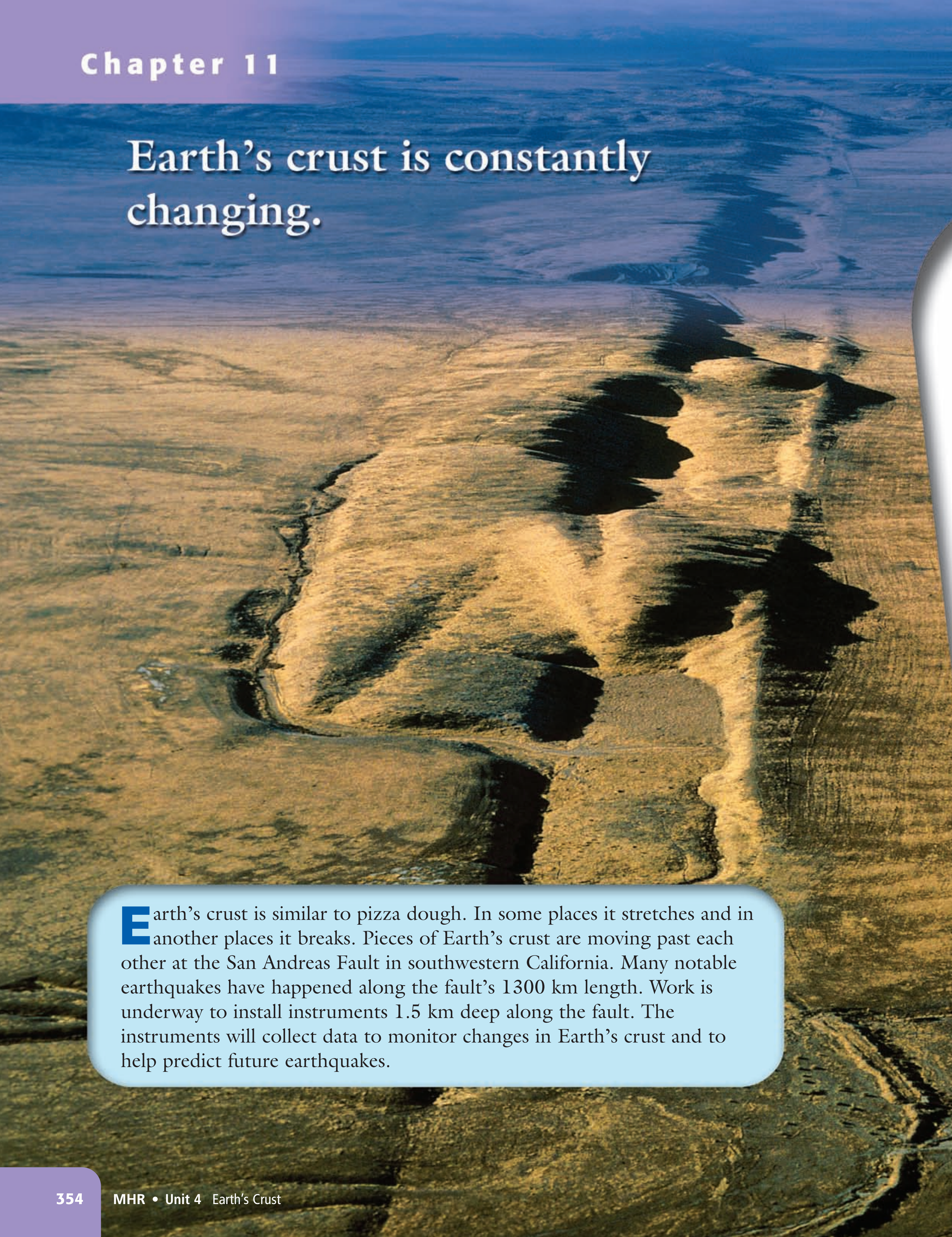
Chapter 11

Earth's crust is constantly changing.



Earth's crust is similar to pizza dough. In some places it stretches and in another places it breaks. Pieces of Earth's crust are moving past each other at the San Andreas Fault in southwestern California. Many notable earthquakes have happened along the fault's 1300 km length. Work is underway to install instruments 1.5 km deep along the fault. The instruments will collect data to monitor changes in Earth's crust and to help predict future earthquakes.

What You Will Learn

In this chapter, you will
- **describe** the structure of Earth
- **identify** evidence to support the theory of plate tectonics
- **explain** why earthquakes and volcanoes occur and how mountains are formed
- **describe** the geologic time scale

Why It Is Important

Understanding how Earth's crust moves can help prevent many disasters. If we know where and when an earthquake might happen or a volcano might erupt, we can save lives and reduce damage and destruction.

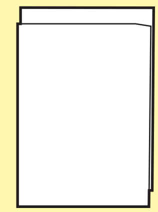
Skills You Will Use

In this chapter you will
- **model** the structure of Earth
- **evaluate** evidence of the movement of continents
- **classify** patterns in earthquake and volcano locations
- **communicate** how people in the past explained volcanoes and earthquakes
- **explain** mountain building systems

FOLDABLES™ Reading & Study Skills

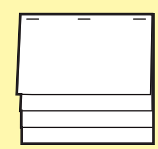
Make the following Foldable to take notes on what you will learn in Chapter 11.

STEP 1 **Stack** two sheets of 8.5″ × 11″ paper so that the back sheet is 2 to 3 cm higher than the front sheet. (**Hint:** From the tip of your index finger to your first knuckle is about 2.5 cm.)

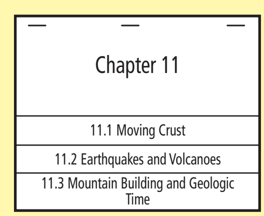


STEP 2 **Bring** the bottom of both sheets upward and **align** the edges so that all of the layers or tabs are the same distance apart. **Fold** the paper and **crease** well.

STEP 3 **Staple** the papers along the fold.



STEP 4 **Label** the Foldable with the chapter title on the top section and the three lesson titles on the small tabs as shown.



Organize Take notes and define lesson terms under each tab as you learn new information throughout the chapter.

11.1 A Moving, Changing Crust

Earth's crust is made up of a series of crustal plates that are always moving. Early theories suggested that only the continents move, but it is now known that the crust under the ocean moves as well. Our knowledge of the moving crust is based on evidence from the continents, including fossils, rocks, climate change, and the shape of the continents. We also have obtained evidence of moving crust from the sea floor by using sonar, magnetometers, and deep-sea drilling. Convection currents beneath the plates may be the cause of the movement of the crust.

Key Terms

continental drift
convection currents
convergent boundary
crust
divergent boundary
inner core
magnetometer
mantle
outer core
pangaea
plate tectonics
sonar
subduction zones
transform boundary

Word Connect

Geo- is from a Greek word meaning "Earth." A geologist studies the rocks on Earth's crust. A geographer may study how climate affects Earth's crust. A geochemist studies the chemical elements that are found in Earth's crust. A geophysicist studies the interactions between matter and energy that produce Earth's features.

Imagine that you are a geologist. You study the rocks and minerals found near Earth's surface and find valuable deposits of metals, gems, oil, and coal. One of your jobs is to learn about the rock layers below Earth's surface. You use a drill to obtain a core sample, which is a long, cylindrical sample of rock.

The deepest hole that has been drilled into Earth's crust is about 12 km deep and took about 20 years to drill. The centre of Earth is about 6000 km below Earth's surface. No one has ever seen the inner layers of Earth, and no tools are yet able to be sent that deep. How can you find out what all those other layers are like?

The Structure of Earth

What is deep inside Earth? Scientists have many answers to this question, but there are still mysteries waiting to be solved. Since we cannot observe Earth's inner layers directly, we can use clues from earthquake waves and satellite images to predict what the layers of Earth might be like. Clues about something that cannot be seen directly are called *indirect evidence*.

We can also use *direct evidence* to learn about Earth's inner layers. Geologists obtain direct evidence by studying rock samples from volcanoes, from mountain ranges, and from deep within the sea floor. Perhaps, during your lifetime, scientists will develop a technology for collecting direct evidence from even deeper inside Earth.

11-1A Examine the Evidence

Find Out ACTIVITY

How well can you describe something you cannot see? In this activity, you will work with group members to infer the identity of something that is out of sight.

Materials

- sealed containers provided by your teacher

What to Do

1. Your teacher will give your group several containers. Each container will have a marble inside it. Some containers will have another substance as well. Examine the containers. Without looking inside, try to figure out the contents.
2. As a group, make a table to record your observations. Record what you think is inside each container. Describe the evidence you used to make your decisions.
3. Discuss your observations and decisions with the other groups. Discuss: How is this activity similar to how scientists determine what is deep inside Earth? How is this activity different?

What Did You Find Out?

1. Which were the easiest contents to identify? Why?
2. Which were the most difficult contents to identify? Why?
3. Which evidence was confusing or misleading? (For example, the contents sounded like one item but were actually something else.)

A Model of Earth

Scientists have used direct and indirect evidence to make a model of Earth's structure. Figure 11.1 on the next page is a model of the four main layers of Earth: the crust, the mantle, the outer core, and the inner core.

Some layers of Earth are solid and some are liquid. Why do you think the layers are different states? In Earth's crust and the upper mantle, temperatures are cool enough for iron and nickel to be in the solid state. In the lower mantle and outer core, temperatures are so high that iron and nickel are in the liquid state. In the inner core of our planet there is such enormous pressure that the very hot iron and nickel are compressed into the solid state.

Did You Know?

Vibrations travel at different speeds through different kinds of matter. Scientists study vibrations from earthquakes to help determine the type and state of matter in Earth's inner layers.

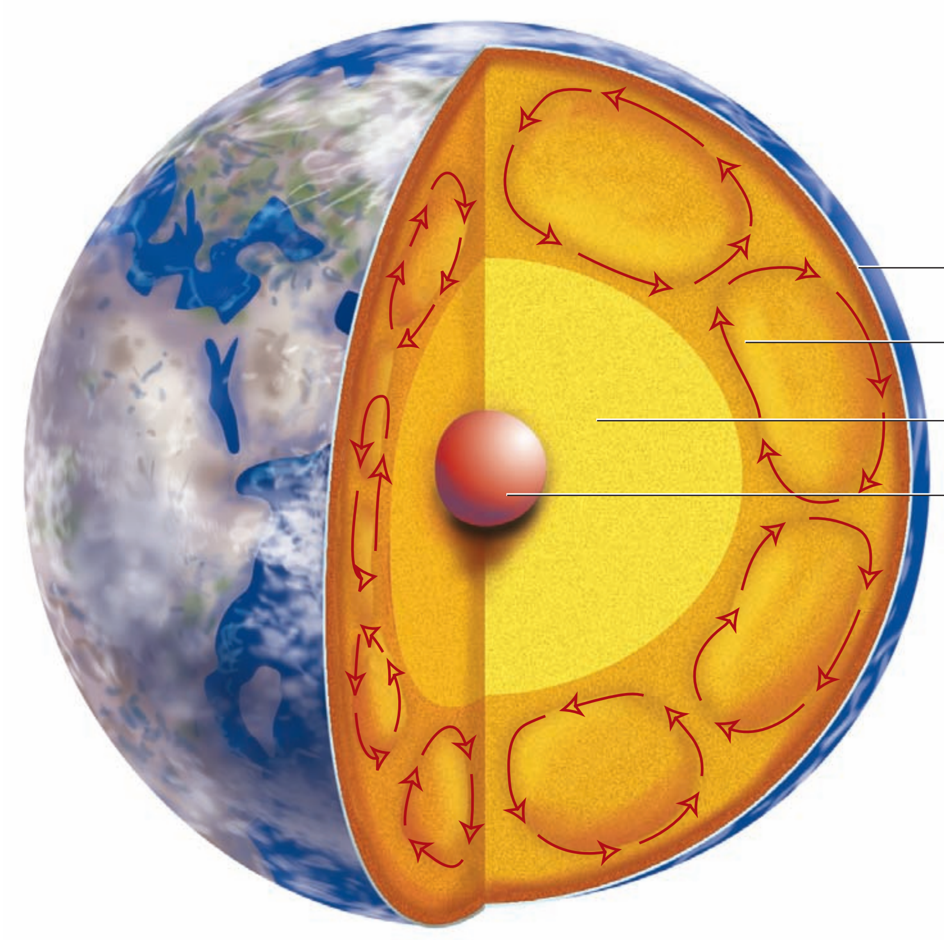


Figure 11.1 A model of Earth

Inner Core

The **inner core** is the deepest and hottest layer of Earth. Many scientists believe the inner core is made of iron and nickel, and possibly other elements, such as silicon and carbon.

Outer Core

The **outer core** is probably made of liquid iron and nickel. Sulphur and oxygen could also be present. The outer core is so hot that the iron and nickel are melted.

Mantle

The **mantle** is the largest and most complex layer of Earth. Most of the upper part is solid rock, made from minerals rich in iron, magnesium, silicon, and oxygen. In the lower part of the mantle the temperature is so high that the rock is partly melted. Scientists picture the rock in the lower mantle as being plastic-like, similar to taffy or caramel.

internet connect

Scientists have discovered an area on the seafloor where the mantle is exposed without a covering of crust. They have sent a submersible to take photographs of the area and drill into the olivine rock found there. You can find out more about the expedition. Begin your search at **www.discoveringscience.ca**.

Crust

On the outside of Earth is a thin layer of solid rock called the **crust.** The crust is where valuable rock and mineral resources are found. The depth of the crust varies from less than 5 km to about 70 km thick. Earth's crust is thinner under the oceans (the oceanic crust) and thicker under the continents (the continental crust). The oceanic crust is mostly made of basalt. The continental crust is mostly made of granite. The crust is broken up into pieces, called plates, which "float" on Earth's mantle and are always moving.

11-1B A Model Planet

Think About It

In what ways is Earth like an apple? The seed core of the apple could represent Earth's outer and inner core. The thin skin of the apple could represent Earth's thin crust. In this activity, you will make or choose a model to represent the structure of Earth.

What to Do

1. Make a model of Earth or find something that you can use as a model. Your model should show the four main layers and show that the crust is broken into pieces.
2. Present your model to the class. Explain how your model represents Earth's layers.

What Did You Find Out?

1. How did you choose the model?
2. How could you make a better model of Earth's layers?
3. How did making and using models help you understand Earth's layers?

Reading Check

1. What are the four main layers of Earth?
2. What are the two types of crust?
3. Why is the inner core of Earth solid?
4. In which layer is the rock plastic-like?

Earth's Moving Crust

Why does Earth's crust move? Scientists have been investigating this question for many years. One scientist who searched for answers was a German meteorologist named Alfred Wegener (1880–1930). A meteorologist is a scientist who studies weather and climate. Like other scientists before him, Wegener noticed something interesting about the shapes of the continents. Look ahead to the map in Figure 11.3. If you cut out the continents from a map, they almost fit together like puzzle pieces. Can you see where the bulge of South America could fit into the indented side of Africa? Are there other continents that might fit together?

Paleogeographic Evidence—Shape of Continents

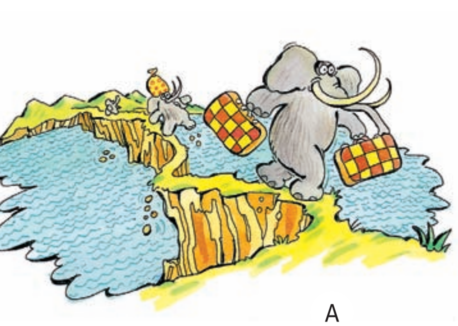
Alfred Wegener thought that the fit of the continents was more than just a coincidence. He suggested that all the continents were joined together in a huge land mass called **Pangaea** (pan-JEE-uh), which means "all lands." He suggested that Pangaea broke apart about 200 million years ago, as shown in Figure 11.2.

Figure 11.2 Pangaea. Try to name the seven biggest land masses on the map. Can you find India? (Hint: It is not yet connected to Asia).

Wegener proposed the **theory of continental drift,** which suggests that the continents change position very slowly, moving over the surface of Earth a few centimetres every year. Wegener could not explain *how* the continents moved, but he collected as much data as he could to support his theory.

The paleogeographic evidence showing that the continents appeared to fit together was Wegener's earliest clue. This led him to look for more information to support his theory. He collected evidence from fossils and rocks. He also studied clues about climate change to try to persuade the scientific world that his theory was valid.

Biological Evidence—Fossils



A

B

Alfred Wegener wondered why fossils of the same animals were found on different continents (Figure 11.3). For example, some fossils found in the Avalon Peninsula in Newfoundland are very similar to those found in Wales. The country of Wales is located 4000 km across the Atlantic Ocean from Newfoundland and Labrador. Many scientists of Wegener's time thought that perhaps there had been a land bridge that has now disappeared, that used to join the continents together (cartoon A). Wegner thought that this fossil evidence helped to support his theory of continental drift (cartoon B).

Figure 11.3 The map above shows the locations of fossils that have been found on many different continents.

Mesosaurus lived in and around fresh water, not salt water as is found in the ocean. Lystrosaurus was not able to swim at all. Glossopteris plants grew in tropical areas, but its fossils have been found in Antarctica, which is very cold and covered with thick ice. What possible reasons can you think of to explain how fossils of these three species have been found on different continents?

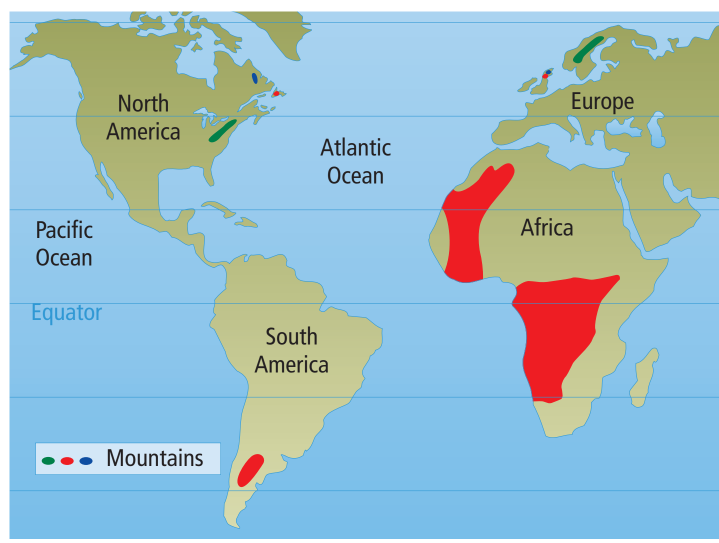


Figure 11.4 How could mountains formed from the same type of rock occur thousands of kilometres from each other across an ocean?

Geological Evidence—Rocks and Rock Layers

Wegener examined the findings of other scientists to see if there might be more evidence to support his idea of continental movement. He discovered that geologists had found similarities in rocks on both sides of the Atlantic Ocean (Figure 11.4). For example, the Appalachian mountain range in eastern North America is made of the same kind of rock as the mountain range that runs through Britain and Norway. The ages of rock in eastern North America and in Britain and Norway are the same as well.

To Wegener, this was additional evidence in support of his theory of continental drift. These rocks look as though they had been formed and pushed up into mountains together, but were now separated by the Atlantic Ocean.

Meteorological Evidence—Climate Change

More evidence came from the location of coal beds. In order for coal to form, there has to be rich, luxurious plant life in a tropical, swampy environment. When the plants die and are compressed under many layers of sediment, coal is formed. However, coal beds are found in places that now have moderate to cold climates, such as in Canada, Europe, and Antarctica. How did tropical plants ever grow in Antarctica? Was the climate once different there, or had Antarctica moved to its present cold location from a place nearer the equator?

Wegener also noted that some places that have warm climates now, such as Africa, India, and Australia, have evidence that they were once partly covered by glaciers. Was the whole world once cold, or had these land masses moved to their present warm locations from a place near the South Pole?

Figure 11.5 This is the last known photograph of Alfred Wegener (on the left) taken as he prepared to cross Greenland.

Rejection of Wegener's Ideas

To support his hypothesis about drifting continents, Wegener thought about what forces might be causing the movement. He proposed that the Moon might be responsible for continental movement, just as it influenced tidal movement. Other scientists disagreed with him. Because Wegener could not satisfactorily explain the origin of the force that was moving the continents, the scientific community rejected his ideas on continental drift. The fixed-continent model continued to be the most widely supported idea. Wegener died in Greenland in 1930, still searching for evidence to support his theory of continental drift (Figure 11.5).

Reading Check

1. What is Pangaea?
2. What theory did Wegener propose?
3. What four types of evidence did Wegener use to support his theory?
4. What could Wegener not satisfactorily explain about continental drift?

11-1C Pangaea Puzzle

Think About It

Most scientists now support the idea of continents moving. In Wegener's time, however, most scientists disagreed with his theory. In this activity, you will evaluate the evidence for continental drift. Imagine that you are part of a scientific panel in Wegener's time. Would you agree or disagree with his theory?

Safety

- Take care using scissors.

Materials

- world map with continental shelf boundaries
- blue paper
- coloured pencils
- scissors
- glue

What to Do

1. Examine Figure 11.3. Draw the three fossils from Figure 11.3 on your world map. Put a legend on your map showing the name and a picture of each of the three fossils.
2. Find other fossil evidence from other sources, such as the Internet, a CD ROM, or books from your library. (Hint: look for *Cynognathus*.)
3. Examine Figure 11.4. Add the three types of rock evidence to your map. Use a different bright colour for each type of rock evidence. Do not cover up your fossil evidence.
4. Label each of the seven continents.
5. Cut out the continents on the world map, around the edges of the continental shelves. Cut India away from Asia along the Himalayan Mountains.
6. Fit the pieces of the world map together to make Pangaea. Once the pieces are in place, glue them to the sheet of blue paper.
7. Transfer the legend to the blue paper by cutting it out or copying it.

What Did You Find Out?

1. What difficulties, if any, did you experience in fitting the pieces of land together?
2. (a) Which pieces were the hardest to fit together?

   (b) How might these pieces have looked 300 million years ago?

   (c) How could you test your ideas?
3. (a) Why was Wegener's theory of continental drift a reasonable theory?

   (b) Why did it make sense at the time?
4. (a) As a young child, what ideas did you have that you had to change as your knowledge increased?

   (b) Was it easy or hard for you to give up your old ideas?

   (c) How might your experience be compared to the experience of scientists?

Evidence from the Sea Floor

The evidence Wegener used to support the idea of continental drift was evidence that had been collected from the continents. In the 1940s, new technology became available that allowed scientists to gather evidence from the sea floor. Three new technologies provided a more detailed picture of the interior of Earth.

- **Sonar** is a sound wave technology that sends out sound waves and then records the time that the sound waves take to bounce back. The sound waves can be sent from a ship and reflected off the sea floor as shown in Figure 11.6. The longer the sound waves take to return to the ship, the deeper the water is. Sonar is used to map the depth and features of the sea floor.

When many sonar tests from Earth's oceans were studied, there was a surprising discovery. It was observed that many features found on the sea floor were similar to features found on land. In fact, there were mountains on the sea floor (Figure 11.7 on the next page).

There were long mountain ranges or ridges in some places, just like the mountain ranges that existed on land. Scientists identified a mountain ridge that stretched north to south along the middle of the Atlantic Ocean. They called this ridge the Mid-Atlantic Ridge. What was causing these mountains to form? The answer would come from another technology: magnetometers.

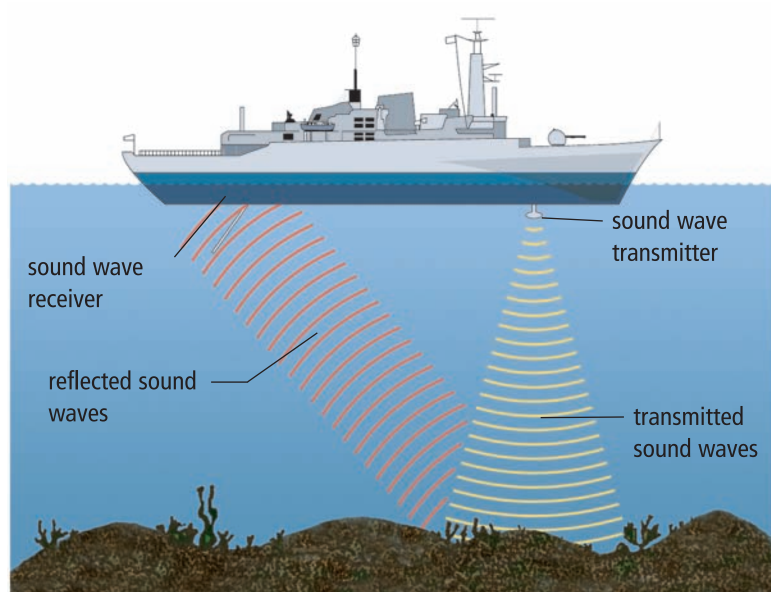


Figure 11.6 Sonar revealed that the sea floor was not flat, as was previously believed.

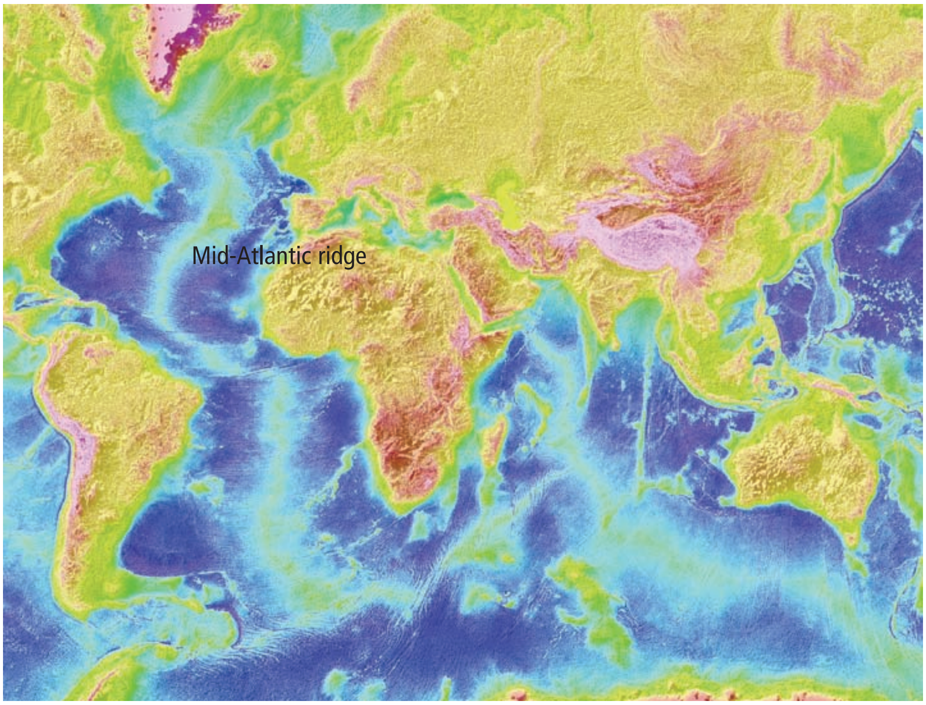


Figure 11.7 The sea floor. The long ridged structures are the mid-ocean ridges.

- **Magnetometers** are sensitive instruments that can detect the direction and strength of a magnetic field. Magnetometers were used to locate submarines during World War II. When ships carrying magnetometers crossed the Atlantic Ocean, the magnetometers usually pointed north, but sometimes they pointed south unexpectedly. The scientists noticed a pattern that looked like stripes of magnetic reversals travelling along a path parallel to the Mid-Atlantic Ridge on both sides of the ridge (Figure 11.8).

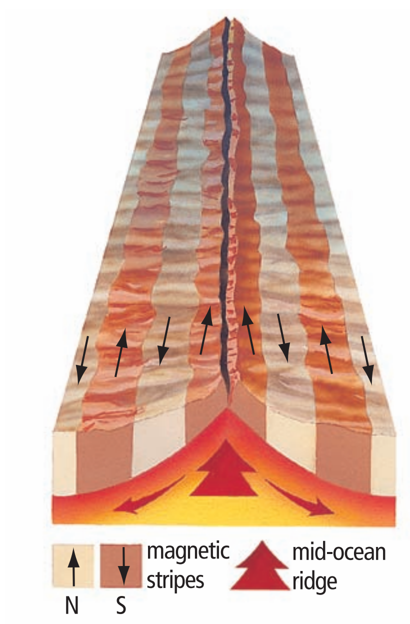


Figure 11.8 The pattern of magnetic reversals on the sea floor led scientists to suspect that the sea floor was spreading. As new crust forms, it takes on the magnetic polarity of Earth.

What was causing the magnetic reversals? You may recall that igneous rock forms from magma. As the magma cools, the iron-bearing minerals such as magnetite stay in line with the magnetic field. So, the stripes on the sea floor that are lined up to the south must have formed at a time when Earth experienced a reversal of its magnetic field. Since the stripes line up with the ridges, it meant that new rock was being formed at the mid-ocean ridges, and the sea floor was spreading.

- In *deep sea drilling*, core samples are collected by drilling deep into the oceanic crust using a drilling rig (Figure 11.9). Tests of the rock samples show that younger rock is closer to the Mid-Atlantic Ridge and older rock is closer to the continents. This was additional evidence that the Atlantic Ocean sea floor was spreading.

Figure 11.9 Scientists on the *Glomar Challenger* used oil drilling technology to sample the rock in one of the longest mountain ranges in the world, the Mid-Atlantic Ridge.

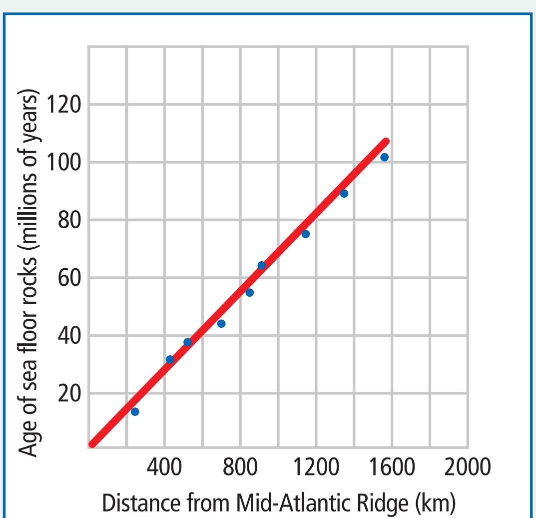
11-1D Evidence from the Sea Floor

Think About It

Science Skills

For help in reading graphs turn to Science Skill 1.

In this activity, you will discover what information rocks can provide about the sea floor. The graph below shows the ages and locations of samples of rock taken from the magnetic stripes at the bottom of the Atlantic Ocean. Each dot represents a sample of rock.



Ages and locations of rock samples

What to Do

Examine the graph and then answer the following questions.

What Did You Find Out?

1. What is the age of the oldest rock and the youngest rock on the graph?
2. How far would you have to travel east or west from the Mid-Atlantic Ridge before you found rocks that were 60 million years old?
3. Write a sentence that states the relationship between the age of rocks in the Atlantic Ocean and the distance they are from the Mid-Atlantic Ridge.
4. What does this evidence suggest is happening to the sea floor? Explain your answer.

Toward a New Theory

The new evidence collected by sonar, magnetometers, and deep-sea drilling indicated that Earth's crust was not fixed in place, as most people believed. If the sea floor was moving, then the continents must be moving, too. But what force was driving the crust to move?

Earlier in this chapter you learned that Earth's crust is broken into pieces called plates. Discoveries on the sea floor showed that when magma rises from an ocean ridge, the magma produces new crust, which pushes the plates apart. As these plates are pushed apart, other plates are pushed together. At some places, called **divergent boundaries,** plates move away from each other. At other places, called **convergent boundaries,** plates move toward each other.

J. Tuzo Wilson, a Canadian scientist, was one of the long line of scientists who have contributed to our understanding of Earth's crust (Figure 11.10). During the 1960s, most scientists still favoured the fixed continent model and dismissed the idea of continental drift. Wilson became a leading spokesperson for the idea of continental drift. He made an important addition to scientific observation when he developed the concept of a third kind of movement along plate boundaries. Instead of pushing together or pulling apart, he hypothesized that some plates were sliding past each other along what he called a **transform boundary.**

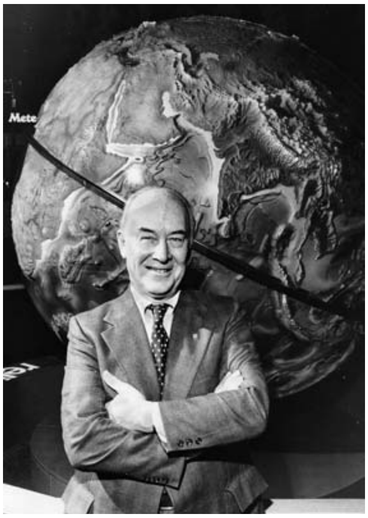


Figure 11.10 J. Tuzo Wilson (1908-1993)

internet connect

You can watch simulations of divergent, convergent, and transform boundaries on the Internet. Start your search at **www.discoveringscience.ca.**

Plate Tectonics

Together with the information about movement on the sea floor, Wilson's idea of transform boundaries brought about a rethinking of Earth's crustal movement. His discoveries helped form a new theory that completely revolutionized this branch of science in the 1970s. The name "continental drift" was no longer appropriate since the sea floor, as well as the continents, was moving. The new theory, called **plate tectonics,** states that Earth's crust is broken up into pieces, called plates that are always moving around on Earth's mantle (Figure 11.11 on the next page). Scientists now study the plates using satellites and lasers to measure plate movements.

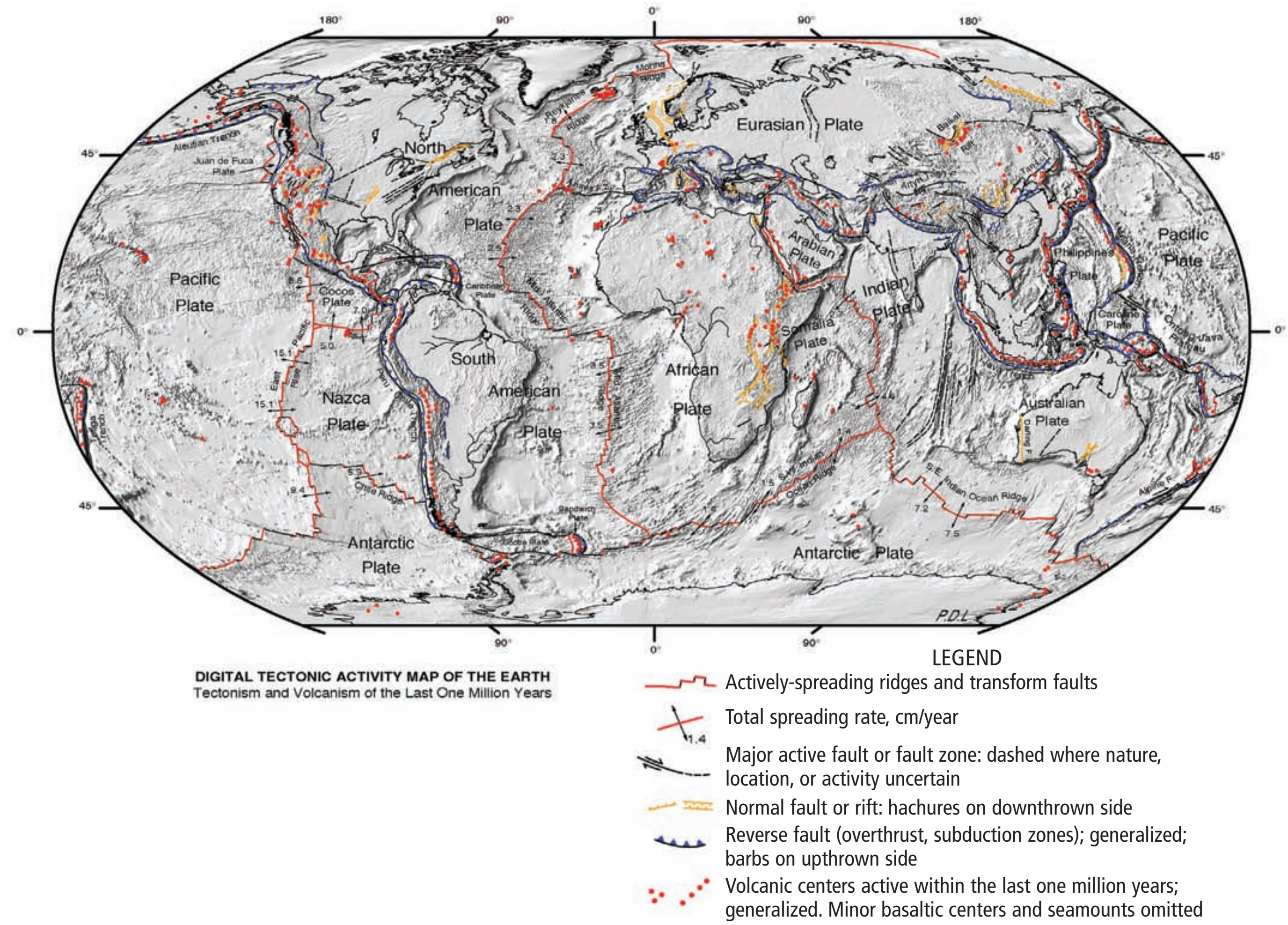


Figure 11.11 This diagram shows the major plates, their direction of movement, and the type of boundary between them. Notice that most plates include both continental crust and oceanic crust.

Did You Know?

Plates that hold the greatest continental masses move more slowly than plates that hold smaller continental masses. The African, Eurasian, and American Plates move about 20 mm per year, in comparison with the Pacific, Nazca, and Cocos Plates, which can move up to 130 mm per year.

Convection Currents

The theory of plate tectonics provides the best explanation, up to now, for all of the evidence that has been gathered. However, scientists are still not sure what causes the plates to move. One explanation is that **convection currents** in the mantle under Earth's crust move the plates (Figure 11.12).

You may recall from earlier studies of heat that hot fluids tend to rise and cool fluids tend to sink. The same process might be occurring in Earth's mantle. Hot magma in the lower mantle moves upward after it is heated by the intense heat in Earth's core. At the upper part of the mantle, the heated rock moves horizontally under the plate above it, taking the plate along as if the plate were on a conveyer belt. When the rock finally cools, it sinks down farther into the mantle. As it does so, it pulls the edge of the plate down with it, forming a deep ocean trench.

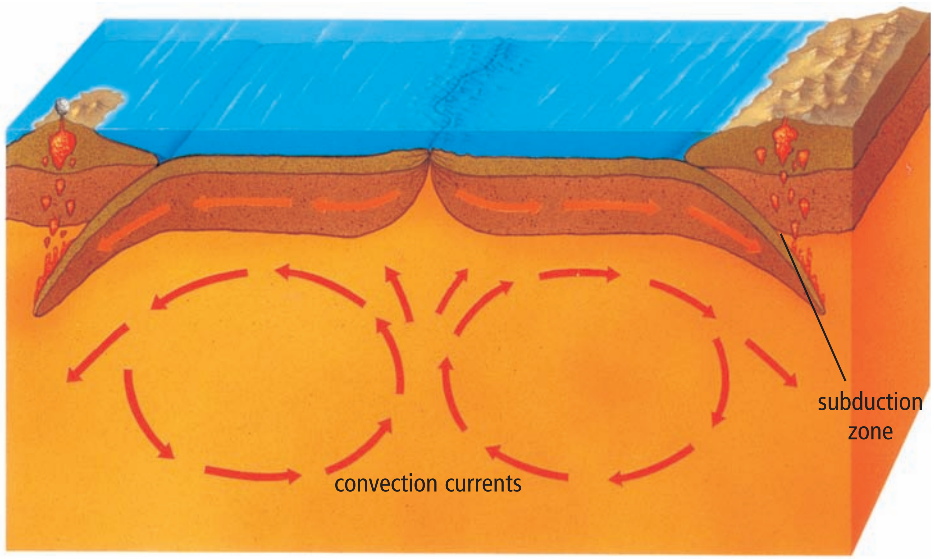


Figure 11.12 This model shows one way that convection currents might move plates.

Each plate touches several other plates, so each movement of one plate affects other plates. When two plates collide or converge, one plate is shoved under the other. The area where one part of the crust is forced below another part is called a **subduction zone** (Figure 11.12).

Convection currents might be the reason why the Atlantic Ocean is widening at the Mid-Atlantic Ridge. Does sea floor spreading mean that Earth's crust is getting bigger? No, because while new crust is forming in the ridge of the Atlantic Ocean, other crust is being pushed or pulled down into the ocean trenches and recycled back into the mantle as molten rock.

Explore More

Plate movements are an example of incremental change, which is change that happens slowly. Where might the plates be in a million years? In a billion years? Find a simulation of plate movements predicted for the next four billion years. Start your search at **www.discoveringscience.ca**.

Reading Check

1. What three new technologies provided information about the sea floor?
2. What are three types of movement that can happen at plate boundaries?
3. What theory did J. Tuzo Wilson help develop?
4. What is a subduction zone?

11-1E Building a Model of Plate Tectonics

Skill Check

- Observing
- Modelling
- Explaining systems
- Evaluating information

Safety

Materials

- 1 large plastic tub
- disposable gloves (optional)
- spoon
- two 1 kg boxes of cornstarch
- measuring container
- water
- 4 petri dishes
- puzzle pieces, marbles, building blocks, bingo chips, etc.

Geologists often have a difficult time duplicating the conditions found in Earth's crust in order to study them. So, as well as studying Earth's crust directly, geologists develop models and computer simulations to use in the laboratory. Models help them develop hypotheses about why Earth's crust behaves the way it does. In this activity, you and your partners may collect the same data, but each of you may develop a different hypothesis. Many geologists create different hypotheses based on the data they collect.

Question

What hypothesis about Earth's crust can you form based on your model?

Procedure

1. Clean the plastic tub.
2. Wear disposable gloves or wash your hands before beginning. It is important that the mixture stays clean. Only one person's hands should be in the mixture at one time.
3. Use the spoon to mix the cornstarch and 500 mL water in the tub. Continue adding water until the mixture is solid when you squeeze it between your fingers and it runs through your fingers when you hold it loose in the palm of your hand.
4. Investigate the properties of this mixture for several minutes. Then, squeeze as much cornstarch as possible from your hands back into the tub.
5. Meanwhile, your partners can work with small amounts of the mixture in petri dishes. Use the bingo chips, puzzle pieces, and any other objects approved by your teacher. Create a model of plate tectonics in the petri dishes while you wait your turn for the larger tub. Slide the objects slowly across the surface. Create different types of boundaries between continental plates. Form an hypothesis about Earth's crust based on your observations.
6. Record your observations and hypothesis.

Analyze

1. (a) State your hypothesis. Support it with evidence from your investigation.
   (b) Describe the appearance of a freshly broken piece of the mixture.
   (c) Explain how this appearance supports your hypothesis.
2. Why do some substances float and some sink in the mixture?

Conclude and Apply

1. In what ways does the mixture resemble a liquid?
2. In what ways does the mixture resemble a solid?
3. Explain why you think the mixture has these unusual properties.
4. How do you think your model helps to explain the concept of plate tectonics?
5. Draw a diagram of your model. Use arrows to show plate movement.

The North American plate and European plate meet in the country of Iceland. On the left side of the photograph is the eastern edge of the North American Plate. On the right is the western edge of the European plate. The two plates are slowly moving apart.

Career Connect

Dr. Charlotte E. Keen

Geophysicist

Charlotte Keen worked on LITHOPROBE, the largest earth science project ever undertaken in Canada, studying the geology of the sea floor. In 1995, she won the J. Tuzo Wilson Medal for her outstanding contributions to geophysics in Canada.

Q. What part of Earth do you study?

A. I look at the continental margin off the east coast of Canada that runs from Baffin Bay right down to south of Nova Scotia. This is the area where the North American continent, of which Canada is a part, once separated from neighbouring continental plates. Continental margins can tell us a lot about how Earth is changing, and the rock underneath them holds great potential for natural resources: oil, gas, and valuable minerals. I study the rock that lies up to 40 or 50 km below that margin.

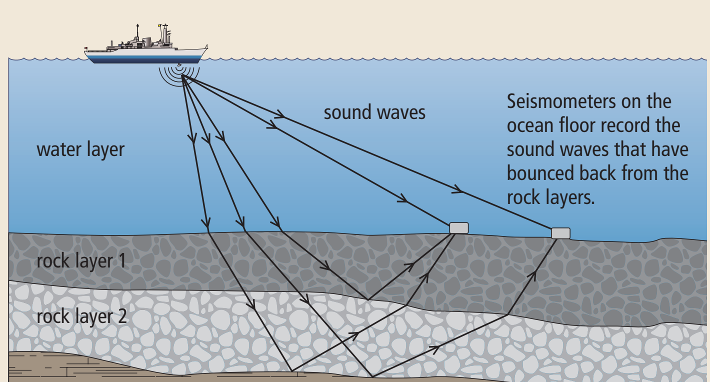
Q. How can you study rock so far below Earth's surface?

A. I look at the way vibrations from sound waves travel through that rock. My colleagues and I plan experiments for the area we want to study. We assemble a team of nearly 100 people, gather the necessary equipment, and then head out to sea. We lower sensitive recording devices called seismometers onto the ocean floor of the area we will study. The ship travels away from the devices, firing an air gun which makes a very loud sound. The sound waves go down through the water and into the rock. Some waves bounce up off layers of rock, others go deeper before they bounce back. When each sound wave reaches the device, it is recorded.

Q. Do the sound waves tell you something about the rock?

A. Yes. Sound waves travel through different types of materials at different speeds. The amount of time it takes for each sound wave to be recorded helps me figure out what kind of rock the sound wave may have passed through. We keep firing the air gun from many different distances, keeping track of exactly where we were and the time at which it was fired. Usually, we are at sea for two to four weeks to record everything that we need. Once we are back on land, I analyze the data from the recording devices to figure out what type of rock exists in each place and how thick the layers are. It is exciting to be able to explore areas where new observations can be made. Who knows what the ocean floor still has to tell us about Earth's crust!

An air gun is fired from the ship, making a loud sound.



Check Your Understanding

Checking Concepts

1. Sketch and label a model of Earth's layers.
2. (a) What two types of evidence do scientists use to determine what is inside Earth?
   (b) Give an example of each type of evidence.
3. (a) How does sonar work?
   (b) What information does sonar provide about the sea floor?
4. What evidence do we have that Earth's magnetic field has reversed over time?
5. What discovery was made when rock samples from deep-sea drilling were tested?
6. (a) What do scientists now think is causing the continents to move?
   (b) Give one reason why the term "continental drift" is no longer appropriate and why we now use "plate tectonics."

Understanding Key Ideas

7. Why are scientists not sure what is inside Earth's inner layers?
8. Copy this chart into your notebook. Complete the chart using the evidence Wegener collected to support his idea of continental drift.

Type of Evidence	Example of Evidence	Why the Example Suggests that Continents Have Moved

9. How is new rock being formed at the sea floor?
10. Draw a diagram to show how convection currents occur in Earth's crust and how they cause plate movement.
11. Describe two ways in which the plate tectonics theory is different from the theory of continental drift.
12. Could one plate move by itself, or do all plates need to move together? Explain your answer.

Pause and Reflect

Suppose that you could invent a way to gather direct evidence from Earth's inner core. Use a diagram to show how your invention would work.

11.2 How Earthquakes and Volcanoes Shape Earth's Crust

An earthquake is the shaking of the ground. When the crustal plates move, tension can build up in the rock, causing it to suddenly move or break, resulting in an earthquake. Most earthquakes occur along plate boundaries. A volcano is an opening in Earth's crust. Volcanoes can be found where plates collide, where plates separate, and where plates are thin. Volcanic eruptions have benefits as well as risks.

Key Terms

bedrock
earthquake
epicentre
fault
focus
Richter scale
Ring of Fire
seismic waves
seismograph
volcano

On Monday evening, November 18, 1929, a huge wave, travelling at over 100 km/h struck the Burin Peninsula in southern Newfoundland. Eyewitnesses described a wall of water 5 m high breaking over the houses around the harbours and pouring in through the windows and doors. Twenty-seven people were killed and many families lost their winter food supply, their heating fuel, their boats, their houses, and all their possessions. Over 10 000 people in more than 40 settlements were affected by the wave. The wave was a tsunami, which is a Japanese word for "harbour wave." The tsunami was caused by an underwater earthquake on the floor of the Atlantic Ocean about 250 km south of the Burin Peninsula.

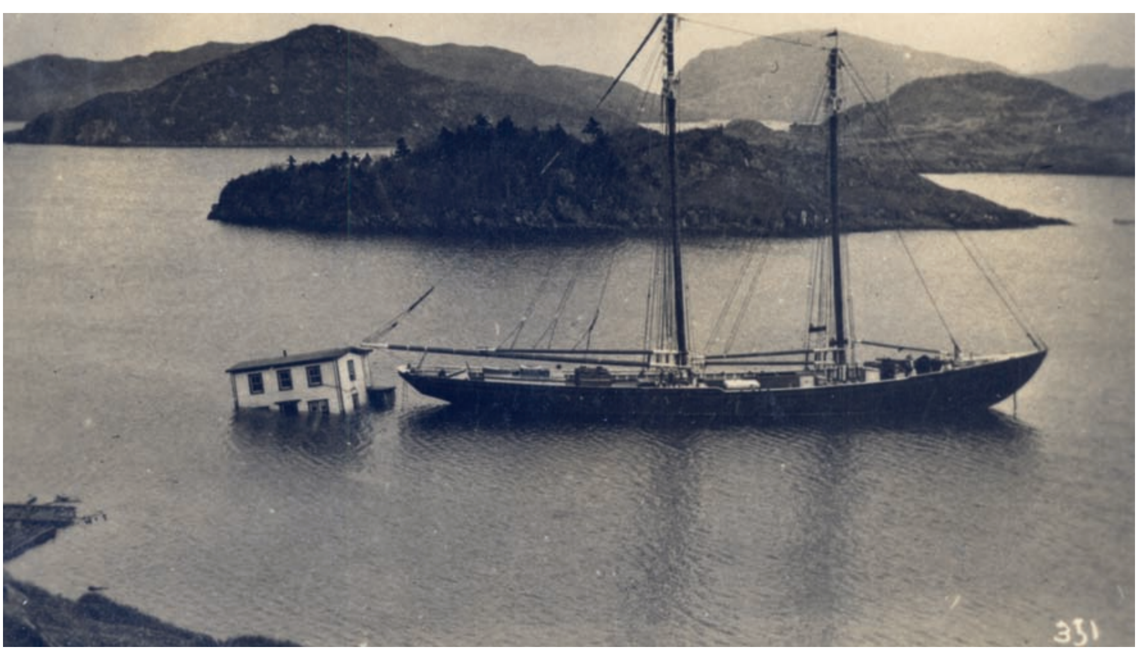


Figure 11.13 A washed-out house is retrieved by a schooner after the 1929 tsunami in Newfoundland.

Figure 11.14 A tsunami is actually a series of waves, and each wave can cause destruction.

Did You Know?

Tsunamis can be caused by underwater landslides and volcanoes, as well as by earthquakes.

On December 26, 2004, an underwater earthquake near Sumatra in Southeast Asia created a tsunami that reached the shores of countries bordering on the Indian Ocean. More than 200 000 people lost their lives and 1.69 million people lost their homes and possessions. This was the single worst tsunami in history.

Most geological processes take place very slowly, over thousands or millions of years. But some processes, like earthquakes, tsunamis, and volcanic eruptions can happen very quickly and with very little warning. Why does Earth's crust sometimes move quickly?

11-2A Seismic Sandpaper

Find Out ACTIVITY

In this activity, you will model how an earthquake can be caused.

Materials

- 2 wooden blocks, each about 5 cm by 10 cm by 15 cm
- 2 sheets of medium grade sandpaper
- masking tape

What to Do

1. Wrap a sheet of sandpaper around each block and secure with masking tape.
2. Hold the blocks straight up and down, one in each hand.
3. Push the blocks together tightly. While you push, try to slide the blocks past each other in different directions.

What Did You Find Out?

1. What happened when you tried to move the blocks?
2. How do you think this activity models an earthquake?

Figure 11.15 An ancient earthquake detector from China. The eight dragons on this urn have little balls inside them. Earthquake movements shake the balls into the toads' open mouths. The direction of the earthquake is determined by which toad swallows the ball.

Detecting Earthquakes

The rock in Earth's crust is under pressure from internal forces. The stresses of moving plates can cause the rock to bend and stretch. Tremendous amounts of energy build up in the rocks. When the pressure is too great, the rock breaks suddenly, creating an earthquake. An **earthquake** is the shaking of the ground. Devices for measuring earthquakes have been used for thousands of years (Figure 11.15).

Seismologists are scientists who study earthquakes. They use a special machine called a **seismograph** to measure earthquakes (Figure 11.16A). Seismographs must be attached to **bedrock**, which is the solid rock that lies beneath the soil, in order to detect the vibrations that result from an earthquake. Inside the seismograph, a marking pen hangs over a rotating drum, very lightly touching the drum. The drum is covered with paper to record the vibrations marked by the pen. When an earthquake strikes, the pen tip moves, making a jagged line. The record of vibrations detected by a seismograph is called a seismogram (Figure 11.16B). Most modern seismographs are electronic, but they are based on the same principles.

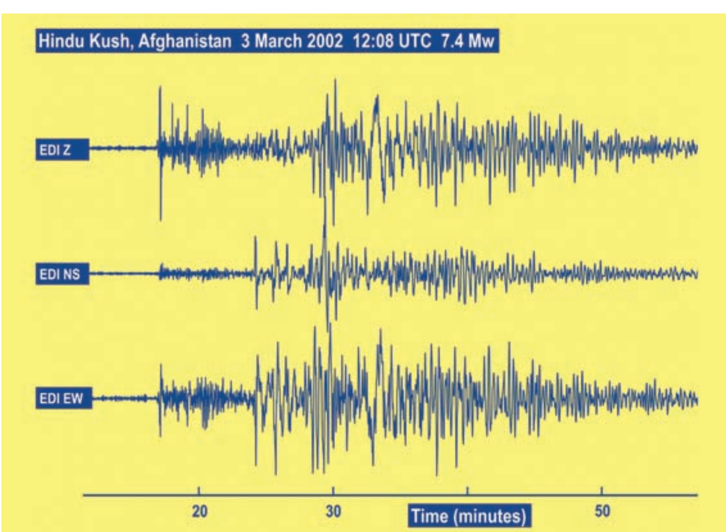


Figure 11.16B The jagged line on this seismogram represents earthquake waves.

Figure 11.16A Seismologists study earthquakes by reading seismographs.

Measuring Earthquakes

Seismologists use a method of measurement called the **Richter scale** to describe the strength of an earthquake (Table 11.1). The Richter scale starts at zero and can go as high as necessary. The amount of energy released increases greatly as the numbers increase. An earthquake that registered 7 would be about 30 times stronger than one that registered 6, and about 900 times stronger than one that registered 5. Most earthquakes that cause damage and loss of life register between 6 and 8 on the Richter scale. The earthquake that caused the Burin Peninsula tsunami measured 7.2 on the Richter scale.

Suggested Activity

Design an Investigation 11-2D on page 385

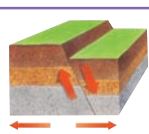
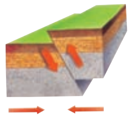
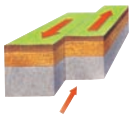
Table 11.1 Richter Scale

Richter Magnitudes	Earthquake Effects	Estimated Number per Year
< 2.0	generally not felt, but recorded	600 000
2.0–2.9	felt by few	300 000
3.0–3.9	felt by some	49 000
4.0–4.9	felt by most	6200
5.0–5.9	damaging shocks	800
6.0–6.9	destructive in populated areas	266
7.0–7.9	major earthquakes, which inflict serious damage	18
≥ 8.0	great earthquakes, which produce total destruction to communities near the source	1-2

Three Types of Faults

A **fault** is a break in rock layers. Table 11.2 shows that there are three types of faults along which rock can move: normal faults, reverse faults, and transform faults.

Table 11.2 Three types of faults

Fault	Where It Is Produced	How It Is Produced	How the Rock Moves
Normal fault 	divergent boundaries	plates move apart	rock above the fault moves downward
Reverse fault 	convergent boundaries	plates push together	rock above the fault moves up and over rock below the fault
Transform fault 	transform boundaries	plates move sideways past each other	rock breaks as the plates try to slide past each other

Word Connect

Seismic comes from a Greek word, meaning "shake."

Seismic Waves

If you have never experienced an earthquake, you might think that the ground shakes only once and then the earthquake is over. There can actually be many episodes of ground-shaking movement, however, caused by seismic waves. **Seismic waves** are the energy waves that travel outward from the source of the earthquake. These aftershocks are actually smaller earthquakes, and they produce even more ground movement. Aftershocks can cause damaged buildings to collapse.

You have probably thrown a small stone into water and watched the ripples spread out from the point where the stone entered the water. Seismic waves travel across Earth's surface in a similar way. They can cause parts of a building to move up while other parts move down. Rigid structures will collapse if the movement is too great.

The place deep in the crust where an earthquake begins is called the **focus** of the earthquake (Figure 11.17). The surface location directly above the focus is called the **epicentre.** Seismic waves travel outward from both the focus and the epicentre. You can use the arrival time of seismic waves to determine earthquake locations. The farther apart the waves are, the farther away is the earthquake.

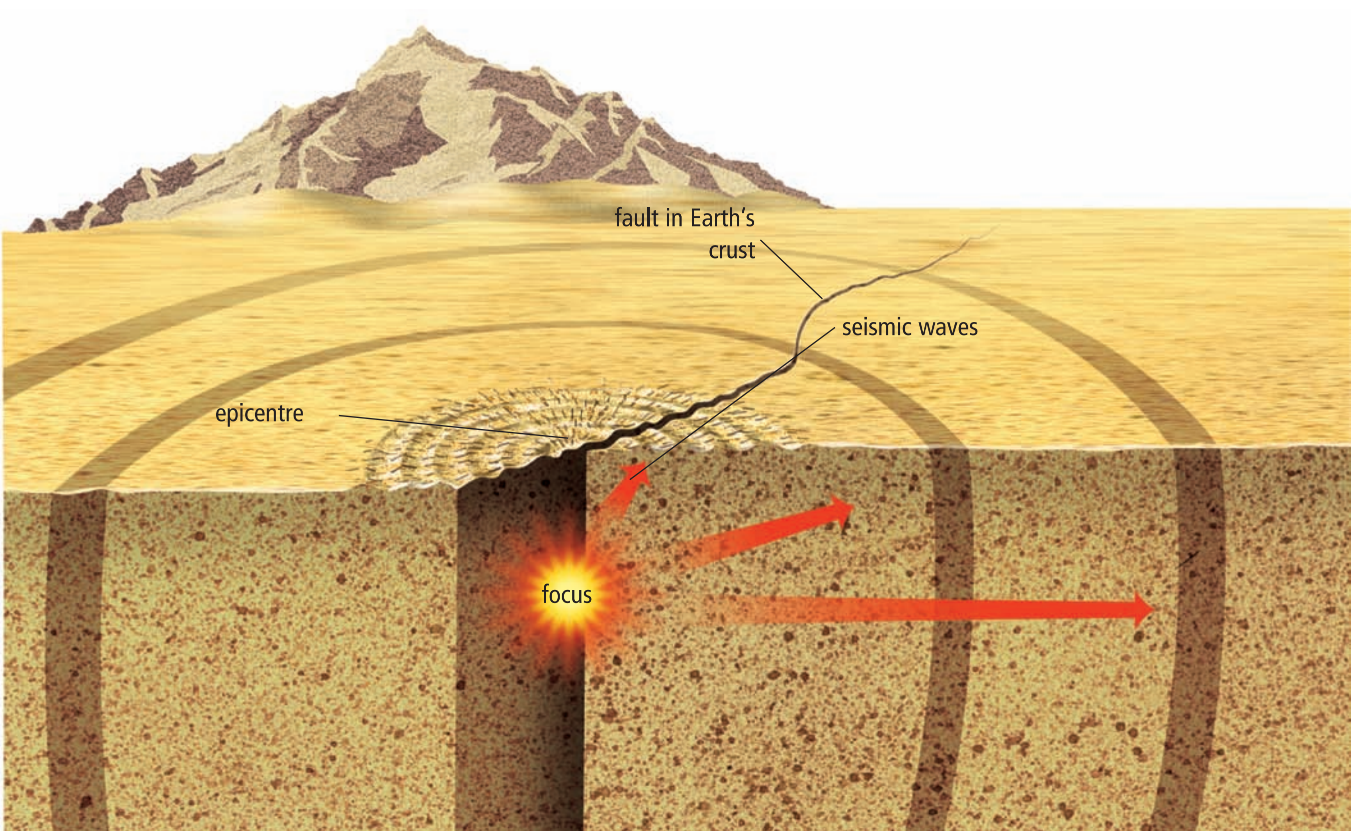


Figure 11.17 Some seismic waves travel out from the focus. Some seismic waves travel out from the epicentre, much like ripples in a pond.

Seismic waves provide some evidence of what might be inside Earth. For example, an earthquake that happened in Kobe, Japan in 1995 was measured at the University of Manitoba. The seismic waves had travelled right through the centre of Earth. Some seismic waves can travel through both liquids and solids and some waves cannot.

internet connect

You can compare arrival times of seismic waves and locate the epicentre of earthquakes online. Start your search at **www.discoveringscience.ca.**

Locations of Earthquakes

Most earthquakes occur along the active plate boundaries, such as off the British Columbia coast. Earthquakes in Canada also occur frequently in the Ottawa and St. Lawrence Valleys, in New Brunswick, and the offshore region to the south of Newfoundland. Earthquakes are less likely to happen at the centre of the plates. The Geological Survey of Canada (GSC) records and locates over 1500 earthquakes in Canada each year, but only a few of these earthquakes are strong enough to be felt by people (Figure 11.18).

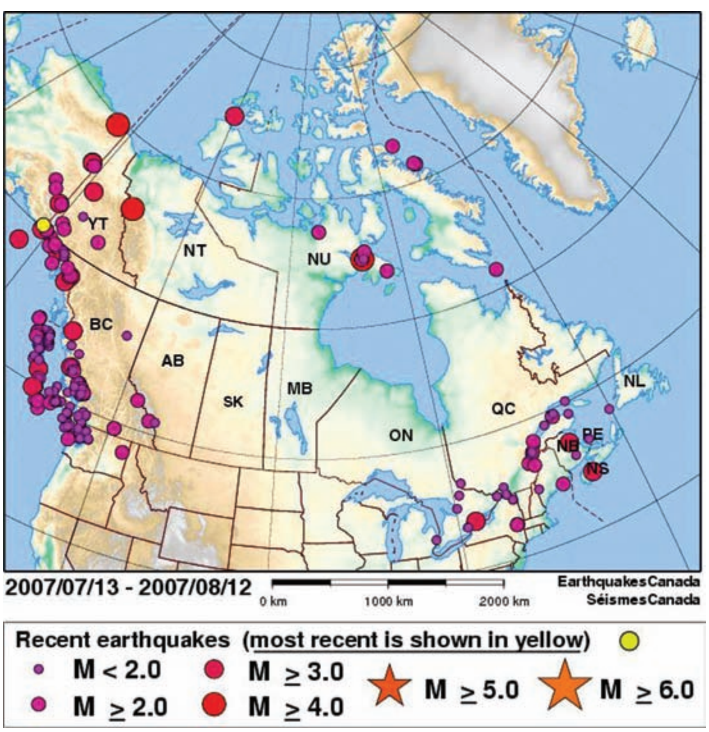


Figure 11.18 Every month there may be more than 100 earthquakes in Canada.

Reading Check

1. Why is a seismograph attached to bedrock?
2. Which is stronger: an earthquake measuring 7 or an earthquake measuring 5 on the Richter scale?
3. What are three types of faults?
4. Where do most earthquakes occur?

11-2B Seismic Safety

Think About It

In this activity, you will list your ideas about how you might prepare for a sudden movement in Earth's crust.

What to Do

1. Consider what changes might be necessary in your bedroom to prevent you from being injured if an earthquake happened while you were sleeping. For example, are there any shelves with heavy objects at the top? Make a list of changes to your bedroom.
2. Think about the items you might need in an emergency kit if an earthquake or tsunami occurred. How long might you need them? Where could you store your emergency kit? Make a list of items for your emergency kit.
3. Compare your lists with another student's lists. Make any changes that you feel would improve your own lists.

Figure 11.19 The volcano Parícutin, erupting

Volcanoes

Imagine watching a volcano appear right before your eyes. A farmer, his wife, and his son in Mexico had this experience in 1943 when the ground in their cornfield suddenly sent clouds of ash, stones, and glowing cinders into the air. The volcanic activity continued for almost ten years, eventually covering the nearby village in ash and lava. The volcano was named Parícutin, the name of the village it covered. Parícutin is now over four hundred metres high (Figure 11.19).

A **volcano** is an opening in Earth's crust. Scientists study volcanoes to learn more about the internal structure of Earth (Figure 11.20). What would you observe if you watched a huge volcano erupt? Imagine the terrific heat, the choking ash, and the streams of red-hot lava.

Figure 11.20 Scientists try to predict when volcanoes will erupt so people living near them can avoid injury or death.

Figure 11.21 The most active volcano on Earth is Kilauea in Hawaii. Kilauea has been continuously erupting since 1983. The lava from Kilauea has flowed into residential areas, causing many millions of dollars of damage.

Benefits and Risks of Volcanic Eruptions

Volcanic eruptions have created many valuable resources. For example, volcanic ash increases soil fertility. Forests and farm crops grow better because the ash adds nutrients and acts as mulch. Underground magma heats groundwater. The heated water can be used as a source of heat, or geothermal energy. Volcanoes release water and carbon dioxide from the interior of Earth, adding important gases to our atmosphere. Unfortunately, volcanoes can also destroy homes, trees, crops, and landscapes (Figure 11.21). The ash can travel great distances and cause breathing difficulties (Figure 11.22).

Did You Know?

A *dormant* volcano has not been active for a long time but has erupted in recorded history. An *extinct* volcano has not erupted in recorded history.

Figure 11.22A Ash from the eruption of Mount Pinatubo blocked the sunlight and buried fields and roads. Torrential rains caused mudflows that destroyed villages and left thousands of people homeless.

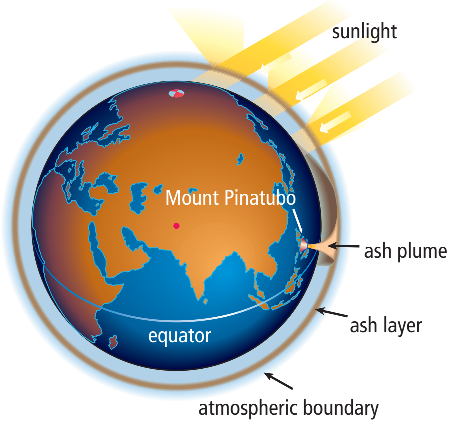


Figure 11.22B Mount Pinatubo erupted in the Philippines in 1991. The huge amount of ash blown out of the volcano formed an ash layer within the atmosphere. The ash layer circled the globe and cooled temperatures around the world.

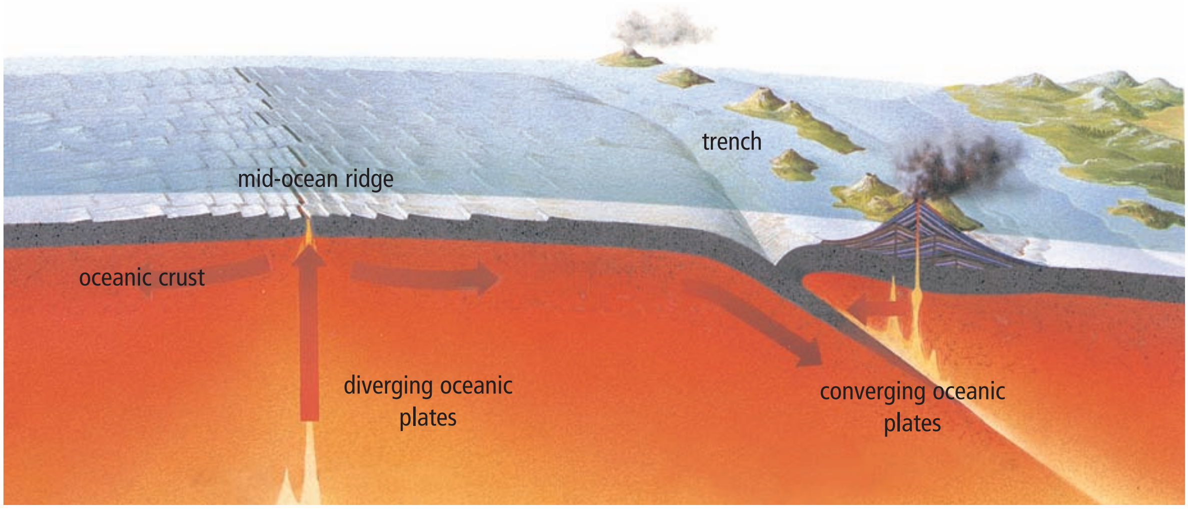


Figure 11.23 If the two converging plates are oceanic plates, either plate might subduct, forming volcanoes.

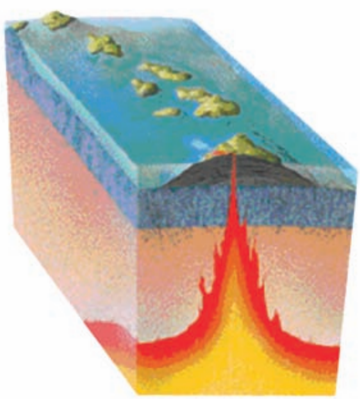


Figure 11.24 The northern islands in the Hawaiian Island chain no longer have any volcanic activity. Which islands in the chain do you think are the oldest?

Did You Know?

A new volcano is forming under the ocean, right beside the main island of Hawaii. It has been named Loihi. It will continue to grow until it is another island in the middle of the Pacific Ocean. Perhaps your descendents will visit Loihi in the future!

Volcano Locations

Like earthquakes, volcanoes can be formed when rock surfaces beneath Earth's crust push against one another, and one layer is forced below the other. In a subduction zone, the descending rock moves deeper and deeper until it melts into magma. The magma rises up through cracks in the rock until it exerts enough pressure to cause the volcano to erupt (Figure 11.23).

Most volcanoes are found along plate boundaries. Volcanoes can be found in the following environments:

- *Where plates collide at convergent boundaries,* the part of the crust that is pushed downward reaches very hot areas where it melts and becomes magma. Eventually there is so much magma, it is forced up through openings, and erupts. An example is where the Pacific plate is being forced under Japan.
- *Where plates separate at divergent boundaries,* magma flows up to the surface. An example is the Mid-Atlantic Ridge.
- *In areas where plates are thin,* magma can be forced up through the cracks to the surface. Hot spots are places where the temperature under the crust is much higher than elsewhere. Hot spots are found below the Hawaiian Island chain in the Pacific Ocean (Figure 11.24).

Volcanoes of the World

A famous eruption occurred in 1980 in Washington state. The rock on the side of Mount St. Helens began to bulge. Scientists knew that an eruption would happen soon, so they had time to warn people to stay away from the area. Figure 11.25 shows how magma built up inside the volcano to cause the eruption.

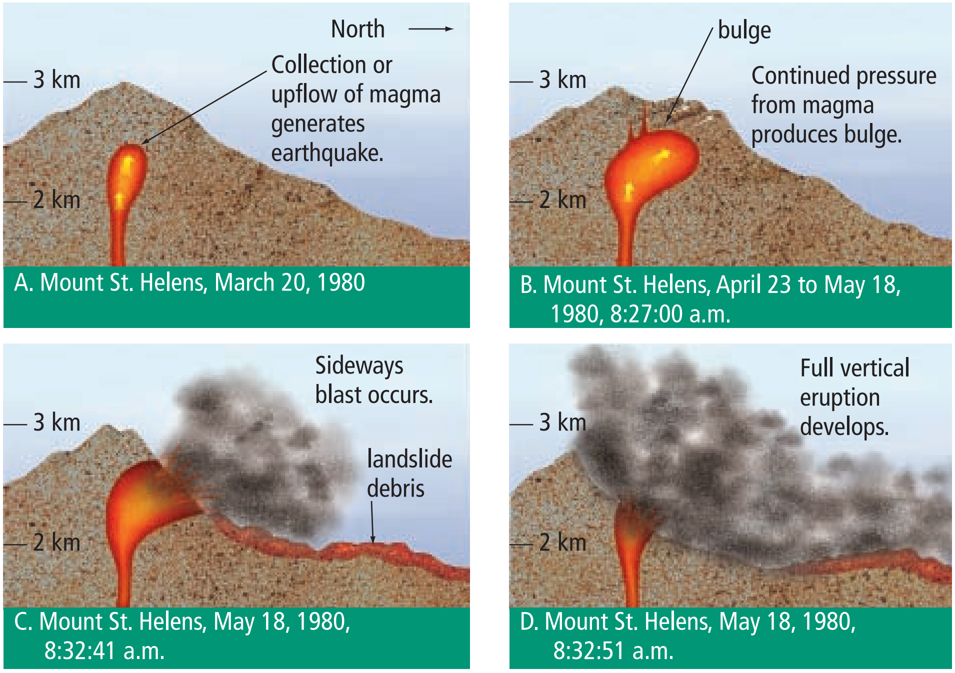


Figure 11.25 Volcanoes erupt in stages, over a period of several weeks, months, or even years.

Suggested Activity

Think About It 11-2E on page 386

Did You Know?

Some volcanoes have flat tops because they erupted beneath a glacier or in a glacial lake. Hyalo Ridge in British Columbia is a typical, flat-topped, steep-sided, sub-glacial volcano.

One of the worst eruptions in history happened on August 27, 1883, when the volcanic island of Krakatau in Indonesia literally blew up. The blast was heard 4800 km away. At least 32 000 people died when tsunamis reaching 30 m in height were triggered by the eruption.

Many scientists believe that Mount Vesuvius, in southern Italy, is due for a large eruption. Mount Vesuvius is considered one of the most dangerous volcanoes in the world because it has a history of violent eruptions (Figure 11.26) and because almost three million people live close to the volcano. Its last eruption was in 1944, and since then a huge area beneath the peak has been filling with magma. The situation is even more dangerous because the opening at the peak is sealed by a rock "plug." Scientists have produced computer simulations to show that, when pressure forces the rock plug out, a cloud of molten rock, ash, and gas will blast about 1.5 km upwards. Plans are being made for emergency measures if such an event occurs.

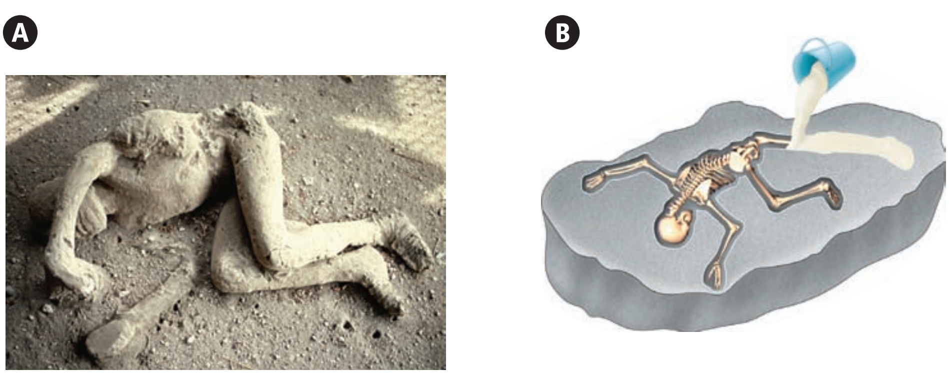


Figure 11.26 Photograph (A) shows a plaster cast of a body buried in the eruption of Mount Vesuvius in 79 C.E. After the body decayed, plaster was poured into the cavity it left. When the plaster cast hardened, the surrounding ash was removed (B).

The volcanoes encircling the Pacific Ocean are called the **Ring of Fire** (Figure 11.27). Krakatau, Mount St. Helens, and Mount Pinatubo are part of this Ring of Fire.

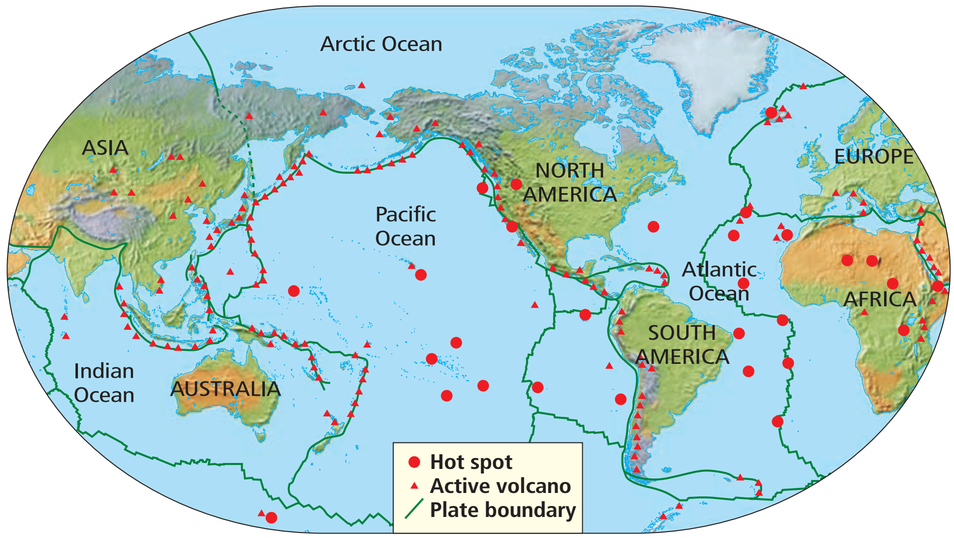


Figure 11.27 The Ring of Fire is a belt of active volcanoes that circles the Pacific Ocean.

Explore More

In November of 1963 the crew of a trawler noticed smoke from the ocean off the coast of Iceland. When they went to investigate, they discovered it was an underwater volcanic eruption. Within a few days the eruption had created an island. With continued eruptions, the island grew for the next four years. Find out more about the island of Surtsey. Visit **www.discoveringscience.ca.**

Reading Check

1. What are three benefits of volcanic eruptions?
2. What are three risks of volcanic eruptions?
3. What are three environments where volcanoes occur?

11-2C Seismic Stories

Think About It

Different cultures throughout history have had ideas and theories about the origins and causes of volcanic and earthquake activity. Anaxagoras, who lived in ancient times in Greece, believed that volcanic eruptions were caused by great winds within Earth. Hawaiian mythology tells of the Fire Goddess Pele, who lived inside the volcano Kilauea. When she was angry, the volcano erupted. North American Aboriginal people also have explanations for the movements of Earth. In this activity, you will investigate how people of various cultures, times, and traditions have explained volcanoes and earthquakes.

What to Do

1. Choose a culture to research. Find a story or explanation about the cause of volcanoes or earthquakes.
2. Learn the story and prepare a way to share it. You might tell it in your own words, create an illustrated book, or prepare a recording or short dramatization. Or you might make a class mural of ancient stories.

11-2D Shake It!

Design an INVESTIGATION

Inquiry Focus

SkillCheck

- Measuring
- Modelling
- Evaluating information
- Working co-operatively

Materials

Suggested list:

- marbles or small rocks
- masking tape
- modelling clay
- paper (sheets of paper or adding machine paper)
- paper clips
- paper plates and cups
- pencils
- pieces of wood
- rubber bands
- shoebox
- soup can or oatmeal cylinder
- springs
- string
- washers
- water

Science Skills

For help in designing an investigation, turn to Science Skill 2.

In this activity, you will design and build a seismograph.

Question

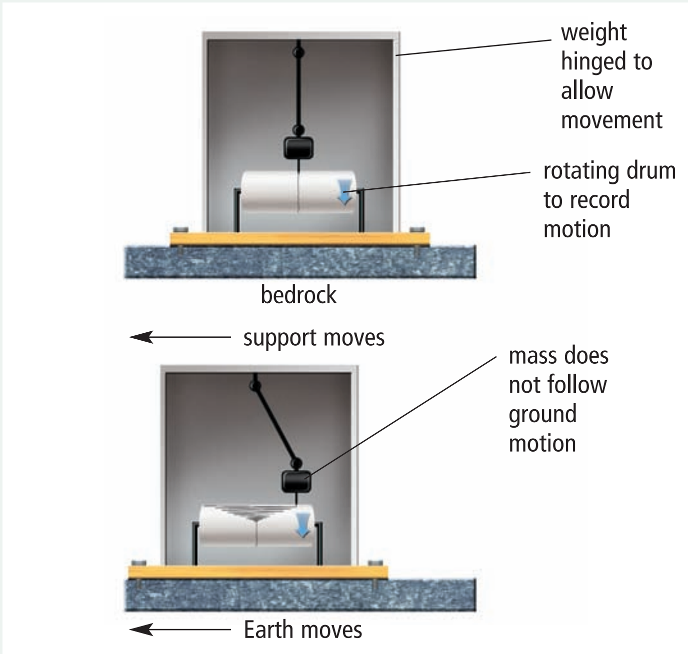
How can you design a device to detect movement?

Procedure

1. Work with your partner to design a seismograph.
2. You can use any combination of the materials listed or other materials approved by your teacher.
3. Draw and label your design. Have your teacher approve your design, and then build your seismograph.
4. Test your seismograph. Make any refinements or improvements you can think of. Record the changes you made to the design and why you made them.
5. Demonstrate your seismograph for other students. Compare it with those designed by your classmates.
6. Discuss your comparisons with your partner, and write down what you noticed.

Conclude and Apply

1. How well did your seismograph work?
2. What improvements could you make to your seismograph based on other groups' designs?
3. What was the most challenging part of designing a seismograph?



11-2E Patterns in Earthquake and Volcano Locations

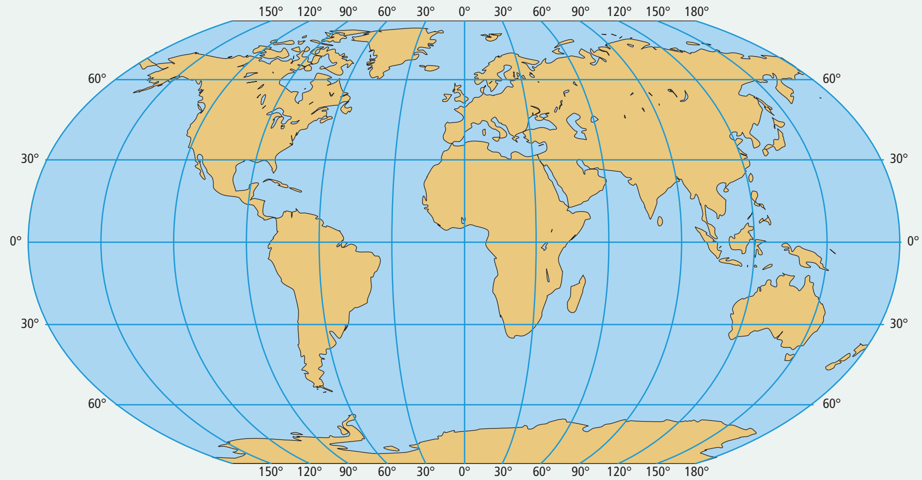
SkillCheck

- Graphing
- Communicating
- Explaining systems
- Evaluating information

Materials

- world map with latitude and longitude lines
- blue, red, and green coloured pencils or markers

In this activity, you will plot earthquake, volcano, and plate boundary locations on a map using lines of latitude and longitude. You will look for patterns in the occurrence of earthquakes and volcanoes, and the locations of plate boundaries.



Procedure

1. Use the tables in this investigation, or obtain your own list of earthquake and volcano locations from the Internet.
2. Mark the locations of earthquakes with blue dots on the map provided by your teacher.
3. Mark the locations of volcanoes on your map with red dots.
4. Mark the locations of the plate boundaries on your map in green.
5. Create a legend on your map to show what each symbol represents.

Analyze

1. Are most of the earthquakes located near volcanoes? Explain.
2. Describe the pattern earthquakes, volcanoes, and plate boundaries in or around the Pacific Ocean.
3. Does the pattern around the Atlantic Ocean look similar to or different from the pattern around the Pacific Ocean? Explain.
4. Where do most earthquakes occur in North America?
5. Describe any other places in the world that appear to have a large number of earthquakes.

Earthquakes Around the World

Longitude	Latitude	Location
72ºW	33ºS	Valparaiso, Chile
78ºE	44ºN	Tien Shan, China
105ºE	36ºN	Kansu, China
140ºE	36ºN	Tokyo, Japan
102ºE	37ºN	Nan Shan, China
85ºE	28ºN	Bihar, India
39ºE	35ºN	Erzincan, Turkey
136ºE	36ºN	Fukui, Japan
133ºW	54ºN	Queen Charlotte Islands
97ºE	29ºN	Assam, India
3ºE	35ºN	Agadir, Morocco
48ºE	38ºN	Northwestern Iran
147ºW	61ºN	Seward Alaska
57ºE	30ºN	Southern Iran
87ºW	12ºN	Managua, Nicaragua
92ºW	15ºN	Central Guatemala
118ºE	39ºN	Tangshan, China
40ºE	40ºN	Eastern Turkey
68ºW	25ºS	Northwestern Argentina
78ºW	1ºN	Ecuador-Colombia border
137ºW	37ºN	Honshu, Japan
102ºW	18ºN	Western Mexico
45ºE	41ºN	Northwestern Armenia
122ºW	37ºN	San Francisco, California
135ºE	35ºN	Kobe, Japan
122ºE	47ºN	Nisqually, Washington
58ºE	29ºN	Bam, Iran
95ºE	3ºN	Sumatra, Indonesia

Volcanoes Around the World

Longitude	Latitude	Location
122º W	46ºN	Mount St. Helens, Washington
123ºW	50ºN	Garibaldi, British Columbia
130ºE	32ºN	Unzen, Japan
25ºW	39ºN	Fayal, Azores
29ºE	1ºS	Nyiragongo, Zaire
152ºW	60ºN	Redoubt, Alaska
102ºW	19ºN	Parícutin, Mexico
156ºW	19ºN	Mauna Loa, Hawaii
140ºE	36ºS	Tarwera, Australia
20ºW	63ºN	Heimaey, Iceland
14ºE	41ºN	Vesuvius, Italy
78ºW	1ºS	Cotopaxi, Ecuador
25ºE	36ºN	Santorini, Greece
123ºE	13ºN	Mayon, Philippines
93ºW	17ºN	Fuego, Mexico
105ºE	6ºS	Krakatoa, Indonesia
132ºW	57ºN	Edziza, British Columbia
74ºW	41ºS	Osorno, Chile
138ºE	35ºN	Fujiyama, Japan
15ºE	38ºN	Etna, Sicily
168ºW	54ºN	Bogoslov, Alaska
121ºW	40ºN	Lassen Peak, California
60ºW	15ºN	Mount Pelée, Martinique
70ºW	16ºS	El Misti, Peru
90ºW	12ºN	Coseguina, Nicaragua
122ºW	49ºN	Mount Baker, Washington
121ºE	15ºN	Mount Pinatubo, Philippines

Conclude and Apply

1. What conclusions can you make about earthquake and volcano locations, based on your observations?
2. If you were a scientist, what might you hypothesize about the areas of Earth's crust where volcanoes and earthquakes are found?

Science Watch

Exploring the Big Deep

Picture the bottom of the sea floor, hundreds of metres below the surface. It is cold and dark and there is enormous pressure from all the layers of water. How can we gather evidence from the oceanic crust when it is such a dangerous place for us to visit?

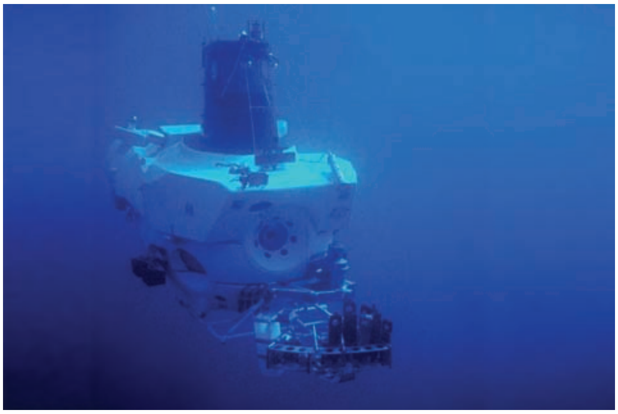
Luckily, a Canadian invention reduces the danger of exploring the sea floor. ROPOS (Remotely Operated Platform for Ocean Science) is a Canadian-owned and operated ROV (remotely operated vehicle) that can dive as deep as 5000 m below the ocean's surface. About the size of a small car, ROPOS is tethered to a mother ship and launched into the ocean inside a large cage. The cage releases ROPOS once it approaches the sea floor.

From the comfort of their control room inside the mother ship, the ROPOS team of pilots and technicians can carry out a wide variety of scientific explorations at the flick of a switch or swivel of a joystick. Live footage of the sea floor is transmitted from video cameras mounted on ROPOS via electrical-optical cable onto video monitors inside the control room. By manipulating two robotic arms on the vehicle, the ROPOS team can collect specimens of deep-sea organisms and geological samples from the sea floor. They can measure surrounding temperatures with temperature probes.

The team navigates ROPOS and its cage with the help of a sonar tracking system and Global Positioning System (GPS) satellites. This precise navigation system allows the ROPOS team to survey and map unexplored areas of the sea floor.

ROPOS and other deep sea vehicles have been used in exploring, filming, and gathering samples from hydrothermal vents in the sea floor. Data gathered by the vehicles has helped scientists better understand undersea volcanoes, seafloor spreading, and plate tectonics—all without having to dip a toe in the ocean!

ROPOS is lowered into the ocean in a metal cage.



The submersible *Alvin* was used to explore the wreck of *RMS Titanic*.

Questions

1. Why is the sea floor a dangerous area for humans to visit?
2. What are three activities ROPOS can perform?
3. How is ROPOS navigated?

Check Your Understanding

Checking Concepts

1. Define *earthquake*.
2. Explain how earthquakes are measured.
3. Explain how rock moves
   (a) in a normal fault
   (b) in a reverse fault
   (c) in a transform fault
4. Describe the difference between the focus and the epicentre of an earthquake.
5. Define *volcano*.
6. What are three environments where volcanoes can occur?
7. Where do most volcanoes occur?
8. Where is the Ring of Fire?
9. The buildings in this photograph were many kilometres from the epicentre of an earthquake near San Francisco. What caused the damage?

Understanding Key Ideas

10. Why does Newfoundland and Labrador experience far fewer earthquakes than British Columbia?
11. An earthquake, with a magnitude of 5.4 on the Richter scale, occurs in Alaska at the same time as an earthquake in California, measuring 5.3. Which earthquake was stronger: the one in Alaska or the one in California?
12. Copy this table into your notebook and complete it.

	How Are They Similar?	How Are They Different?
Locations of earthquakes and volcanoes		
Causes of earthquakes and volcanoes		

13. Why is it easier to predict *where* an earthquake will occur than *when* an earthquake will occur?
14. How do volcanoes support the theory of plate tectonics?

Pause and Reflect

An unusually low tide can be an indication that a tsunami is about to occur. Why do you think this is?

11.3 Mountain Building and Geologic Time

The movement along plate boundaries creates great heat and pressure. The pressure can cause the rock to fold and fault, forming mountains. Sometimes the heat can melt rock and cause it to rise to form volcanoes. Three different land masses were pushed together millions of years ago to form Newfoundland. The geologic times scale divides Earth's history into smaller units, based on when certain life forms appear. Fossils are the remains of living things.

Key Terms

fold
fossil
geologic time scale

"You're really growing, aren't you?" How many times has someone made a comment like this to you? Have you ever thought the same kind of comment could be applied to a mountain? How do mountains form? Which ones are still growing? Why do they stop growing? These are the kinds of questions that scientists ask as they try to solve some of the mysteries related to Earth's crust.

Mountain building takes many years, and it creates some of the most beautiful scenery in the world (Figure 11.28). Each mountain range has a distinctive and fascinating geological history due to plate tectonics.

Did You Know?

Mountains that are jagged at the top are young; mountains that are more rounded are older. The top of Mount Everest in the Himalayas, like you, is still growing taller. The Appalachians are an older mountain range that is in the process of being worn down.

Figure 11.28 Western Brook Pond is a popular destination in the Long Range Mountains on the island of Newfoundland.

11-3A Make a Mountain

Find Out ACTIVITY

In this activity, you will model how layers of sedimentary rock form into mountains.

Materials

- 3 sheets of flexible, spongy Styrofoam™ of different colours

What to Do

1. Pile the Styrofoam™ sheets on top of each other.
2. Put your hands on each side of the stacks and push together.

What Did You Find Out?

1. What happened to the Styrofoam™ as you pushed the sides together?
2. What happens to bendable objects when they are squeezed?
3. (a) Infer: Can rocks bend?

   (b) On what evidence do you base your answer?
4. Suppose you had cut a fault (crack) through the layers before you squeezed them. How might your results be different?

Rocks under Pressure

Most mountains are large areas that have been uplifted due to the movement or heating of plates. Sedimentary rocks that are placed under slow, gradual pressure can either fold or fault. A **fold** is a bend in rock layers. A fault is a break in rock layers.

Fold mountains: When plates collide at convergent boundaries, the rock is placed under great heat and pressure (Figure 11.29). Rocks can fold if they are hot enough to act like bendable plastic. Some of the sedimentary rock can be changed to metamorphic rock during the process of folding. The Himalayan mountains are being built this way as the Indo-Australian Plate collides with the Eurasian Plate. The Appalachian Mountains are another example of fold mountains.

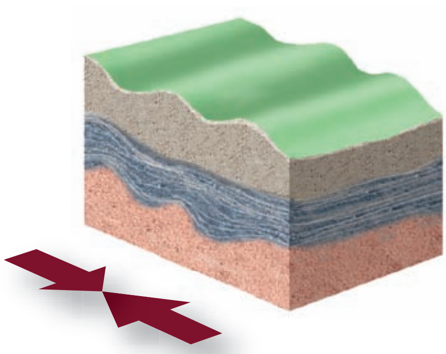


Figure 11.29A Fold mountain

Figure 11.29B Trace the sedimentary layers of Mount Kidd in Alberta with your finger. Which forces can bend and fold a mountain?

Fault block mountains: Sometimes the rocks in Earth's crust are too brittle to fold. When pressure is exerted on the rocks, they break, forming a fault. A fault can be the result of squeezing or stretching of Earth's crust. When sedimentary rock is squeezed from the sides, it can form into slabs that move up and over each other like shingles on a roof. This process is called *thrust faulting*. When Earth's crust is streched, fault blocks can tilt or slide down. The older rock may end up on top of the younger rock. These huge chunks of rock form mountains called fault block mountains (Figure 11.30).

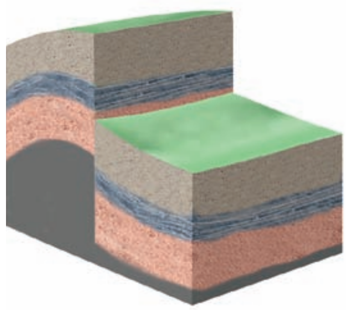


Figure 11.30A Fault block mountain

Figure 11.30B The Andes Mountains in South America are examples of fault block mountains.

Volcanic eruptions: Mountains can be formed by the convergence of continental plates and oceanic plates (Figure 11.31A). The continental plate is lighter and rides over the oceanic plate. Melted rock wells up under the edge of the overriding plate, pushing up mountains. When magma is forced up by pressure from deep within Earth, it can uplift the rock and create features on Earth's crust. The melted rock can break through the surface and erupt as volcanoes. Domed mountains are broad, circular mountains formed when layers of rock are uplifted. (Figure 11.31B on the next page).

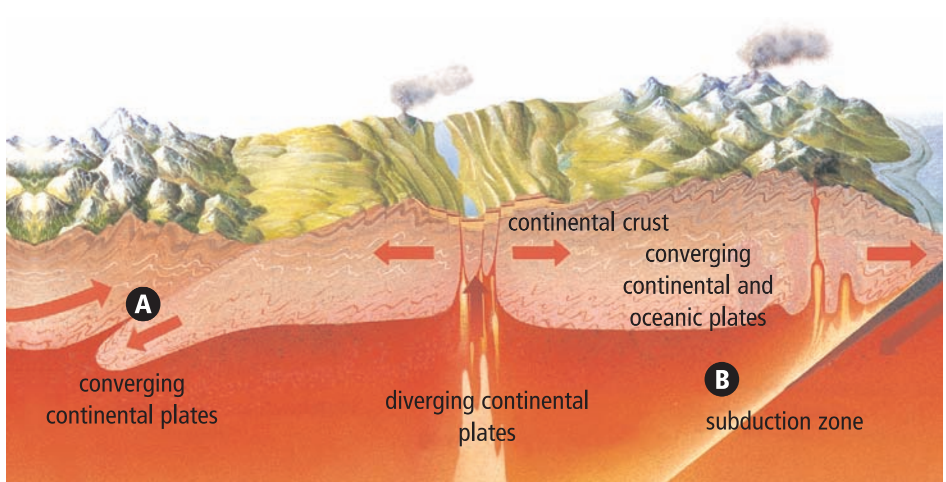


Figure 11.31A If converging plates are both continental, their leading edges crumple, forming mountains (A). If an oceanic plate slides under a continental plate, melting occurs, forming volcanoes and mountain ranges (B).

Figure 11.31B Mount St. Helens (foreground) and Mount Adams (background) are examples of domed mountains.

In Figure 11.32 you can review the locations of major mountain ranges. You can turn back to Figure 11.11 to view the locations of mountain ranges on the sea floor.

Figure 11.32 Major mountain ranges

Reading Check

1. How are fold mountains formed?
2. How are fault block mountains formed?
3. Where are mountains and volcanoes found together?

internet connect

In Gros Morne National Park, geological features that usually lie deep underground are exposed at the surface. The park was declared a UNESCO World Heritage site to preserve its unique geological landscape. Find out more about Gros Morne National Park. Visit **www.discoveringscience.ca.**

Putting Newfoundland Together

You may recall that the continents were once joined in a super continent called Pangaea. It is likely that the land that eventually became the island of Newfoundland was once near the centre of the ancient continent. The moving continents may have converged, forcing up a huge mountain chain that included what we now call the Appalachians, of which the Long Range Mountains are a part. When Pangaea separated, part of the mountain chain became the eastern edge of North America, and part became the northern and western edges of Britain and Norway.

Evidence of continental collisions and movements can be found in many parts of Newfoundland and Labrador today. For example, in Gros Morne National Park huge slabs of ancient sea floor have been uplifted to form Table Mountain (Figure 11.33).

Three types of rock were pushed together to form the island of Newfoundland as shown in Figure 11.34. The oldest rock is in the Western Zone, which is over 1 billion years old. The rocks of the Central Zone are the remains of volcanic islands that were crushed and forced into the Long Range and Topsail mountains. The rock in the Eastern Zone is related to the rock of Africa and Europe, a reminder of 200 million years ago when Africa and North America began to separate.

Figure 11.33 Table Mountain

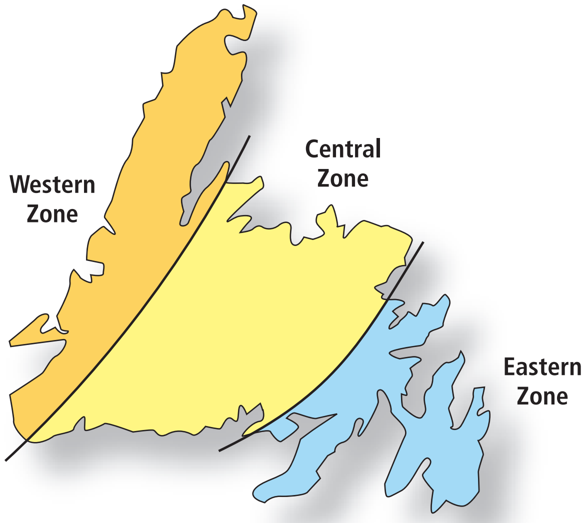


Figure 11.34 Newfoundland can be divided into three zones based on the origin of the rock.

Fossils

Figure 11.35 This species of trilobite, *Paradoxides davidis*, is from the Manuels River Gorge on the Avalon Peninsula. Our modern spiders and insects are relatives of the ancient trilobites.

Newfoundland and Labrador rock provides clues about Earth's evolution, and scientists come from all over the globe to study it. Our province of has some of the oldest rock and oldest fossils found anywhere in the world. **Fossils** are the remains of organisms that lived long ago. Some fossils are preserved as films on rock, some are petrified (turned to stone), some are the actual remains preserved in ice, and some are traces such as footprints in mud that hardened into rock.

One common fossil found worldwide is the trilobite, an extinct arthropod (Figure 11.35). Trilobites found in Western Newfoundland are from species that lived in warm, shallow waters. Trilobites found on the Avalon Peninsula are from a species that lived in cool, deep water. These fossils provide evidence that rock from several areas joined together long ago to form the island of Newfoundland.

Geologic Time Scale

How old are the fossils of Newfoundland and Labrador? How old is Earth? Figure 11.36 on the next page shows the major divisions of the geologic time scale. The **geologic time scale** divides Earth's history into smaller units, based on the appearances of different kinds of life forms in the fossil record, such as simple life forms, dinosaurs, and mammals.

It is estimated that our planet formed almost 4.6 billion years ago. Notice in Figure 11.36 that human existence on Earth represents a very small proportion of that geological time. It can be very difficult to imagine how long 4.6 billion years is. If we compare this period of time to a 24 h day, for example, humans have only been here for the last second.

Did You Know?

Students have made important fossil discoveries in Canada. A 12-year-old girl found the first dinosaur skeleton in British Columbia in 1988. In 2000, two boys, age 8 and 11, playing along a creek discovered dinosaur footprints near Tumbler Ridge. In 1967, S.B. Misra, a student at Memorial University in Newfoundland discovered Ediacaran fossils at Mistaken Point.

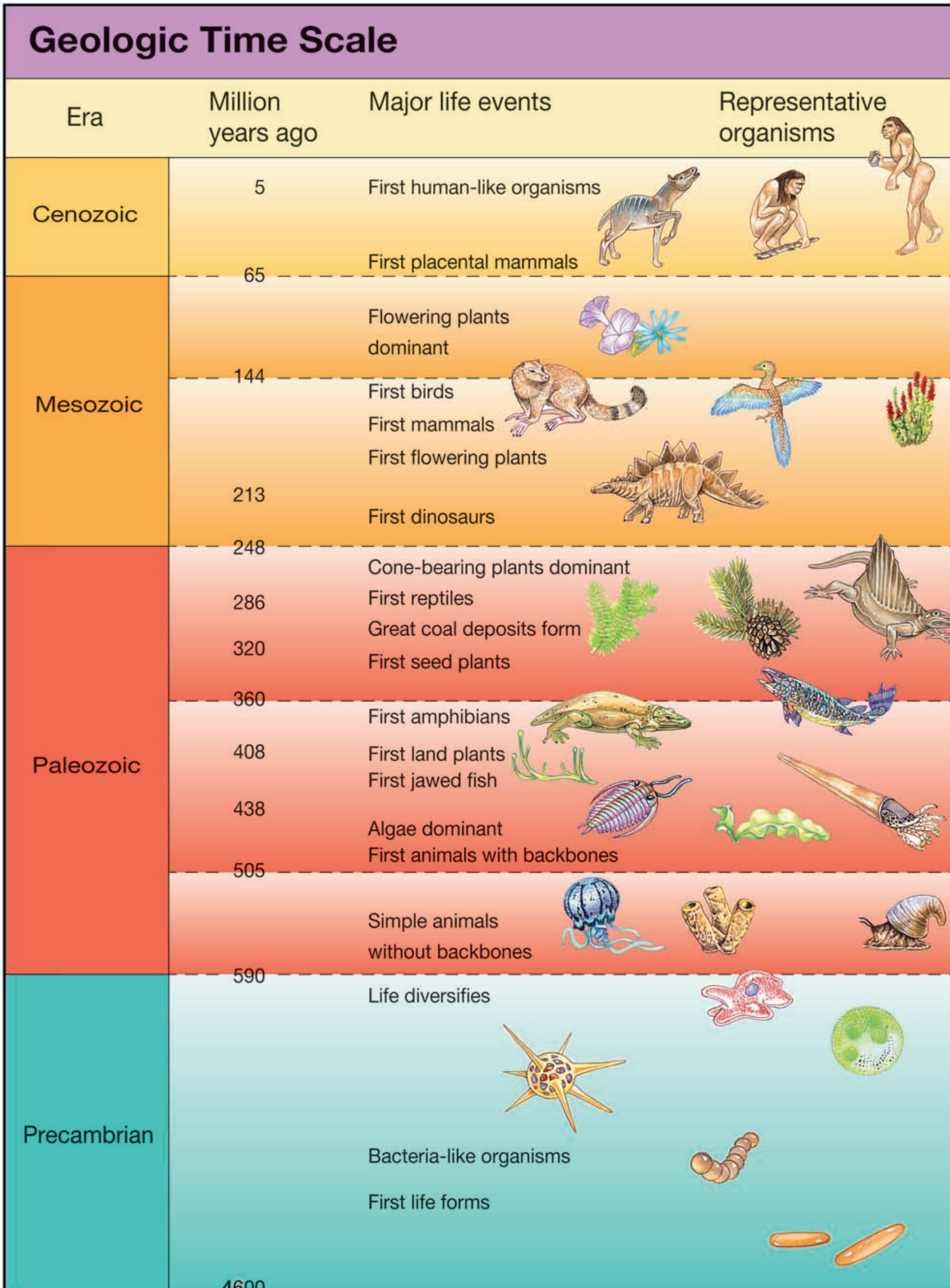


Figure 11.36 Notice the following main events of each era. (i) Precambrian—formation of Earth and appearance of simple life forms; (ii) Palaeozoic—appearance of more complex life forms; (iii) Mesozoic—appearance and extinction of dinosaurs; and (iv) Cenozoic—appearance of humans.

The Fossil Record

The largest era is the Precambrian era, lasting approximately 4 billion years. During most of the Precambrian era, life was microscopic. However, during the late Precambrian, more complex animal organisms called Ediacarans appeared in the fossil record. Some of the best and oldest fossil evidence of life on Earth can be found in the Ediacaran fossils at Mistaken Point, on the Avalon Peninsula (Figure 11.37). The fossils have been preserved under beds of volcanic ash. The local community at Mistaken Point helps protect the fossils and assists scientists in making new discoveries.

The appearance of fossils in rock layers has provided important clues for scientists about Earth's age and evolution. For example, the disappearance of dinosaurs from the fossil record marks the end of the Mesozoic era and the beginning of the Cenozoic era about 65 million years ago.

Fossils also provide evidence for the theory of plate tectonics. In 1884, 24-year-old Joseph Burr Tyrrell noticed a brown object sticking out of the banks of the Red Deer River in Alberta (Figure 11.38). With his hands and his geologist's hammer he began to clear the dirt from the object and gradually uncovered a dinosaur skeleton. He had just discovered the world's richest collection of dinosaur fossils, and proof that the climate of the land in Alberta had once been much warmer.

Figure 11.37 An Ediacaran fossil from Mistaken Point

internet connect

The recent discoveries of Ediacaran fossils and other evidence of Precambrian life have led to some proposed changes to the geologic time scale. Find out more about the revised geologic time scale. Start your search at **www.discoveringscience.ca.**

Figure 11.38A Joseph Burr Tyrrell (1858-1957)

Figure 11.38B The Albertosaurus was one of Tyrrell's many discoveries.

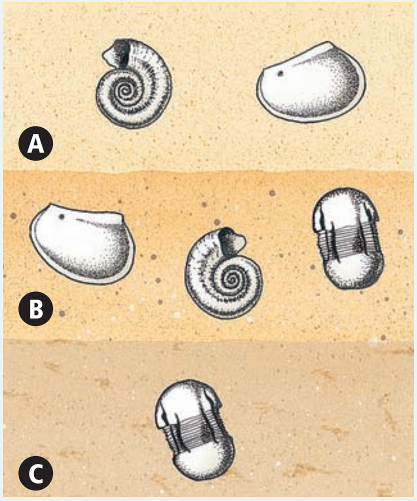
11-3B Tell-Tale Layers

Think About It

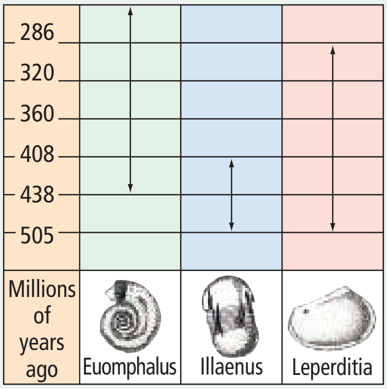
In this activity, you will investigate how fossils can be used to determine the age of rock layers.

What to Do

1. Examine the cross-section below. It shows three layers of sedimentary rock and the fossils found in each rock layer.



2. The chart below identifies each fossil. The vertical arrows show the time span in which the animal lived.



3. Identify the time range in which each rock layer might have been formed.

What Did You Find Out?

1. When might rock layer A have formed?
2. When might rock layer B have formed?
3. When might rock layer C have formed?

Explore More

Find out more about the fossils of Newfoundland and Labrador. Visit **www.discoveringscience.ca.**

Reading Check

1. What is a fossil?
2. What are divisions in the geologic time scale based on?
3. How do fossils contribute to our understanding of Earth?
4. Approximately how old is Earth?

11-3C Canada—Past, Present, and Future

Think About It

Imagine you are a time traveller suddenly transported to millions of years in the past or millions of years in the future. Do you think you would recognize the area where you now live? In this activity, you will describe how a region of Canada has changed and might change in the future.

What to Do

1. Your teacher will assign your group one of the four eras of the geologic time scale and a region of Canada.
2. Choose the format you will use to present your information, such as a mural or timeline.
3. Decide group roles for researching, preparing, and presenting your information.
4. Research to find out what the land, plants, and animals (if any) might have been like in your region in your assigned era. Find out what your region is like today. Predict what it will be like millions of years from now.
5. Create and share your presentation.

What Did You Find Out?

1. What was the most difficult part about representing your region in the past?
2. How has your present-day region changed from how it was in your assigned era?
3. What factors did you need to consider in predicting how your region might look in the future?

11-3D Rock Stars

Think About It

Earth scientists investigate how rocks got to where they are today. It is a journey that has taken place over millions of years. There are many Canadian earth scientists who are rock stars—they have contributed important discoveries to our understanding of Earth's crust. In this activity, you will research the contributions of a Canadian earth scientist and share your information with your classmates.

What to Do

1. Choose a Canadian earth scientist from your own research or from the following list.
2. Research the contributions your scientist has made to our understanding of Earth's crust.

Frank Dawson Adams	William Logan
Helen Belyea	Albert Peter Low
Steve Blasco	Lawrence Whitaker Morley
George Dawson	Alexander Murray
J. William Dawson	Guy Narbonne
Herb Dragert	F. Fitz Osbourne
Catherine Hickson	Ann Sabina
James P. Howley	Alice Wilson

3. Choose a format to share your information. For example, you could make a poster, write a poem, create a slide show presentation, or design a booklet. Or your class could prepare a time line that illustrates the evolution of our understanding of Earth's structure.

11-3E Model Mountains of Moving Magma

Find Out ACTIVITY

In this activity, you can model the formation of domed mountains and other features caused by the movement of magma.

Safety

- Be careful not to poke yourself with the scissors.

Materials

- scissors
- clear plastic disposable glass
- 125 mL soil
- tube of toothpaste

What to Do

1. Work with a partner.
2. Use the scissors to cut a hole in the centre of the bottom of the plastic glass. Make the hole large enough to insert the mouth of the toothpaste tube.
3. Cover the bottom of the hole with your finger while you pour the soil into the glass.
4. Remove the cap from the toothpaste. Insert the mouth of the toothpaste tube into the hole from below the glass.
5. Have your partner hold the glass while you press against the tube to force the toothpaste into the soil.
6. Observe the surface of the soil.

What Did You Find Out?

1. How was this activity similar to the formation of domed mountains?
2. (a) What do you think would happen if you added rocks on top of the soil before squeezing the tube?

   (b) How might those results be similar to features found on Earth's crust?
3. What features in addition to domed mountains do you think moving magma might make?
4. Chapter 10 describes the difference between intrusive and extrusive rock. If the toothpaste hardened in your model, which type of rock would it represent? Why?

11-3F Building a Mountain–Building Theory

Inquiry Focus

SkillCheck

- Classifying
- Modelling
- Explaining systems
- Evaluating information

Materials

- world map provided by your teacher
- 3 colours of coloured pencils or makers
- atlas or other source of mountain locations

What is a mountain? The term *mountain* has no simple definition because there are so many different ways mountains can be built. In this activity, you will investigate the location of many of Earth's mountain ranges. You will create a legend to distinguish mountains from each other based on how they were formed.

Question

What has created the major mountain ranges on Earth's surface?

Procedure

1. Research the location of Earth's major mountain ranges. Be sure to include the mountain ranges on the sea floor.
2. Classify the mountains based on how they were formed.
3. Choose a separate colour for each type of mountain category.
4. Record the location of as many mountain ranges as you can on your map.
5. Add a legend to your map to explain your system of colouring.
6. You probably found mountains for which you could not explain the origin. Form an hypothesis about how these mountains might have developed.

Analyze

1. What categories did you create to classify your mountains? Why?
2. Where do most of the mountains on Earth's crust occur?
3. (a) Compare your map with the map of volcano locations in Figure 11.27. What similarities can you observe between the locations of mountain ranges and that of volcanoes?
   (b) How does volcanic activity contribute to mountain building?

Conclude and Apply

1. (a) How do the locations of mountain ranges compare with the locations of plate boundaries?
   (b) What are the exceptions?
2. Describe at least three different ways in which mountains can be created.
3. (a) Predict where new mountain ranges might occur in the next 3 to 4 million years.
   (b) On which facts do you base your prediction?
4. Write a definition of the word *mountain*.

Science Math connect

Keeping Track of All Those Zeros

Geologic time measures a very, very long time. We measure our lives in terms of days, weeks, and years, but these are blips in time compared to Earth's 4 600 000 000 years. Numbers on the geologic time scale can be difficult to write out on a sheet of paper, let alone use in calculations. You can get dizzy just looking at all those zeros!

Scientists reduce the number of zeros in a large number while still keeping track of them by using scientific notation. With scientific notation, very large (and very small) numbers can be expressed in a shortened form, which makes it easier to make precise calculations and compare the size of different numbers.

Scientific notation consists of two parts: a *coefficient* and a *base.* The coefficient is a number between 1 and 10 and the base is a power of 10. The general format for scientific notation is:

$N \times 10^x$ Where N = a number greater than or equal to 1 and less than 10

^{x} = the exponent or "power of 10"

Using scientific notation, large numbers become much easier to work with because the zeros are tucked up into the exponent. So:

100 becomes 1.0×10^2

1000 becomes 1.0×10^3

1 000 000 becomes 1.0×10^6

How about writing out Earth's age using scientific notation?

4 600 000 000 years becomes 4.6×10^9 years

Notice there are eight zeros in the number, yet the exponent or power of 10 is 9. This is because the exponent represents the number of digits to the right of the first digit (in this case 4), whether they happen to be zeros or not.

Geologists, palaeontologists, and astronomers use the abbreviations "mya" and "bya" when discussing large numbers. The abbreviation mya means "million years ago," and like its counterpart bya ("billion years ago"), it is used as a unit to measure time. In scientific literature, the abbreviations Ma (mega-annum) and Ga (giga-annum) are often used instead of mya and bya and mean the same thing. Using these abbreviations, Earth's age is 4.6 bya or 4.6 Ga.

If you need to use even bigger numbers, consult the chart below.

Number of zeroes	Number
3	thousand
6	million
9	billion
12	trillion
15	quadrillion
18	quintillion
21	setillion
24	septillion
27	octillion
30	nonillion
33	decillion

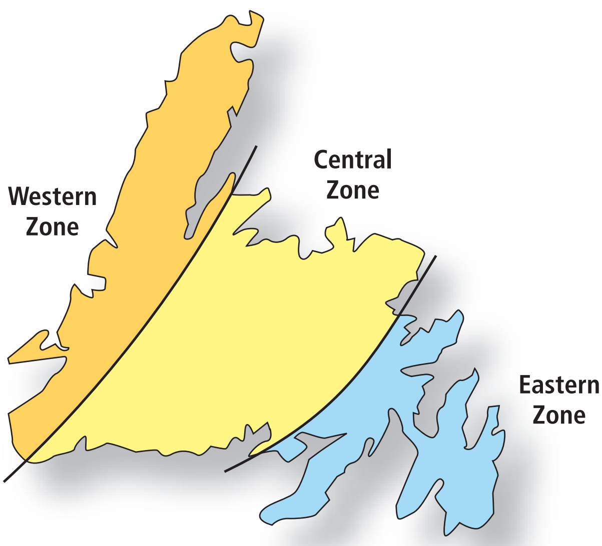
Questions

1. How would you write the number one trillion (1 000 000 000 000) using scientific notation?
2. Using either the abbreviation mya or bya, when did dinosaurs appear on Earth? (Refer to Figure 11.36, the geologic time scale in this section.)
3. When might you need to use very large numbers, such as trillions or quadrillions?

Check Your Understanding

Checking Concepts

1. Draw and label an example of a fold mountain showing how it was formed.
2. Draw and label an example of a fault block mountain showing how it was formed.
3. How does volcanic activity contribute to mountain forming?
4. In which directions can rock move along a fault?
5. Where has the rock come from in each of Newfoundland's three zones?



6. What are fossils?
7. What is the geologic time scale?
8. (a) Name the four major eras in Earth's history.
   (b) What is an example of a life form from each era?
9. What did Joseph Burr Tyrrell discover?

Understanding Key Ideas

10. Why do the Appalachian Mountains in eastern North America have a much lower elevation and a more rounded texture than the Rocky Mountains in Western Canada?
11. Why is there little fossil representation in the Precambrian rock record?
12. Why have dinosaur fossils been found in areas where they would not be able to live if they were alive today?
13. Make a circle graph of the geologic time scale. Show the four eras in their correct proportion.

Pause and Reflect

How do mountains become taller? How do mountains become smaller? Use a sketch to help explain your answers.

Chapter Review

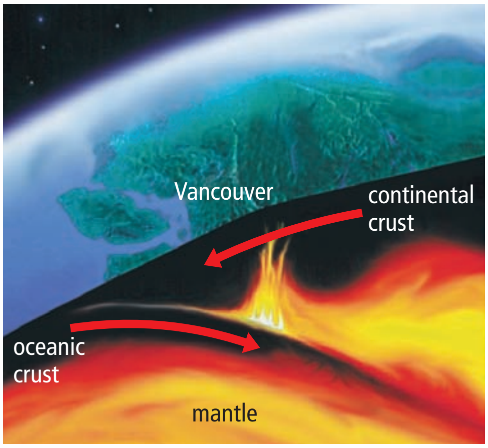
Prepare Your Own Summary

In this chapter, you investigated how and why Earth's crust moves and some of the ways it has changed over the course of geologic time. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 9 for help using graphic organizers.) Use the following headings to organize your notes.

1. Plate Tectonics
2. Earthquakes
3. Volcanoes
4. Mountains
5. Geologic Time

Checking Concepts

1. Make a labelled diagram of the four layers of Earth.
2. (a) Describe Pangaea.
   (b) Why does Pangaea no longer exist?
3. What are three types of evidence for continental drift?
3. What are three types of evidence of moving crust from the sea floor?
4. How do convection currents help explain plate movement?
5. How does the Richter scale help geologists describe earthquakes?
6. Draw and label three types of faults.
7. (a) Where do most of the world's earthquakes happen?
   (b) Why?
8. (a) Where are most of the world's volcanoes found?
   (b) Why?
9. Describe three ways that mountains can be formed.
10. (a) Where are most of the world's mountain ranges found?
    (b) Why?
11. What is the difference between a fold and a fault?
12. How were life forms in the Mesozoic era different from life forms in the Cenozoic era?
13. (a) What type of zone is shown in the photograph below?
    (b) What features or events occur at this zone?
    (c) Why do the features or events occur there?



Understanding Key Ideas

14. Read the newspaper article below, and answer the following questions:
(a) What inaccuracy does this article contain?
(b) An earthquake in the city of Kobe, Japan in 1995 killed thousands of people and cost many billions of dollars in property damage. Aside from its greater strength, why do you think the Kobe earthquake killed thousands of people, while the earthquake described in this article only killed 60 people?

About 60 people were killed, many as they slept, during an earthquake in central Bolivia yesterday. A 5.9 magnitude earthquake struck, followed by a second one, 13 min later, with a magnitude of 6.8. The epicentre was 89 km below Earth's surface. Repeated aftershocks—up to 150 in the first 12 h alone—sent panicked residents fleeing any buildings left standing. About 30 000 people, mostly farmers, live in the area hit by the earthquakes. Eighty percent of houses in the community where the earthquakes struck were destroyed, the hospital roof caved in, and a landslide blocked access to the town. Reports indicate that the town was almost wiped out. People gathered in main plazas after the jolts, fearing the aftershocks would bring down more buildings. Streets were cleared of rubble by tractors so that workers could assist the injured and homeless.

Adapted from *Winnipeg Free Press*, May 23, 1998

15. Explain why we do not have fossil evidence of all the species that once lived.

16. Here are answers to three different questions. Write a question for each answer:
(a) Alfred Wegener
(b) J. Tuzo Wilson
(c) Joseph Burr Tyrrell

17. Some volcanoes erupt quietly and other eruptions are violent. What do you think causes the difference?

18. Trilobites discovered along Manuels River on the Avalon Peninsula are directly related to trilobites found across the Atlantic in Wales. How does this support the theory of continental drift?

19. How could you demonstrate convection currents?

20. Describe how convection currents have changed the surface of Earth.

21. Prepare a time line that illustrates the evolution of our understanding of plate tectonic theory.

Pause and Reflect

Sea floor spreading along the Mid-Atlantic Ridge averages about 2.5 cm per year, or 25 km in a million years. This may seem like a slow rate, but over the past several hundred million years, it has caused a tiny inlet of water between the continents to grow into the vast Atlantic Ocean. What do you think the continents will look like 135 million years from now? Sketch your ideas in your science notebook.