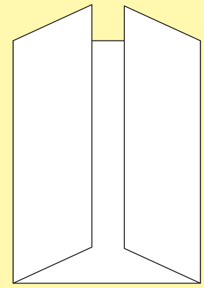
Skills You Will Use

In this chapter, you will
- **explain** tectonic plate movement and its effects
- **communicate** your knowledge of plate tectonics
- **model** tectonic plate movement and volcanic eruptions
- **evaluate information** from a graph of earthquake energy waves

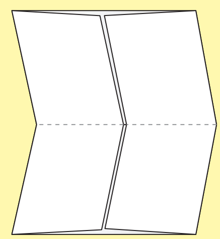
FOLDABLES™ Reading & Study Skills

Make the following Foldable and use it to take notes on what you learn in Chapter 12.

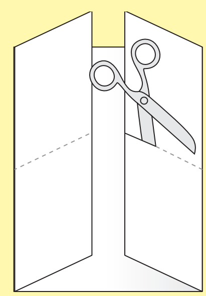
STEP 1 **Make** a shutterfold using 28 cm x 43 cm paper.



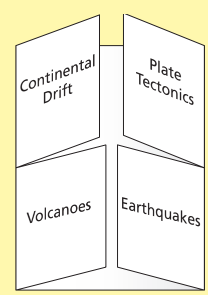
STEP 2 **Fold** the shutterfold in half like a hamburger. **Crease** well.



STEP 3 **Open** the paper, and **cut** along the inside valley folds.



STEP 4 **Label** the four doors as shown.



Organize Beneath the door tabs, record information and define terms. On the back of the Foldable, glue a map of the world and indicate the boundaries of the tectonic plates and significant volcanoes. Use the Internet to research recent earthquakes, and mark their locations on the map as well.

12.1 Evidence for Continental Drift

Various pieces of evidence indicate that the continents were once joined but later drifted to their current positions. First, the coasts of the continents can be aligned. Second, regions of some continents that are far apart have similar rocks, mountain ranges, fossils, and patterns of paleoglaciation. The process of sea floor spreading provides a mechanism for continental drift. The continents are attached to huge slabs of rock, known as tectonic plates. When the tectonic plates move across Earth's surface, they carry the continents with them.

Words to Know

continental drift theory
earthquakes
hot spot
magnetic reversal
paleoglaciation
plate tectonic theory
spreading ridge
tectonic plate
volcanoes

Humans are passengers on the solid rock slabs we call continents. However, the idea that these huge land masses move may seem hard to believe. In fact, in the early 20th century, when German scientist Alfred Wegener proposed the continental drift theory, the idea was revolutionary. The **continental drift theory** states that the continents have not always been in their present locations but have "drifted" there over millions of years. Wegener's first clue that the continents were in motion came from his and others' observations of world maps (Figure 12.1).

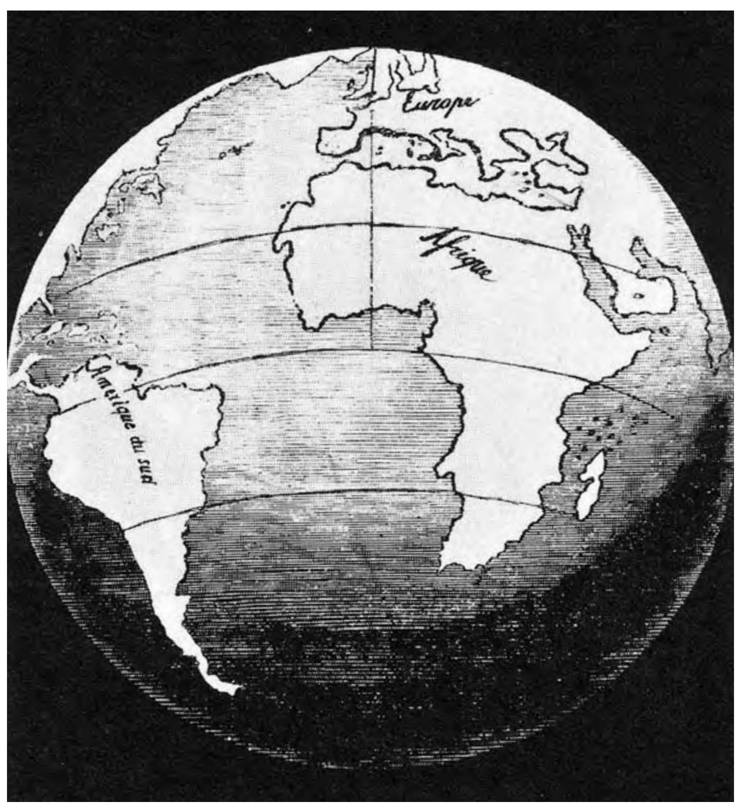


Figure 12.1 The first piece of evidence for continental drift was the matching shapes of the continents, as shown in the earliest reliable world maps.

Did You Know?

Scientists can learn a lot about the land we live on by studying the sea floor. In order to study the area off the west coast of North America, scientists have placed 800 km of fibre optic cable on the sea floor. From depths of up to 2.8 km, the cable transmits video recordings and other data to a University of Victoria shore station. From there, the data are sent to scientists around the world.

12-1A Coast to Coast

Think About It

For as long as there have been reliable world maps, people have noticed a striking feature—the shapes of the continents relative to one another. In this activity, you will take on the role of an early cartographer (map maker). You will make an hypothesis to explain the way the continents appear.

What to Do

1. Examine Figure 12.1 on the previous page, an early map showing South America and Africa. What do you notice about the east coast of South America relative to the west coast of Africa?
2. Suggest an hypothesis that would explain your observation in Step 1.
3. Suppose you wanted to find other evidence to support your hypothesis. What would you need to find out about the plants, animals, and geography of eastern South America and western Africa?

What Did You Find Out?

1. What evidence from world maps supports the continental drift theory?

The Jigsaw Puzzle Fit

The apparent match on a world map between South America's eastern coastline and Africa's western coastline gave Wegener his first piece of evidence for continental drift. To Wegener and many others, the fit appeared too close to be coincidental. Wegener suggested that, millions of years ago, all the continents were joined as a "supercontinent." He named the giant land mass Pangaea, from the Greek words *pan*, meaning all, and *gaea*, meaning Earth. In truth, the continental edges do not match as perfectly as pieces of a puzzle. A better alignment is obtained by matching the continental shelves, which are the submerged original shorelines of continents.

Wegener also compared geological structures, fossils, and evidence of ancient glaciers on different continents. These clues did not seem significant until Wegener placed the continents together (Figure 12.2).

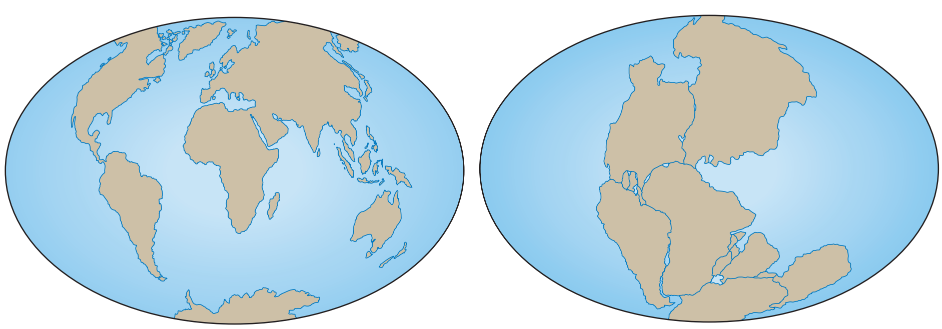


Figure 12.2 Wegener noted similar features in distant continents. These features matched across continents that appeared to fit together.

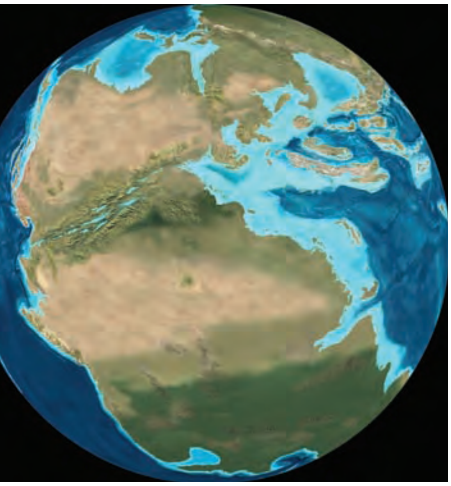


Figure 12.3 Modern scientists created this map to show how worldwide mountain ranges might have looked on Pangaea over 200 million years ago.

Matching Geological Structures and Rocks

Wegener's analysis of rocks and mountain ranges supported his idea that the continents were once joined. He noted mountain ranges that begin on one continent, end at the coastline, and then appear to continue on a continent across an ocean. There are also many similarities between rock structures, such as folds, and the ages of rocks on continents that are separated by thousands of kilometres of ocean. For example, rocks found in Newfoundland are the same type and age as rocks found in Greenland, Ireland, Scotland, and Norway.

Wegener reasoned that the world's major mountain ranges would have been continuous when the continents were joined as Pangaea (Figure 12.3).

Matching Fossils

Wegener was intrigued by the fact that similar fossils occur in various locations around the world. One fossil that particularly interested him was that of a sharp-toothed, freshwater reptile called *Mesosaurus*. Fossils of *Mesosaurus* have been found in only two places: southeastern South America and southwestern Africa. Because *Mesosaurus* was a small, freshwater animal, it seemed unlikely the animal would have survived crossing the 6000 km of open ocean between the two continents. Furthermore, the fossils of two land-dwelling animals, *Cynognathus* and *Lystrosaurus*, have been found throughout the continents in the southern hemisphere, separated by vast oceans. Given that these land animals could not have swum so far, the existence of Pangaea seemed the best explanation for the fossil findings (Figure 12.4). Members of the same species would have been separated when the giant landmass broke apart.

Another fossil of interest was that of *Glossopteris*, a fern. Wegener could not understand why fossils of this plant would be found so widely spread apart, from South America and Africa to Australia, India, and Antarctica. Ferns do not grow in cold climates, and there was no evidence that, 200 million years ago, polar climates were milder. If, however, the continents were once joined as Pangaea, the location of the fossilized ferns made sense: In the past, Antarctica must have been closer to the equator and thus had a warmer climate. Since then, Antarctica has moved to its present location at the South Pole.

Figure 12.4 Alfred Wegener used the locations of similar fossils and rocks on separate continents to formulate his hypothesis that all continents were once joined. His hypothesis makes sense in light of the theory of evolution, which explains that members of the same species share the same ancestors.

Climatic Evidence for Continental Drift

Work by many scientists added support to the evidence for continental drift that Wegener had collected. The effects of ice ages on Earth's surface are one example. Glaciers are vast masses of ice, found in our time at the poles and high in the mountains. During ice ages, however, glaciers covered large areas of land. When glaciers advance or retreat, they mark the land with proof of their existence, leaving behind large, U-shaped valleys, deeply scratched rocks, and various types and patterns of rock formations. **Paleoglaciation** refers both to the extent of ancient glaciers and to the rock markings they have left behind.

Word Connect

The prefix "paleo-" originates from the Greek word meaning old or ancient. What do you think paleobiologists, paleontologists, and paleoclimatologists study?

Scientists were puzzled by evidence of glaciers in parts of the world that are now tropical, such as parts of India and Africa. They wondered how glaciers could have formed in places where temperatures were rarely known to dip below freezing. If the continents were once joined, however, with much of the land mass sitting towards the South Pole, then evidence of glaciers across South America, Africa, and India made sense (Figure 12.5).

Coal deposits in Antarctica are another piece of evidence that was hard to account for. Coal forms from the decomposition of once living things—usually tropical swamp material. The South Pole has never had a tropical climate, which suggests that Antarctica was once in a warmer location than it is now. If the mystery could be explained by massive global climate change, evidence for warmer climates would be found on all continents, which it was not. Instead, as Wegener concluded almost a century ago, each continent contained clues about an ancient super continent that had broken into smaller pieces. The best explanation for the Antarctic coal deposits was that the continents were once situated in very different locations.

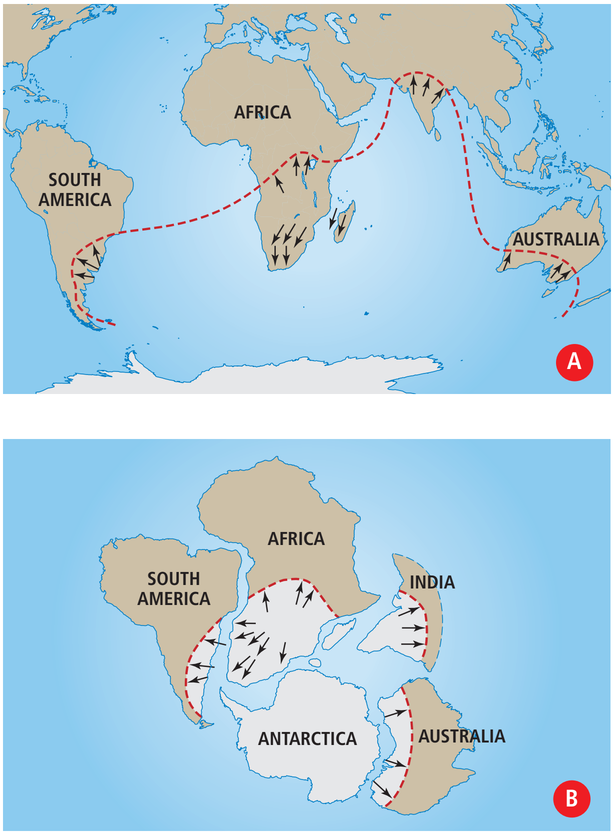


Figure 12.5 There seems to be no pattern to paleoglaciation found around the world (A). A pattern emerges when the continents are fitted together to form Pangaea (B).

Reading Check

1. What did Wegener observe in maps that supported his concept of continental drift?
2. What land mass does Pangaea refer to?
3. How did Wegener explain the fact that there are mountain ranges that appear to start on one continent and continue on another?
4. Why was Wegener interested in fossils of *Mesosaurus*, *Cynognathus*, and *Lystrosaurus*?
5. What is the term for the features left on the land by ancient glaciers?

How Can Continents Move?

Although Wegener had gathered a great deal of evidence for continental drift, the scientific community did not receive his idea with enthusiasm. In order for Wegener's hypothesis to become an accepted theory, he needed to answer a key question: What makes continents drift? It would take over 30 years, major technological advancements, and the research of a Canadian geophysicist before the continental drift theory was accepted.

internet connect

The Ring of Fire is a zone around the Pacific Ocean with many earthquakes and volcanic eruptions. To learn more about the Ring of Fire, visit **www.bcscience10.ca**.

A Possible Mechanism

In the years following Wegener's death in 1930, new findings made scientists reflect on his hypothesis. As with many great scientific discoveries, a series of seemingly unrelated events combined to generate support for an idea once considered far-fetched.

In Wegener's time, scientists did not know that the surface of Earth is broken into large, movable slabs of rock called **tectonic plates**. Since the early part of the 20th century, however, much has been discovered about the large, rigid plates that move around the surface of Earth, sliding over a layer of partly molten rock.

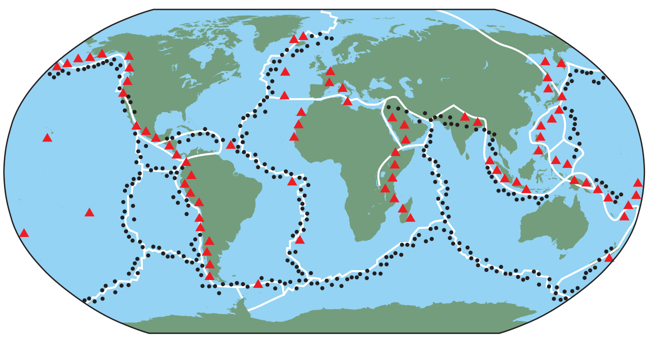


Figure 12.6 Earthquakes and volcanoes occur most often at the boundaries between tectonic plates.

One observation that turned out to be related to the movement of tectonic plates was the locations of volcanic eruptions and earthquakes around the world. **Volcanoes** are openings in Earth's surface, that, when active, spew out gases, chunks of rock, and melted rock. An **earthquake** is a sudden, ground-shaking release of built-up energy at or under Earth's surface. Volcanic eruptions and earthquakes are dramatic events, and it would be reasonable to assume they occur everywhere. In fact, a plot of volcanoes and earthquake zones on a map reveals a particular pattern—one that outlines the boundaries between tectonic plates (Figure 12.6).

Another intriguing observation was the depth of the oceans. In 1872, the British vessel HMS *Challenger* set sail on a scientific expedition. One of the voyagers' goals was to map the ocean floors. Oceanographers were amazed to discover a long mountain range running north to south down the length of the Atlantic Ocean. This range lay right along the middle of the ocean floor, which earned it the name **Mid-Atlantic Ridge** (Figure 12.7). Scientists wondered what forces could have produced the underwater mountain range. The relationship among ocean mountain ranges, earthquakes, volcanoes, and continental drift became clearer with the development of new technologies that allowed greater ocean exploration.

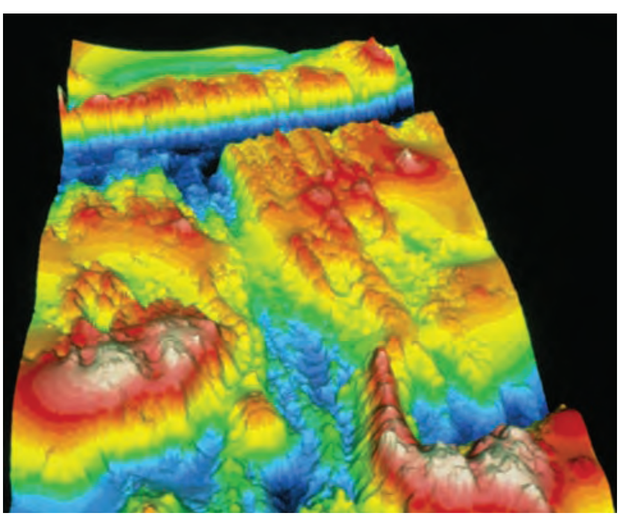


Figure 12.7 The Mid-Atlantic Ridge is a mountain range in the Atlantic Ocean. This image was made using sonar data. The colours represent the ocean's depth, from white (shallowest) to dark blue (deepest). The top of the image is the northern end.

Evidence from ocean rock and sediments

From the 1940s onwards, the drive to map the ocean floor led to many discoveries. Oceanographers made one such discovery when they took rock samples from the Mid-Atlantic Ridge to determine the age of the ocean floor. A peculiar pattern emerged: the youngest rocks were found closest to the ridge (Figure 12.8). In addition, the layer of ocean sediment—the small particles of silt and organic debris deposited on the ocean floor—became thicker the farther it was from the ridge. Initially, scientists could not explain these observations.

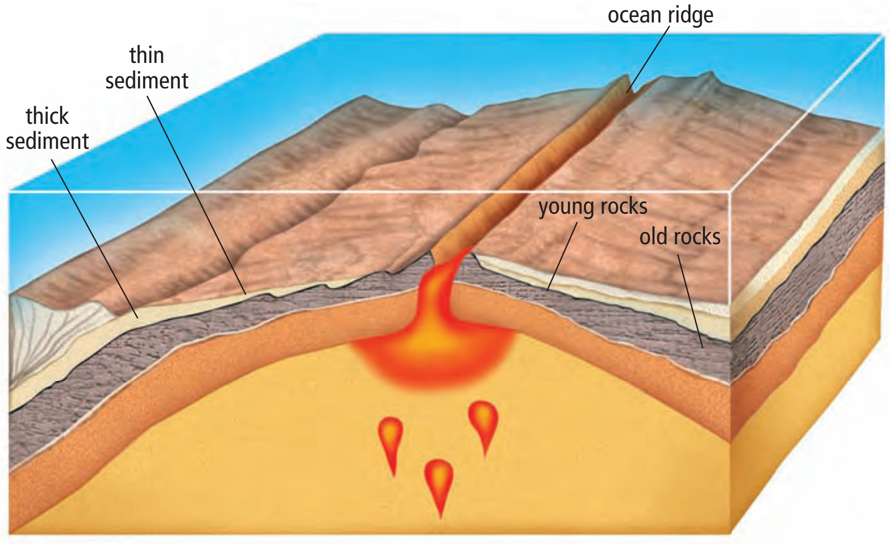


Figure 12.8 With increasing distance from the centre of a ridge, rocks on the sea floor are older and the ocean sediment is thicker.

Evidence from paleomagnetism

Like a bar magnet, Earth has north and south magnetic poles and a magnetic field. In fact, the reason that a compass needle points north is because the needle aligns with Earth's magnetic field lines (Figure 12.9). Iron and other magnetic metals in rocks also usually align with these field lines.

Earth's magnetic field is not unchanging, however. It not only changes in strength from time to time but, over thousands of years, its direction can completely reverse, a process known as **magnetic reversal**. Why this seemingly random event occurs is not well understood, but scientists think that Earth's magnetic field is produced by the motion of liquid iron in the planet's interior. If the motion of this material changes in some way, Earth's magnetic north pole becomes its magnetic south pole, and vice versa. Magnetic reversal does not affect Earth's physical appearance, and so Earth's geographic North and South Poles do not change. In the past 10 million years, Earth's magnetic poles have shifted an average of four or five times per million years.

Much like a compass needle that has been frozen in place, ancient rocks often preserve the strength and direction of Earth's magnetic field as it was when the rocks were formed. **Paleomagnetism** is the study of

Did You Know?

At the south or north magnetic pole, the needle of a compass will spin wildly! Compass readings are also affected by magnetic fields due to nearby electric transmission lines or rocks containing magnetic metals.

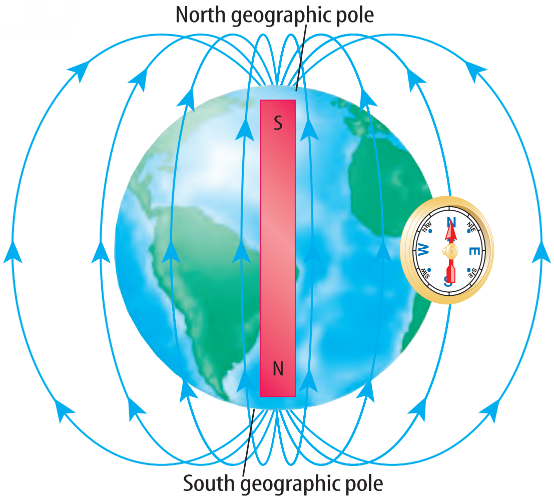


Figure 12.9 Earth is like a large bar magnet. When Earth's magnetic poles are similar to its geographic poles, as they are now, the direction of Earth's magnetic field is called normal polarity. When Earth's magnetic poles reverse so that they are opposite to Earth's geographic poles, the orientation is called reverse polarity. During a period of reverse polarity, a compass needle would point in the general direction of the geographic South Pole.

Suggested Activity

Find Out Activity 12-1B on page 514

the magnetic properties of ancient rocks. In the 1950s, oceanographers began surveying the magnetic polarity across the bottom of the Atlantic Ocean using a device called a magnetometer, which detects variations in magnetic fields. The scientists discovered a surprising pattern of stripes in the direction that iron-containing minerals pointed on the sea floor. The pattern, which they named **magnetic striping**, was repeated on both sides of the Mid-Atlantic Ridge (Figure 12.10).

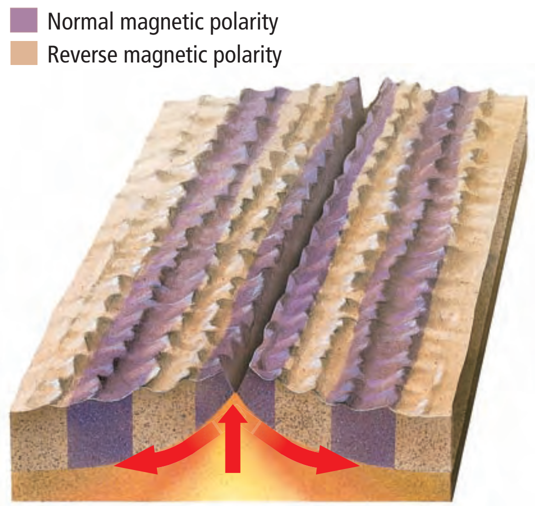


Figure 12.10 Over time, the orientation of Earth's magnetic field has reversed many times. Periods of normal polarity and reverse polarity can be detected by measuring the magnetic fields of rocks on the sea floor.

Sea floor spreading: an explanation

In 1960, an American geology professor named Harry Hess proposed an explanation that tied together data on the age of ocean rocks, sediment thickness, and magnetic striping. He suggested that **magma**—molten rock from beneath Earth's surface—rises because it is less dense than the material that surrounds it. The magma cools and hardens when it breaks through Earth's surface, at a **spreading ridge**, forming new sea floor. As convection currents cause more magma to rise, the new magma forces apart the hardened material and, like a conveyer belt, continuously pushes older rock aside (Figure 12.11). Understanding this process, which Hess called **sea floor spreading**, was an important step in developing a theory about tectonic plate movement.

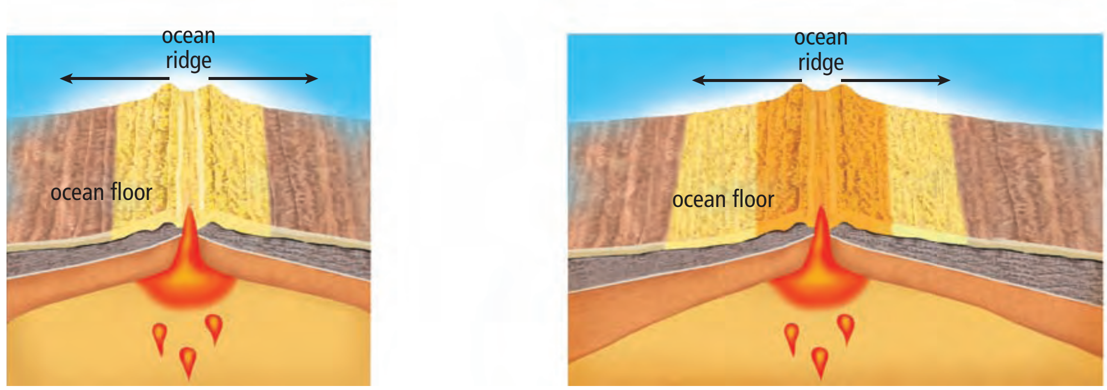


Figure 12.11 Convection currents under Earth's surface may cause magma to rise, which causes the sea floor to spread apart.

Table 12.1 Hess's Evidence for Sea Floor Spreading

1.	Earth is like a large bar magnet and has two poles.
2.	New ocean floor forms when magma from under Earth's surface rises, cools, and hardens at an ocean ridge. New magma pushes older rock away from the ridge.
3.	The magma is molten basalt, a dark rock that is rich in iron. As the basalt cools, it becomes magnetic.
4.	The magnetic minerals in the hardened basalt are like tiny compass needles that align with Earth's magnetic field.
5.	Earth's magnetic poles reverse over hundreds of thousands of years.
6.	Minerals in the basalt keep the alignment they had when the rock cooled. Therefore, some portions of hardened rock will have normal polarity, and others will have reverse polarity.
7.	Rocks with magnetic striping, alternating bands of normal and reverse polarity, surround ocean ridges.
8.	The pattern of magnetic striping is the same in rocks on either side of an ocean ridge.
9.	Ocean sediments are thicker the farther away they are from a ridge. This is because the oldest rock is farthest from the ridge and has had the most time to accumulate sediments.

Figure 12.12 J. Tuzo Wilson was the first person to suggest that the Hawaiian Islands were formed by a tectonic plate passing over a hot spot, where magma rose up from under Earth's surface. As the tectonic plate moved in the direction of the arrow, new islands formed, resulting in a chain of islands.

In the mid-1960s, Canadian geologist J. Tuzo Wilson released a scientific paper that combined the concepts of sea floor spreading and paleomagnetism to explain continental drift. Wilson suggested that chains of volcanic islands, such as the Hawaiian Islands, were formed when a tectonic plate passed over a stationary hot spot (Figure 12.12). A geologic **hot spot** is an area where molten rock rises to Earth's surface. The figure shows a map view of the Hawaiian Islands, which are in a row.

Wilson thought that continents must break up at certain areas, move across Earth's surface, and then rejoin. His hypothesis explained the formation of mountains and ocean basins and the cause of earthquakes and volcanic eruptions. Wilson's hypothesis also gave a reason for the movement of tectonic plates and helped explain the transformation of rocks from one type to another in the rock cycle. Later named the **plate tectonic theory**, it is considered the unifying theory of geology.

Reading Check

1. What is a tectonic plate?
2. What is the Mid-Atlantic Ridge?
3. Describe the orientation of Earth's magnetic field during a period of normal polarity.
4. What is a geologic hot spot?

Explore More

The break-up of Pangaea about 200 million years ago was not the first time tectonic plate movement has rearranged Earth's continents. Geologists believe there were two, or possibly three, supercontinents before Pangaea. Find out how the continents have shifted over time. Start your search at **www.bcscience10.ca.**

12-1B Sea Floor Spreading and Magnetic Striping

Find Out ACTIVITY

Sea floor spreading provides a basis for the process of continental drift. In this activity, you and a partner will analyze the pattern of magnetic stripes on opposite sides of a ridge.

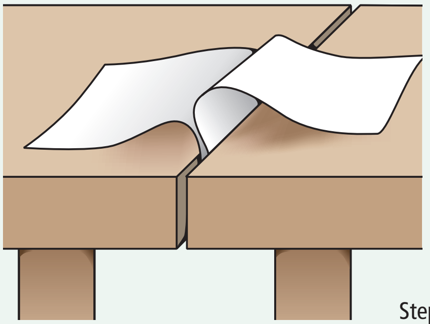
Safety

- Be careful when handling the scissors.

Materials

- 28 cm × 43 cm piece of paper
- scissors
- 2 different colour felt pens or paints
- 2 small tables
- ruler
- calculator (optional)

What to Do



Step 4

1. Fold the sheet of paper in half lengthwise. Cut the sheet along the fold.
2. Put a tick mark on each paper strip every 2 cm. The distance between each tick mark will represent an interval of 1 million years.
3. Push together two small tables, leaving a small (0.5 cm) gap between them. The gap will represent a spreading ridge.
4. Place the two strips of paper with the marked sides together. From underneath the tables, thread the paper strips through the gap. Pull up the paper strips so that about 3 cm of paper is exposed. Bend the paper so that the end of one strip lies flat on the left side of the gap and the other lies flat on the right side of the gap.
5. Have one partner colour across the gap between the tables and onto both pieces of paper. The width of the coloured section of paper should be no more than 3 cm on either side. This colour will be associated with a period of normal polarity.
6. Have the other partner pull the paper strips in opposite directions across each tabletop. Pull the paper strips only a few centimetres at a time. The exposed paper simulates the new ocean floor, which continuously forms at a spreading centre. As new sea floor is formed, older material is pushed away from the ridge.
7. Repeat steps 5 and 6, this time using a different colour. This colour will be associated with a reversal of Earth's magnetic field to reverse polarity.
8. Repeat steps 5 to 7, alternating between the two colours, until you have used the full length of the paper strips. Once finished, leave the papers laid end to end across the gap while you complete the following questions.
9. Clean up and put away the equipment you have used.

What Did You Find Out?

1. (a) Compare the pattern of stripes on the two strips of paper. In this model, how often did magnetic reversals occur?
   (b) What does the pattern of stripes indicate about the direction of the motion of tectonic plates on either side of a ridge?
2. How can you use the striped pattern to measure the rate of sea floor spreading?
3. Rate $= \frac{\text{distance}}{\text{time}}$ In order to calculate the rate of sea floor spreading (that is, the rate at which the plates are moving away from one another), what information would you have to obtain about the sea floor?
4. How convincing do you find magnetic striping to be as evidence for sea floor spreading? Explain.
5. In this activity, you eventually reached the end of the paper strips. Would sea floor spreading end in the same way? Explain.

12-1C Piecing Together Pangaea

Conduct an INVESTIGATION

Inquiry Focus

Skill Check
- Observing
- Predicting
- Communicating
- Modelling

Safety

- Be careful when handling the scissors.

Materials

- photocopy of continents
- scissors
- 21.5 cm × 28 cm sheet of paper
- glue

Science Skills

Go to Science Skill 2 for help with stating an hypothesis.

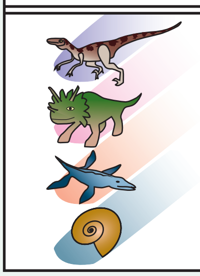
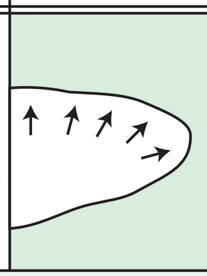
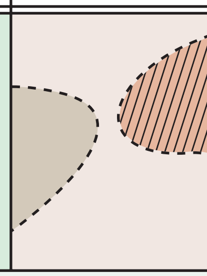
Scientists have used many separate lines of evidence to determine how the continents might once have fit together. In this activity, you, too, will use various pieces of evidence to reconstruct the supercontinent Pangaea.

Question

How did the continents fit together before Pangaea broke apart?

Procedure

1. Obtain a photocopy of the continents from your teacher. Cut out each continent, trimming the pieces just to the edge of the dotted lines. The dotted lines represent the true continental edges, the continental shelves.
2. Use the clues provided in the legend below and the shapes of the continents to help you reconstruct Pangaea. Piece together the continent shapes into a supercontinent on a separate piece of paper, but do not glue them down yet.
3. Once you have assembled your pieces, check with your teacher before gluing them to the blank sheet of paper.
4. Copy the legend below onto the paper with your map of Pangaea.
5. Clean up and put away the materials you have used.

Fossils	Glacial Deposits	Matching Folded Mountains	Coal Deposits
			

Analyze

1. Which continents were easiest to fit together? Explain why.
2. Of the pieces of the evidence that you used to reconstruct Pangaea, which provided the best clues as to how the continents were once joined? Justify your answer.
3. (a) Were there any pieces of Pangaea that you found difficult to place?
   (b) If so, what other evidence would have helped you to place these pieces?

Conclude and Apply

1. (a) In a few sentences, summarize the steps you took to reconstruct Pangaea.
   (b) How was the process you took similar to the methods Alfred Wegener used to support the continental drift theory?
2. Why did you use several pieces of evidence to reconstruct Pangaea, not just one?
3. (a) Hypothesize where the continents might be situated in 200 million years.
   (b) Describe how ecosystems of British Columbia's west coast might change as a result. Justify your answers.

Science Watch

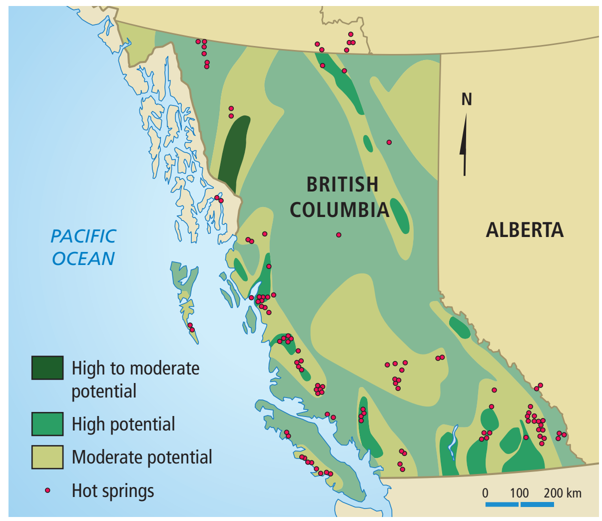
Extracting Earth's Energy

One day, energy from underground may heat, cool, and provide electrical power to homes across British Columbia. With increasing awareness of the environmental impact of fossil-fuel use, more people are looking for cost-effective alternative energy sources. One of the more promising sources is geothermal energy—thermal energy from Earth's core.

In some areas, molten rock just below Earth's surface heats underground water. This natural process, which occurs at the boundaries between tectonic plates, produces hot springs and steamy spurts of water known as geysers at Earth's surface. The steam can be used to turn turbines in order to generate electrical power. In Iceland, where there are many geysers, geothermal power plants are common. The first geothermal power plant in Canada is the South Meager Geothermal Project near Pemberton, British Columbia, where geologists have found a magma chamber not far underground.

Geothermal power plant in Iceland

Geothermal energy can also be used for heating and cooling buildings. Unlike most heating systems, which burn fuel in order to heat air, geothermal heat pumps transfer hot water from place to place. In order to heat a building, water is sent through pipes underground. Thermal energy from under Earth's surface heats the water, which is pumped back above ground. The hot water releases thermal energy, which warms the building. In order to cool a building in summer, the geothermal heat pump works in reverse. Warm water from inside the building is sent through pipes to the outside where the ground is relatively cool. Thermal energy is transferred from the water to the ground, and the cooled water is pumped back to the building.



Sources of geothermal energy in British Columbia

Geothermal heat pumps are inexpensive to operate, non-polluting, and use renewable energy. Like geothermal power plants, geothermal heat pumps are gaining popularity with developers in British Columbia. Some researchers suggest these methods could meet about 50 percent of the province's energy needs.

Questions

1. What is geothermal energy?
2. What are two ways in which people can use geothermal energy?
3. List three benefits of using geothermal energy.

Checking Concepts

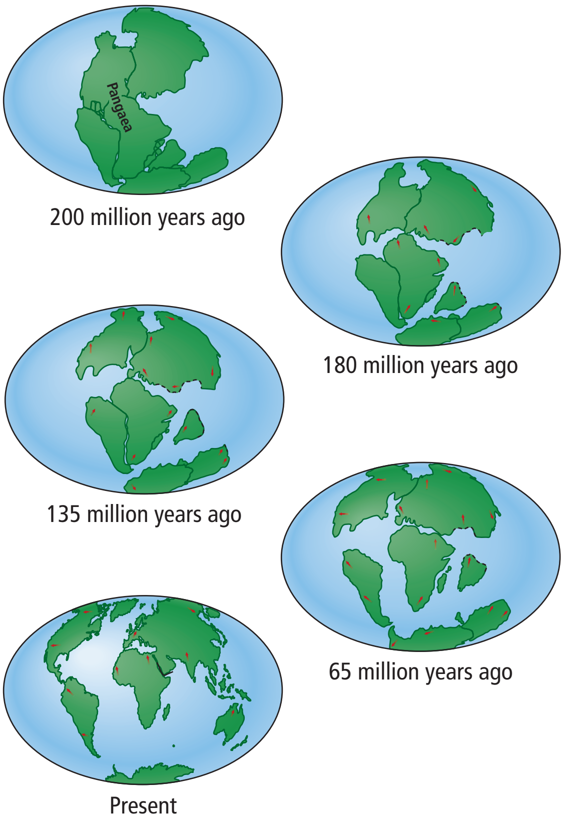
1. What is a supercontinent?
2. List three pieces of evidence that indicate that continental drift occurred in the distant past.
3. Briefly describe two pieces of evidence that suggest that Antarctica was once located farther from the South Pole than it is today.
4. What is sea floor spreading?
5. What is the relationship between continental drift and earthquakes?
6. Describe the theory of plate tectonics in your own words.

Understanding Key Ideas

7. Coal deposits form when plant matter sinks under water, begins to decompose, and is compressed. Explain how the presence of coal deposits in Siberia, northern Canada, and the Antarctic support the continental drift theory.
8. Despite the evidence Wegener found to support the continental drift theory, the scientific community of his day thought the idea of moving continents was ridiculous. What crucial question could Wegener *not* answer that might have changed other scientists' minds?
9. Why does the thickness of ocean floor sediments increase the farther they are from a ridge?
10. How does sea floor spreading explain the movement of tectonic plates?
11. Suppose a geologist is studying two distinct areas next to a spreading ridge. The magnetic direction of the minerals in the oldest area is opposite to the magnetic direction of minerals in the newest area.
    (a) Which area is closest to the centre of the ridge, the older or newer area? Explain.
    (b) What can the geologist conclude about Earth's magnetic field during the time when the two areas formed?
12. In a few sentences, explain how information from paleoglaciation and paleomagnetism support the idea that continental plates have moved over the past several million years.

Pause and Reflect

A marsupial is a type of mammal that carries its undeveloped young in an abdominal pouch. Scientists believe that many kinds of marsupials once lived throughout the world. Today, however, many marsupials are found only in Australia. How does the continental drift theory explain the modern distribution of marsupials? Use the diagram shown here to help you answer this question.



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.

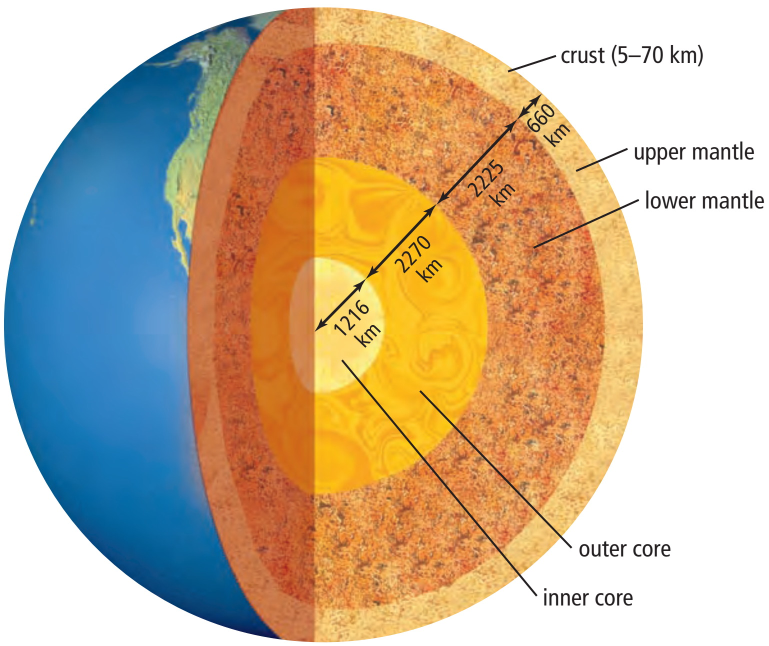


Figure 12.13 A cross-section of Earth

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.

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?

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).

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!

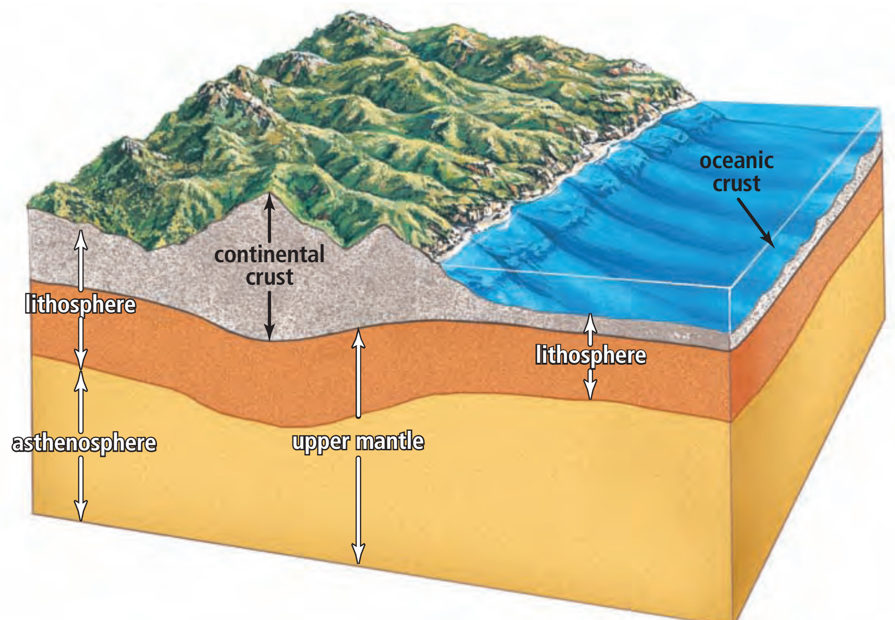


Figure 12.14 A cross-section through Earth's surface

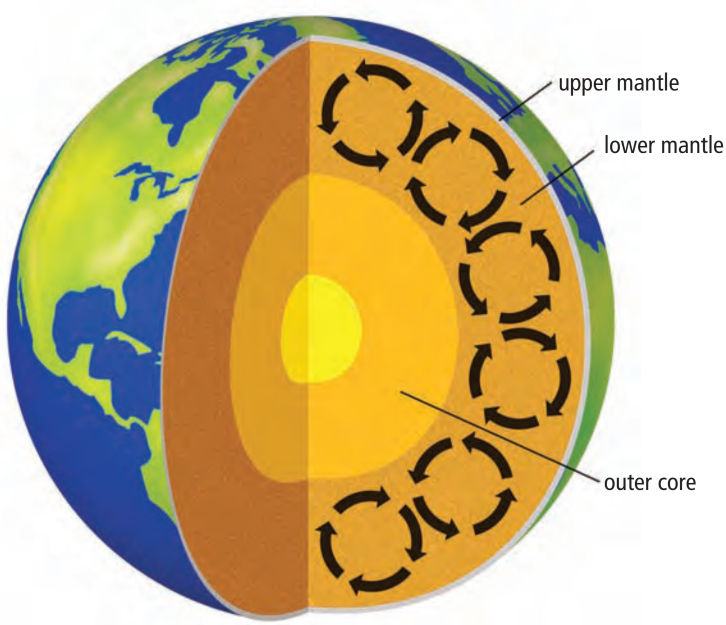


Figure 12.15 Convection currents in Earth's mantle circulate heat and magma.

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.

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.

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 of the coast of Japan, visit **www.bcscience10.ca** and follow the links.

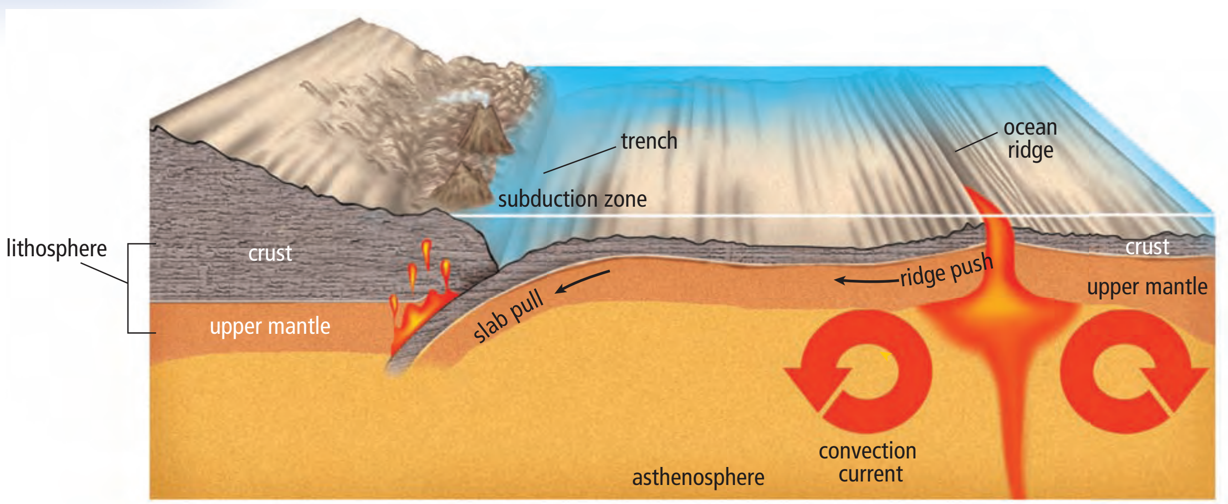


Figure 12.16 Thermal energy from inside Earth, gravity, and tectonic plate interactions affect the movement of tectonic plates.

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

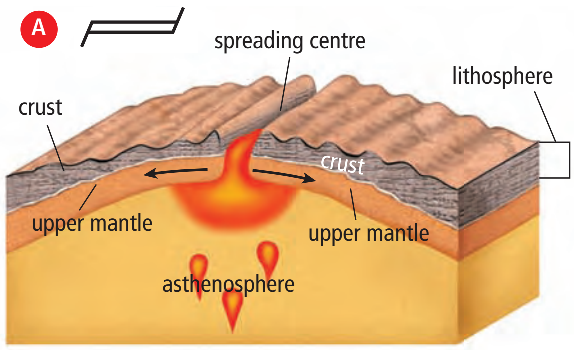


Figure 12.18 A spreading centre at a divergent plate boundary (A). The East African Rift (B)

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.

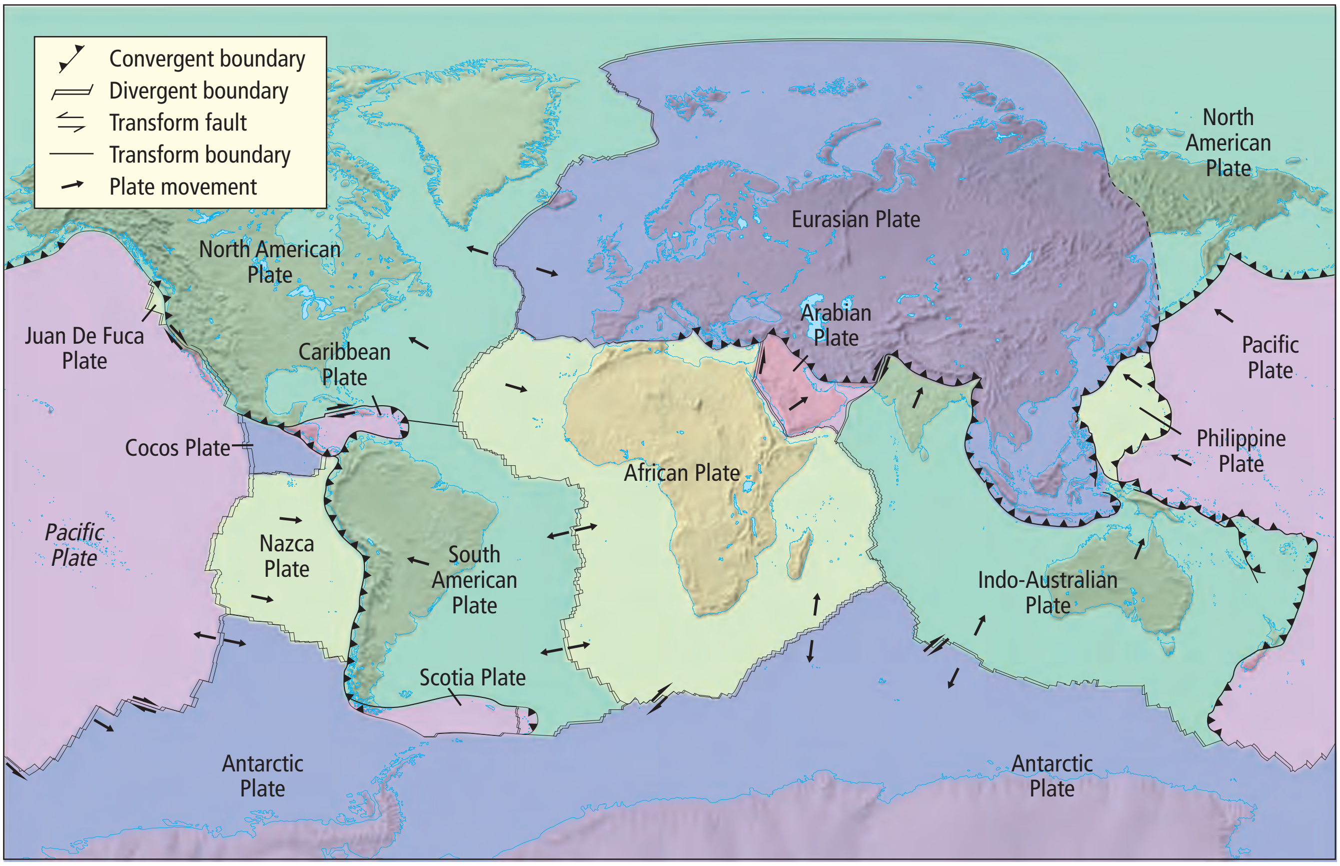


Figure 12.17 Tectonic plate boundaries

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.

Did You Know?

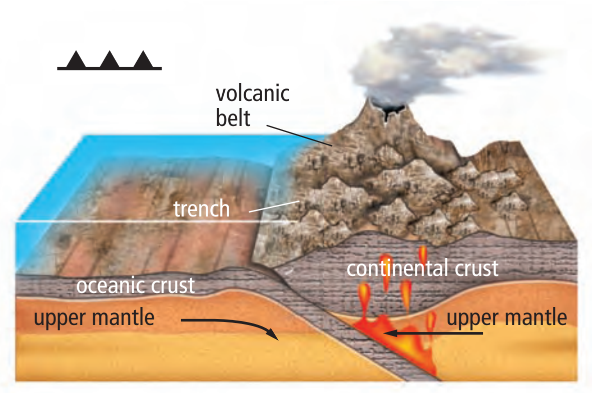
On December 26, 2004, an extremely large earthquake occurred in the Sumatra area of Indonesia. The high-energy earthquake generated a large sea wave, or tsunami, that killed over 200 000 people.

Oceanic-oceanic plate convergence

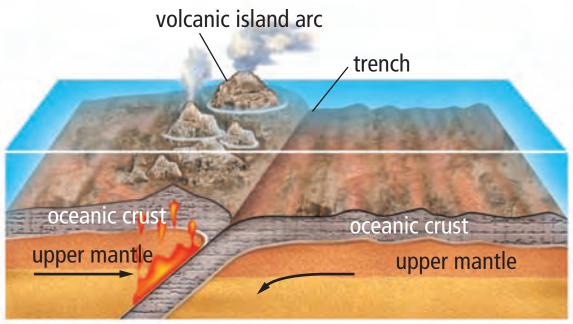
Subduction also occurs where two oceanic plates converge (collide). Cooling will cause one plate to be denser than the other, and the denser plate will slide deep into the mantle. In this case, convergence may produce a long chain of volcanic islands known as a **volcanic island arc** (Figure 12.19B). 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

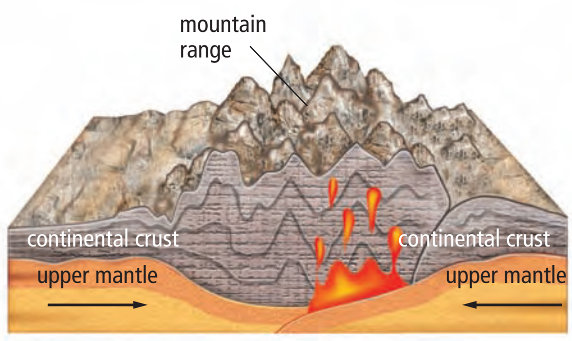
When continental plates collide, subduction does not occur since the plates' similar densities prevent either one from being forced into the mantle (Figure 12.19C). As the massive rocky plates slowly collide, their edges fold and crumple, forming great mountain ranges. The youngest and highest mountain 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.



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 faul**t. 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.

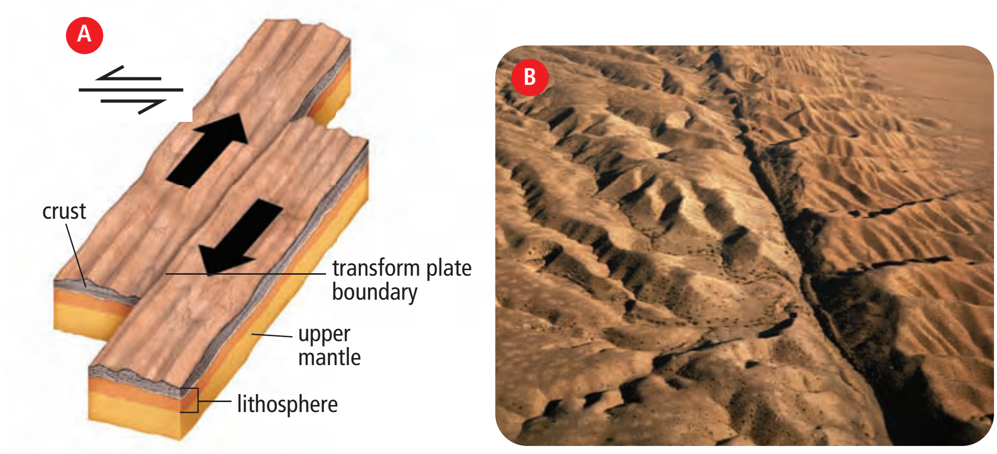


Figure 12.20 Transform faults can occur when tectonic plates move alongside one another (A). The San Andreas Fault is in the United States (B).

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.

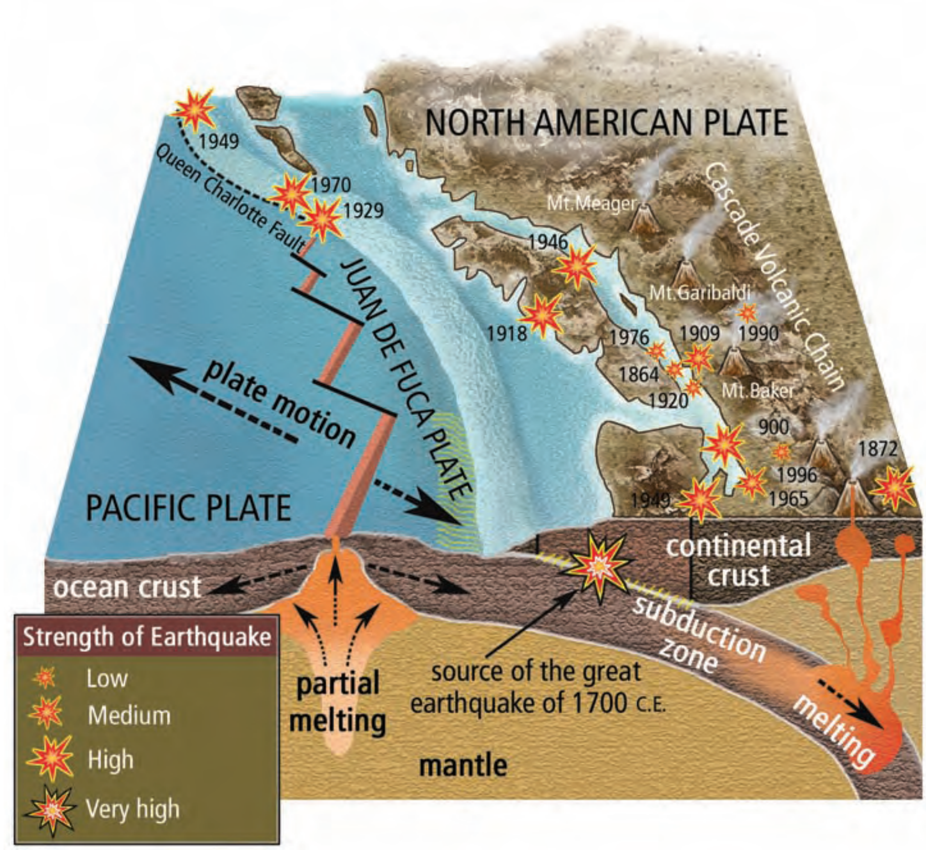


Figure 12.21 British Columbia sits near the boundary of the North American and Juan de Fuca Plates, an area where large earthquakes can occur.

Describing earthquakes

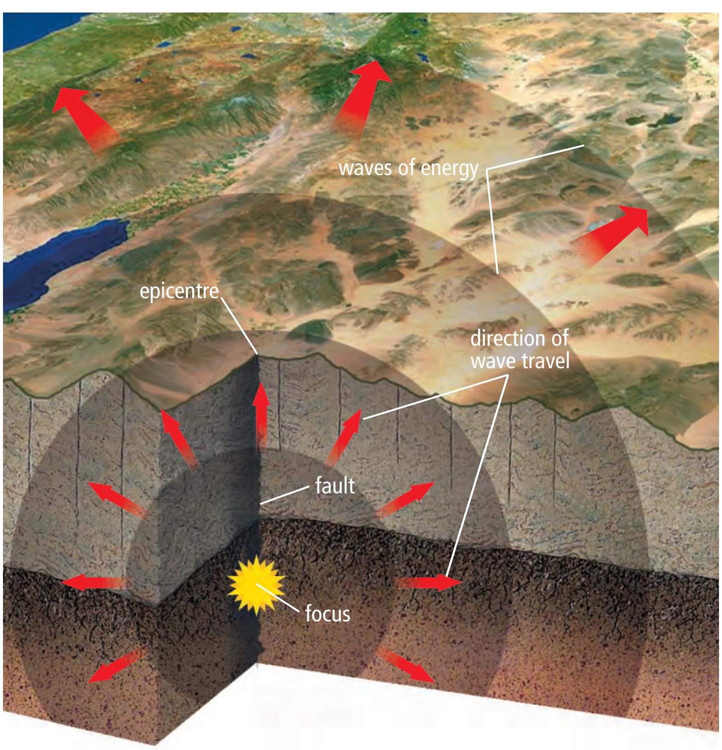
Because every earthquake involves a unique set of forces and geological structures, it is very difficult to accurately predict the timing, size, and location of a particular earthquake. Furthermore, the events leading to earthquakes occur over time periods that dwarf a human lifespan. However, the plate 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.

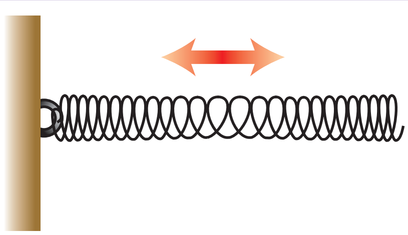
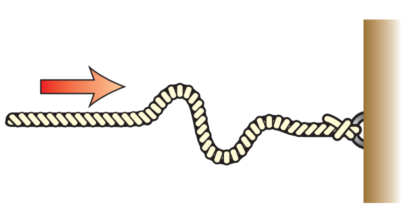
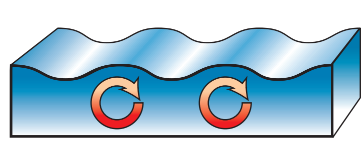
Seismic waves can be either body waves, which travel underground, or **surface waves** (**L-waves**), which roll along Earth's surface much like ripples in a pond. Body waves travel faster than surface waves and are usually the first energy waves felt after an earthquake.

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	• 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	• 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	• 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.

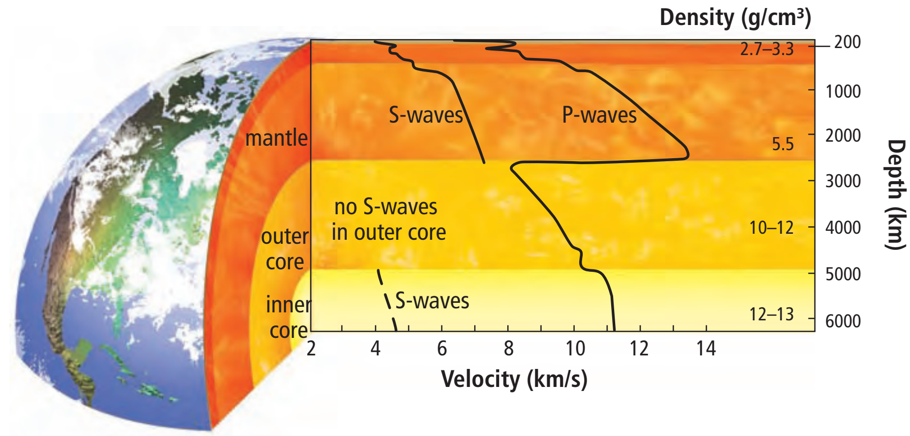
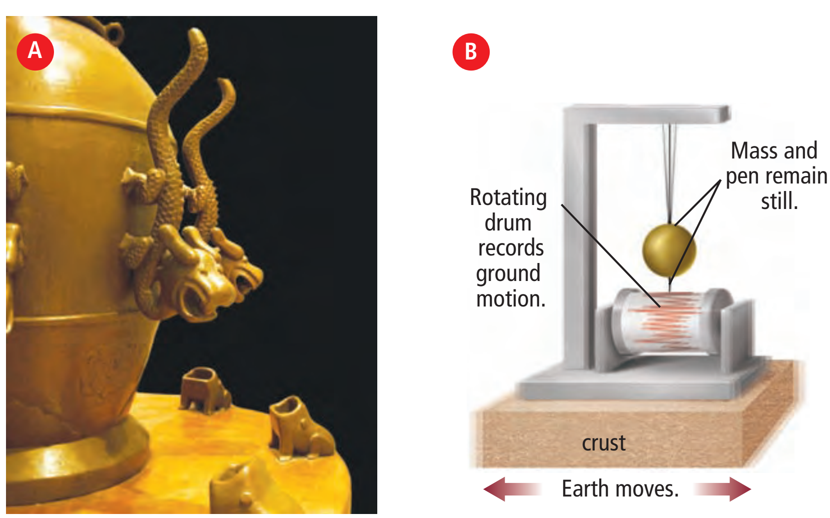


Figure 12.23 The path of seismic waves. P-waves and S-waves travel underground and are affected by the density of the material they travel through. Because L-waves travel along Earth's surface, they move more slowly than P-waves and S-waves.

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.

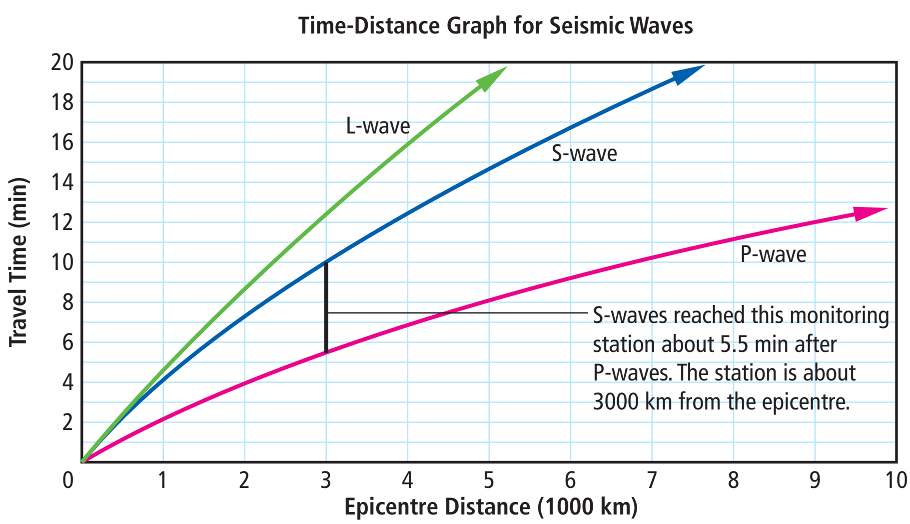


Figure 12.25 A time-distance graph shows how long it takes for different seismic waves to travel a certain distance.

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?

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.

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

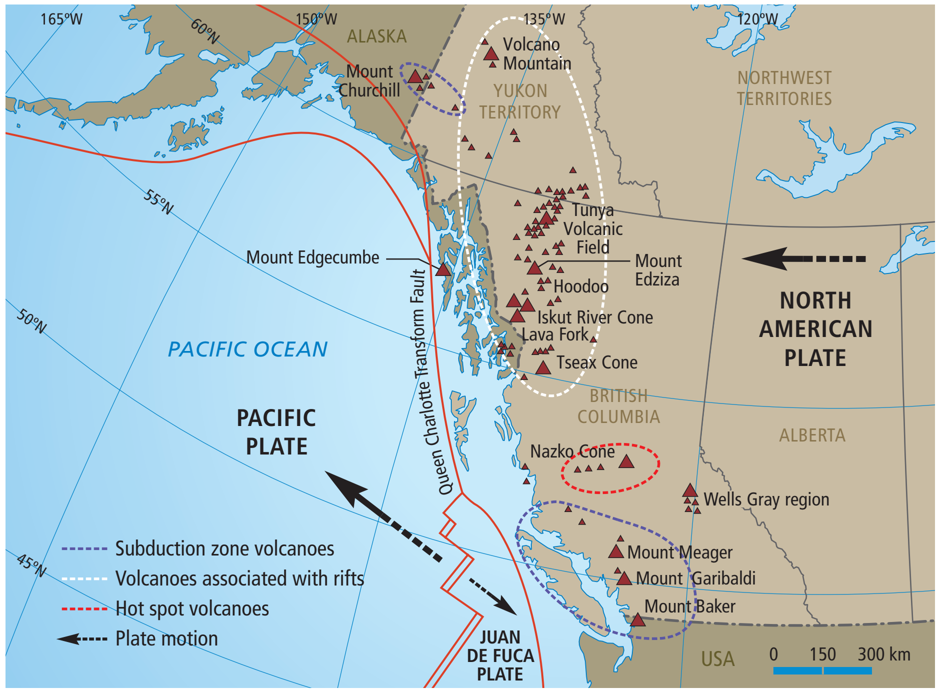


Figure 12.26 Volcanoes in and near British Columbia

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.

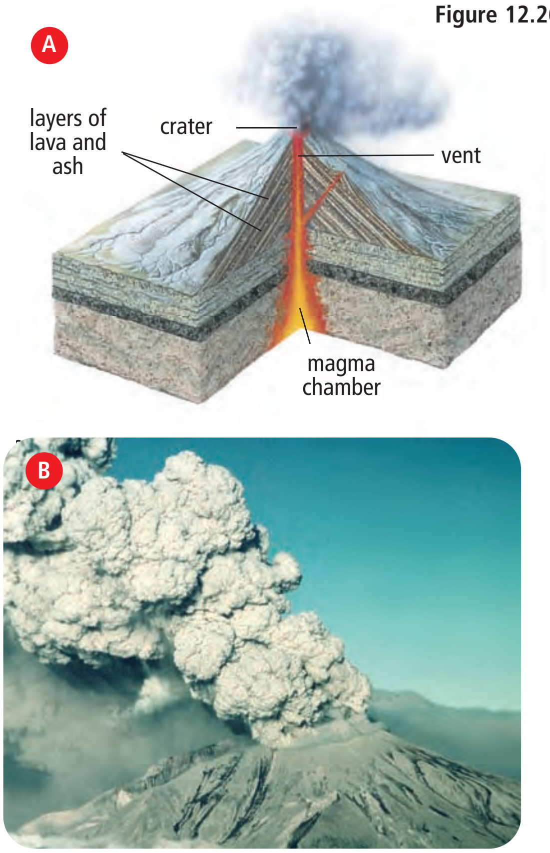


Figure 12.27 A composite volcano (A). Mount St. Helens, Washington (B).

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 km^2 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.

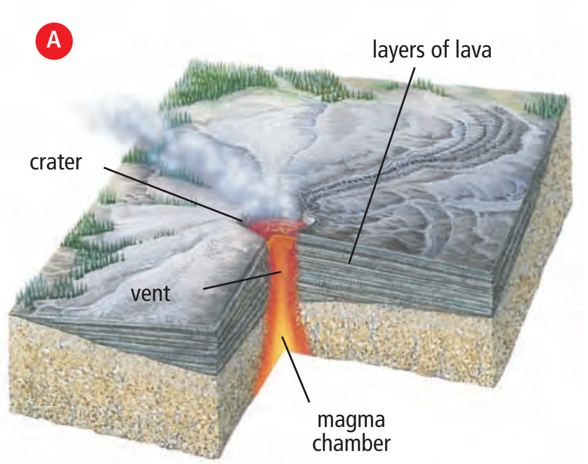


Figure 12.28 A shield volcano (A). Yellowstone National Park lies over a hot spot. The most recent volcanic eruption in the area occurred about 70 000 years ago (B).

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.bcscience10.ca.**

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.

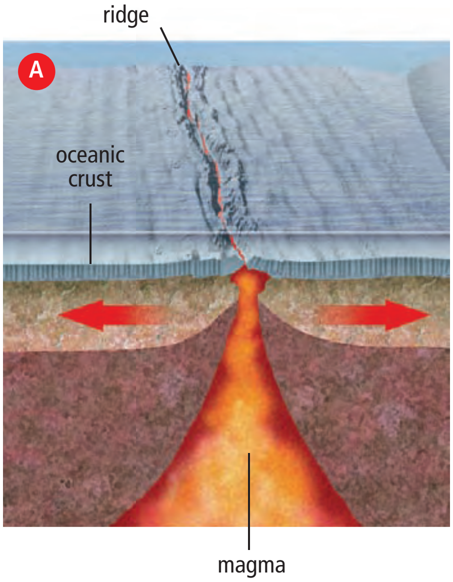


Figure 12.29 Ridges are due to rift eruptions under the ocean (A). The Krafla volcano, northern Iceland (B). Iceland is an island that is part of the Mid-Atlantic Ridge.

12-2C Interpreting Seismograms

Think About It

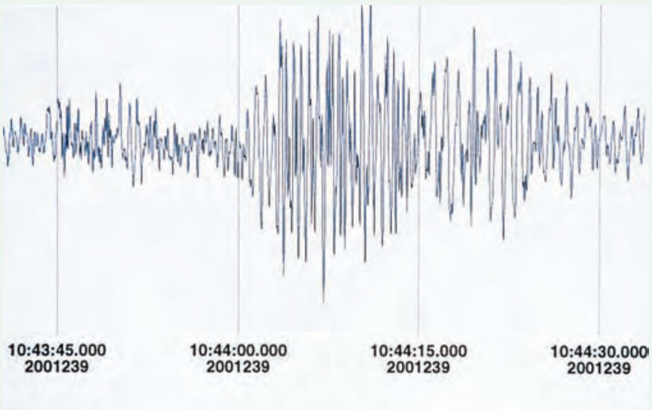
Seismograms are graphs that show the arrival times and sizes of seismic waves. The height of the peaks and the depth of the valleys in the graph correspond with the energy of the seismic waves. In this activity, you will interpret a seismogram in order to track the timing and strength of an earthquake.

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

12-2D Volcanism and Plate Tectonics

Teacher Demonstration

SkillCheck

- 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

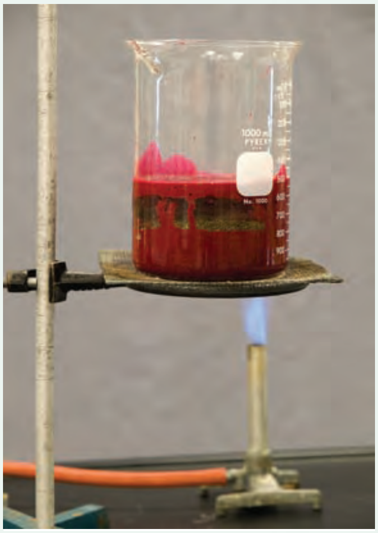
Science Skills

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.

Career Connect

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

1. List four things Catherine Hickson does as a research scientist.
2. Why is age dating important to a community planning for natural disasters?
3. 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.

Chapter 12

Chapter Review

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:

1. Continental Drift Theory
2. Plate Tectonics
3. Plate Boundaries
4. Volcanoes
5. Earthquakes

Checking Concepts

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

Understanding Key Ideas

12. 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?
13. Match the mapping symbols given below with the correct tectonic plate boundaries.

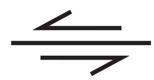
A

Transform plate boundary ______

B

Convergent plate boundary ______

C



Divergent plate boundary ______

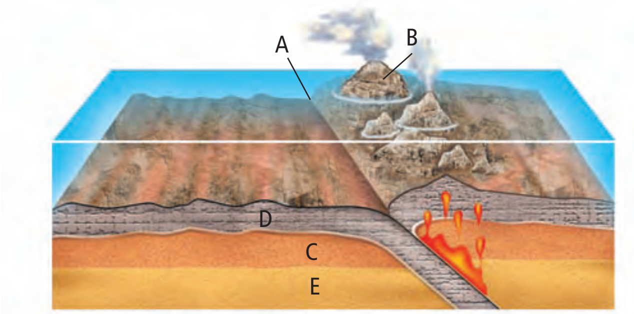
14. Volcanoes do not usually form at continental-continental plate boundaries or transform plate boundaries. Why not?
15. How does the pattern of mountain ranges on different continents provide evidence for continental drift?
16. Describe what might happen if mantle convection suddenly stopped.
17. How 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?

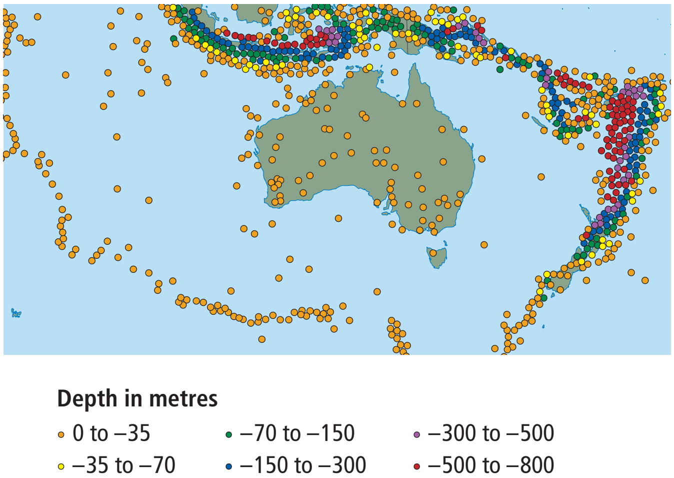
21. Label the features on the tectonic plate boundary shown below.



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.



(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?